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Optimising methods for monitoring programs: Olympic marmots as a case study

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Abstract. Monitoring of rare and declining species is one of the most important tasks of wildlife managers. Here we present a large-scale, long-term monitoring program for Olympic marmot (*Marmota olympus*) throughout its range across a logistically challenging mountainous park. Our multiple-stage process of survey design accounts for the difficulty imposed by access to remote habitats and funding constraints. The Olympic marmot is endemic to the Olympic Mountains, Washington State, USA. Although nearly all of its range is enclosed within Olympic National Park, declines and local extirpations of the species have been documented. We considered several possible alternative survey approaches, and propose a monitoring program designed to reflect extinction–recolonisation dynamics using presence–absence data. The sampling design is based on annual surveys of a set of at least 25 randomly selected clusters (closely located groups of sites with record of current or historical occupancy by marmots), and supplemented by sampling 15 never-occupied sites to test for new colonisations. The monitoring plan provides a framework that park managers can use for assessing changes over time in Olympic marmot distribution across the range of the species. Our sampling design may serve as a useful case study for establishing monitoring programs for other species with clumped distributions.

Additional keywords: *Marmota olympus*, occupancy, Olympic National Park, presence–absence.

Introduction

Monitoring is one of the main tools of species conservation and management. Appropriate design and implementation of monitoring programs is of particular importance in the case of rare and declining species (Thompson *et al*. 1998; Thompson 2004). It requires detailed knowledge of the species' biology, as well as careful consideration of possible survey design to maximise reliability.

Balancing financial and logistical constraints against the quality of data is a universal challenge for wildlife monitoring programs, especially in remote areas. In many cases, the logistics of getting to and among sampled areas can be daunting, so a survey design balancing the rigor of random sampling against the ease of sampling nearby sites within a 'cluster' is required. Further, the metric to be used to assess trend or health of a population in a monitoring program is not always obvious, with options ranging from presence–absence to indices of abundance to direct estimates of abundance.

We aim to clarify through example how specific decisions for a logistically challenging wildlife monitoring program might be made with respect to the monitoring metric, sampling design, timing, personnel, and dealing with incomplete detectability. As an example of a large-scale, long-term monitoring program accounting for financial and logistical constraints, we present the multiple-stage process of survey design for the Olympic marmot throughout its range in Olympic National Park. The Olympic marmot (*Marmota olympus*), endemic to the Olympic Peninsula, Washington State, has the most restricted range and limited numbers among all US marmots. The species is found exclusively in high-elevation alpine meadows (Barash 1973). Abundance per site is 2–30 animals, with many colonies containing only one or two family groups and few colonies with over 20 animals; these small colonies occur on scattered habitat patches of grass-forb meadows within a matrix of unsuitable habitat (deep forested valleys, rocks and snow fields). Although nearly all (~90%) of its habitat is protected within Olympic National Park, it appears that the Olympic marmot has suffered severe declines and local extirpations in recent years, with over half of the 25 colonies periodically documented since the 1950s now extinct, no known colonisations of new areas, and total numbers reduced by perhaps half from the estimates in the late 1960s (Barash 1989; Griffin *et al*. 2008). Several possible hypotheses explaining the current decline – including climate change, predation, disease and inbreeding – are being considered for the Olympic marmot based on historical data coupled with an

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ongoing field study in Olympic National Park (Griffin *et al*. 2007, 2008; Witczuk 2007). Surveillance monitoring can facilitate testing these hypotheses of decline (Nichols and Williams 2006). Furthermore, effective management plans for this endemic species require quantitative information about population status, trends and distribution. We considered and evaluated several alternative survey methods, and here propose an approach for monitoring using presence–absence data across a logistically challenging mountainous park. Because it can easily be conducted by volunteers and park interns, surveillance monitoring of marmots would be an efficient and effective method for evaluating park-wide population changes in the future, thereby directing park management for the endemic marmot.

Sampling area

The monitoring program targets marmot habitat within the alpine zone of Olympic National Park, Washington State (Fig. 1). The terrain of the Olympic Mountains is rugged with the highest peak reaching an elevation of 2427 m. The maritime climate of the peninsula is characterised by wet winters and dry summers. The western side of the peninsula is one of the wettest places in the USA south of Alaska, with an average of ~360 cm of rainfall per year, whereas the eastern part is relatively dry as it lies in a rain shadow (Houston and Schreiner 1994). The alpine zone is characterised by a short growing season and high year-to-year variability in temperature, winter length and snowpack. Low-elevation areas are predominated by lush coniferous forest with Sitka spruce (*Picea sitchensis*), western hemlock (*Tsuga heterophylla*), western redcedar (*Thuja plicata*) and Douglas-fir (*Pseudotsuga menziesii*). Patches of forests at higher elevation are composed of subalpine fir (*Abies lasiocarpa*) and mountain hemlock (*Tsuga mertensiana*). Alpine meadows occur above 1500 m and are dominated by showy sedge (*Carex spectabilis*), pink mountain heather (*Phyllodoce empetriformis*) and blueberry (*Vaccinium deliciosum*) on wet sites and spreading phlox (*Phlox diffusa*) on dry sites (Houston and Schreiner 1994).

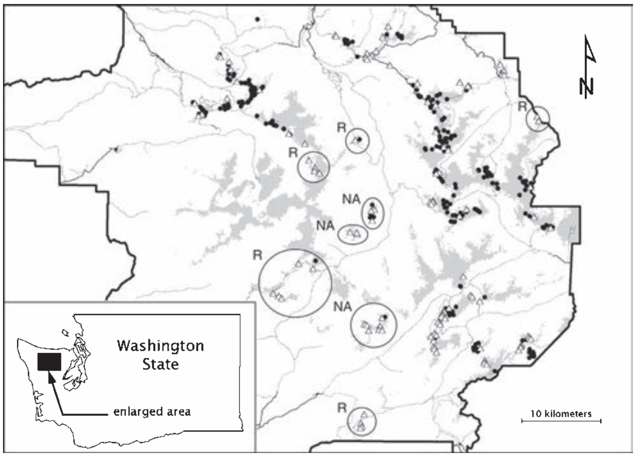

Fig. 1. Distribution of polygons representing areas in Olympic National Park that have been occupied by Olympic marmots in the past or present. Black circles, occupied polygons; white triangles, abandoned polygons; grey area, alpine zone; thin solid lines, roads; thin dashed lines, trails; thick solid line, park boundary. NA, clusters of polygons removed (19 polygons total) from the sampling frame because of inaccessibility; R, remote and isolated clusters of polygons removed for variants *b*, *c* and *d* (18 polygons total).

Monitoring methods

As with most wildlife species, several possible approaches could be used to monitor Olympic marmots over time: (i) estimates of abundance using capture–mark–recapture (CMR) by either live trapping (e.g. mark–resight method) or genotyping of non-invasive hair samples; (ii) indices of abundance (visual counts of marmots, burrow counts, pellet counts, hibernacula counts); and (iii) estimates of distribution using presence–absence measures (occupancy estimation). In this section we will describe why abundance-based methods are less efficient for a range-wide Olympic marmot monitoring program than the third method, presence–absence occupancy estimation.

Abundance estimates

Trend detection based on formal estimates of abundance incorporating adjustments for incomplete detectability via CMR would in many ways be the most precise and informative metric for tracking population size changes over time (Pollock *et al*. 2002; Mills 2007). However, in a remote backcountry setting CMR can be expensive, labour intensive and demanding in terms of crew experience. Although our ongoing marmot studies in Olympic Park have successfully used live trapping (Griffin *et al*. 2008), the logistics of hauling traps into remote sites is daunting, and qualified personnel must be available for several days to handle captured animals. Collectively, this means that live trapping is feasible only on a few relatively accessible sites relative to the size of the study area. Genetic techniques using DNA extracted from hair samples (Morin and Woodruff 1996; Taberlet *et al*. 1999; Mills *et al*. 2000; Banks *et al*. 2003) provide the possibility of sampling more remote areas because traps do not need to be carried; furthermore, non-invasive samples can be obtained more rapidly than trapped animals, and with less-skilled field crew members. However, field and laboratory expenses to obtain individual identification from non-invasive genetic samples are still considerable.

Abundance indices

There may be some limited value in visual counts of unmarked individuals as an index of relative abundance of marmots. Marmots inhabit open habitats and are sedentary, highly visible, diurnal and tolerant of close observation. Counting methods were developed for the Alpine marmots (*Marmota marmota*) in the Alps (Cortot *et al*. 1996; Lenti Boero 1999) and Vancouver Island marmots (*Marmota vancouverensis*; Bryant and Janz 1996). Repeated counts of Vancouver Island marmots initiated in 1979 were the main tool of the long-term population monitoring that eventually revealed catastrophic decline of the species (Bryant 1998, 2000). Also, numerous authors have tested visual counts for indexing density of prairie dogs and ground squirrels (Zegers 1981; Fagerstone and Biggins 1986; Powell *et al*. 1994; Severson and Plumb 1998) usually with positive results. However, unadjusted incomplete counts rely on the critical assumption that the number of animals observed during repeated visual counts constitutes a constant proportion of the true abundance (Thompson *et al.* 1998). As season, time of day and weather conditions substantially influence the number of animals active above ground, changes in detectability across time will substantially decrease accuracy of counts.

Likewise, sign indices such as burrow or pellet counts are less expensive and take less time (Karels *et al.* 2004), but are unlikely to accurately reflect true population size differences between habitats or over time, particularly for Olympic marmots or other alpine-dwelling marmots. These marmots are highly social and family groups usually share large, main burrows in the centre of the territory (Barash 1973; Armitage and Downhower 1974; Arnold 1990; Blumstein and Arnold 1998). Thus the number of burrows is likely independent of the number of animals. Furthermore, burrows are usually permanent constructions, lasting several years, and their number does not reflect year-to-year changes in density (Ramousse *et al.* 1997; Van Horne *et al.* 1997). Finally, burrow persistence and the number of burrows used by Olympic marmot colonies of similar size could vary with habitat type (Van Horne *et al.* 1997); for example, a different number of shelters could be used by marmots inhabiting rocky outcrops compared with those digging on the meadows.

Similarly, the use of faecal pellet counts for monitoring abundance (Karels *et al.* 2004) is problematic for Olympic marmots. First, faeces scattered randomly in vegetation among the numerous burrows in the home range are rare and difficult to find; those on porches (mounds by the burrow entrance) are often destroyed by animals' movements and digging activity. In some colonies we did observe latrines but in many others faeces are extremely rare. The number of faeces is likely site dependent – latrines in rock crevices lasted longer than those on porches. These factors will likely corrupt the relationship between abundance of pellets and marmots.

Occupancy estimates

Recent developments in presence–absence occupancy estimation provide a complementary metric to count-based approaches for monitoring Olympic marmots. Presence–absence assessment over time balances the collection of precise information from intensive sampling of estimated abundance over a small part of the entire population against larger-scale sampling of occupancy. In effect, it targets detection of changes in occupancy measured as the proportion of the sampling units where the species is present.

Although in some cases presence–absence data could be used to monitor population size (MacKenzie *et al.* 2005; Stanley and Royle 2005), the strongest inferences from presence–absence sampling relate to changes in species distribution (Finley *et al.* 2005; Joseph *et al.* 2006). Well-designed presence–absence monitoring should capture a general reduction in site occupancy as a result of constrictions of spatial distribution and population decline.

Marmots could be easily monitored by presence–absence techniques as they are diurnal, visible and dig multiple burrows that are relatively easy to detect (Bryant 1998). A monitoring program should ensure constant effort of site searching in consecutive periods to reduce observer bias. Standardised presence–absence surveys require a detailed protocol (see Accessory Publication on *Wildlife Research* website) for searching and recording animal sightings and presence indices (e.g. calls, burrows, pellets). Detection of pellets constitutes a useful addition to the more subjective burrow categorisation while determining site occupancy status (discriminating between active and recently abandoned sites). Scattered marmot scats are unlikely to last longer than one season (Ramousse *et al.* 1997; Karels *et al.* 2004); thus, the presence of scats usually confirms current site occupancy. Using these protocols, surveyed sites for marmots may be categorised as: occupied, abandoned (historical presence now extinct) or null (no signs of marmot activity).

The presence–absence method could be compromised by false negatives (undetected presence) and its variability across time and space (Field *et al.* 2005; MacKenzie *et al.* 2005). In the case of imperfect detectability, MacKenzie *et al.* (2006) incorporate repeated surveys of sites within the season, allowing estimation of detection probabilities to facilitate unbiased estimates of occupancy. However, we have found that for Olympic marmots, detectability is very high, 92% or greater, even with a naïve observer (see section *Detectability assessment*). Griffin *et al.* (2008) found a similar detectability using an independent estimate in the same system. Therefore, an efficient solution to be used here is a 'removal design' (MacKenzie *et al.* 2006) whereby a second survey within the season is made only for those sites where marmots were not detected. With such a high detectability, one additional survey will be sufficient for near-complete removal of the non-detection bias.

A potential drawback of the method is possible nonlinearity of the presence–absence index (Thompson *et al.* 1998). Until the last marmot from a given habitat patch is gone, extinction of the site and decrease of overall occupancy is not revealed. Given that marmots are long lived, detection of the decline may be delayed for many years (Field *et al.* 2005). However, as a complement to intensive trend analysis of abundance at selected sites, occupancy sampling provides a feasible method for range-wide assessment of the Olympic marmot status across time.

Sampling design

Sampling frame

Determination of the monitoring sampling frame constitutes a crucial step of the design and highly influences the inferential scope of the results. A representative sampling network of sites across the park should provide adequate coverage of marmot habitat, with focus on the areas of known (recent and historical) marmot distribution in order to detect extinction and recolonisation events.

The Olympic marmot monitoring sampling frame is based on polygons, or spatial sampling units, delineated by breaks in aspect and encompassing marmot habitat determined to be occupied or abandoned during 2002–2006 field surveys (Griffin *et al.* 2008) or from other historical records of previous occupancy (Barash 1973; Wood 1973). We further excluded from the sampling frame 19 polygons inadequate for frequent monitoring activities because of inaccessibility. The resulting sampling frame consists of 310 polygons (Fig. 1): 212 occupied (68.4%) and 98 abandoned (31.6%), so that current occupancy is 0.68. Overall, polygon sizes ranged from 0.6 to 50 ha (median = 4.2 ha), with a majority of polygons (68%) less than 10 ha. For the 5% of polygons over 50 ha, we would sample the 50 ha centred on marmot colonies to facilitate efficient sampling.

Although new colonisations of habitats not previously occupied are thought to be unlikely (Griffin *et al.* 2008), the proposed occupancy monitoring program contains an additional component, outside the sampling frame, to sample for possible colonisation in potentially suitable habitats. The colonisation sampling would be conducted in areas with no record of previous occupancy but in suitable habitat as determined by a detailed marmot habitat model (Griffin 2007). Each year, a different set of polygons (10% of the number sampled from the sampling frame) would be sampled.

Sampling plan

Although 'convenience sampling' of sites near trails or roads would minimise monitoring costs, it would greatly decrease the inferential scope of the study. On the other hand, random selection of single polygons (simple random sampling) would be an inefficient use of the observer's time in the rugged unroaded terrain of the mountainous park. Additionally, before locating a sampled polygon, the observer often may walk through several other polygons without recording observed marmots.

Here we present a sampling design that relies on randomly chosen clusters of polygons (closely located groups of polygons). Cluster sampling represents a trade-off between randomisation and the cost efficiency of sampling (Thompson 2002). Polygons to be sampled are naturally clustered on separated mountaintops. Much more time is usually needed to travel between clusters (from several-hour- to 2-day-long hikes) than to visit several nearby polygons within the cluster. Also, cluster sampling decreases the number of time-consuming ascents, increases observer familiarity with an area, and is logistically efficient because several polygons can be sampled from a single backcountry base camp. Collectively, the benefits of cluster sampling should greatly increase the number of surveyed polygons per sampling period per observer while preserving the intent to obtain a representative sample of the marmot population in the park.

Sampling plan calculations

In this section we consider the necessary sample sizes and efficiencies when sampling the universe of potential polygons in the sampling frame using either simple random sampling or one of three variants of cluster sampling (Fig. 2). To conduct cluster sampling we first divided the sampling frame into clusters. The predetermined size of the cluster was five polygons (a total area that our personal experience indicated could be surveyed easily during 1 day) and 86% of all clusters consist of four to six polygons, but because of logistical constraints, some smaller or larger clusters were included (overall $\bar{x} = 4.7$; minimum = 1; maximum = 7). Clusters were created subjectively, exclusively with respect to the time efficiency of the survey. To determine the most effort-efficient clusters we used our personal knowledge of the area and a Geographic Information Systems (GIS) model of topography, assigning polygons to a cluster based on close proximity to each other and to a shared access point so they could be easily accessed from one base camp. Ultimately, the 310 polygons in the sampling frame were grouped into 66 clusters. Five of the clusters (containing 18 polygons) were highly isolated and predominantly abandoned (only two polygons constituting these clusters are occupied; Fig. 1).

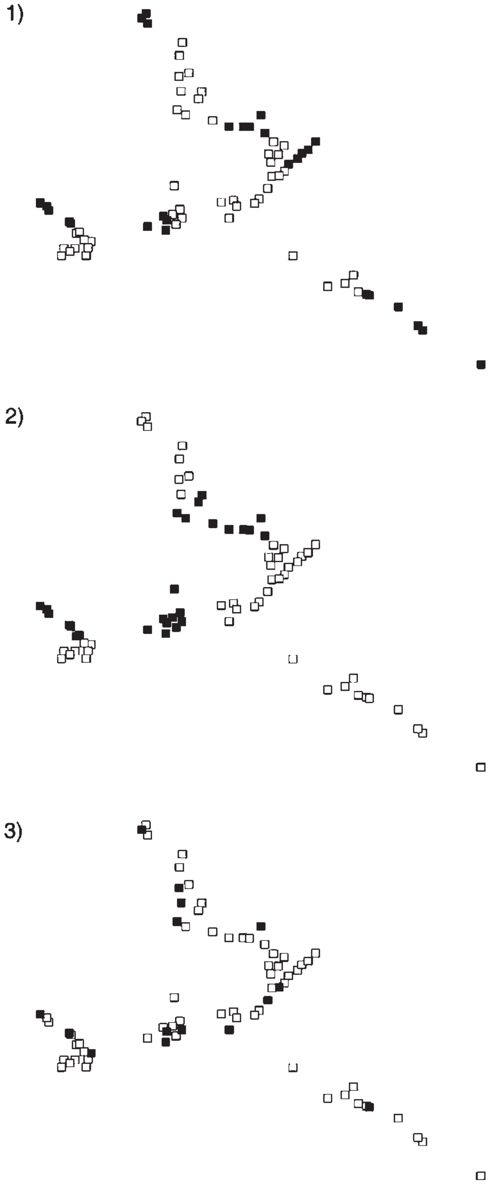

Fig. 2. Schematic maps showing, for one possible scenario, differences in polygon selection for four sampling variants for monitoring occupancy of Olympic marmots in Olympic National Park: (1) variants *a* and *b* (small clusters); (2) variant *c* (big clusters); and (3) variant *d* (simple random sampling). For clarity only the north-western area of the park is shown. Squares represent polygon centers; ■, selected polygons; □, omitted polygons. Notice that the larger clusters chosen under variant *c* sample a smaller area of the park.

Because of their remote location these clusters would be very costly to survey; thus, we evaluated plans both with and without these five clusters. After excluding these clusters, the current observed occupancy (proportion of occupied polygons) in the sampling frame changed from 0.68 to 0.72

We also assessed a variant of monitoring with clusters approximately twice as large, creating 33 big clusters containing nine polygons on average. Finally, we also considered simple random sampling of all polygons as an alternative to cluster sampling, excluding all polygons in the five remote clusters.

Thus, we evaluated four different variants of sampling universes: (i) 66 small clusters (full sampling frame of 310 polygons and approximately five polygons per cluster); (ii) 61 small clusters (reduced frame of 292 polygons); (iii) 33 large clusters (292 polygons and approximately nine polygons per cluster); and (iv) simple random sampling (292 polygons). To compare all scenarios, we calculated the required sample sizes to estimate occupancy to within 10% of the true occupancy with 95% confidence and then estimated the sampling effort necessary to achieve this under each plan.

We determined the necessary sample sizes for cluster sampling based on the standard formula (Thompson 2002):

$$n = \frac{1}{\frac{1}{N} + \frac{d^2}{s^2 z^2}}, \tag{1}$$

where n = sample size, N = the total number of clusters in the sampling frame (66, 61 or 33 depending on the variant considered), d = the maximum allowable difference between the true occupancy and its estimate (0.1 in this case), s^2 = variance of the occupancy among clusters (determined from the current marmot occupancy data to be 0.13, 0.11 and 0.09 for variants *a*, *b* and *c*, respectively), and z = standard normal quintile corresponding to the chosen α level ($\alpha = 0.05$).

The sample size required for simple random sampling was determined based on (Thompson 2002):

$$n = \frac{1}{\frac{N-1}{N n_0} + \frac{1}{N}}, \quad \text{where } n_0 = \frac{z^2 p(1-p)}{d^2}, \tag{2}$$

N = the total number of polygons in the sampling frame (292), p = the current proportion of occupied polygons in the sampling frame (0.72), and z and d are defined as in Eqn 1.

To assess the relative effort of each sampling plan we drew 15 random samples of the required size for each of the four sampling variants. For each of the simulated monitoring scenarios we calculated the minimum effort required (Fig. 3). Effort was calculated as a sum of time spent getting to the sites (both total driving time from the Olympic National Park headquarters to trailheads and total hiking time needed to reach all polygons from trailheads, including multiple trips needed), and time spent sampling polygons once there (polygon sampling time was proportional to its size based on pilot studies estimating 0.5–2 h for a two-person team).

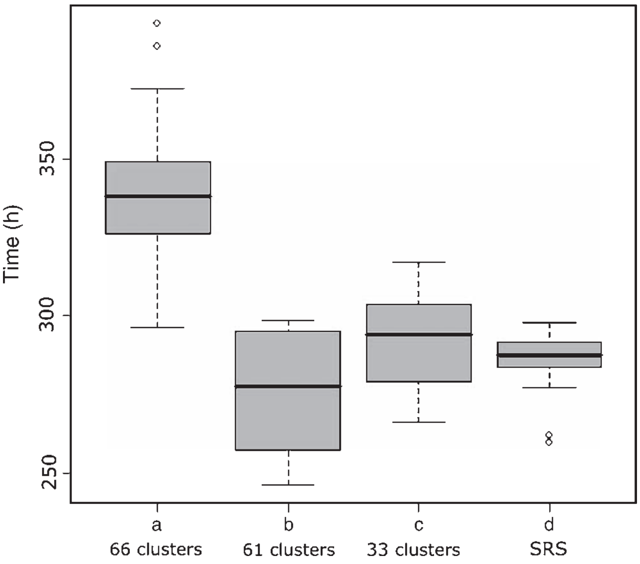

Fig. 3. Boxplots of the minimum effort (time in h) computed for four monitoring scenarios ($n = 15$, $F = 34.2$, $P < 0.0001$).

Based on the computations presented above, the least-efficient sampling design would be the one with the full sampling frame of 310 polygons (variant *a*); inclusion of the remote and predominantly abandoned clusters in this variant led to high variance of occupancy among clusters and subsequent high required sample size (Table 1) and high effort (~342 h required; Fig. 3). Comparing the two cluster variants (*b* and *c*) that sampled 292 polygons, variant *c* sampled a smaller number of large (nine-polygon) clusters, which increased survey effort (Fig. 3) and sampled less area overall (see Fig. 2) compared with variant *b* with five-polygon clusters. Simple random sampling allows for the smallest sample size (Table 1) but is less efficient in terms of sampling effort because the selected polygons are highly scattered (Figs 2, 3). Overall, the most efficient sampling design is variant *b*, which has high coverage across the park (sample size of 120 polygons) with the lowest effort (Fig. 3).

Using the current known occupancy of 0.72, we carried out a small-scale simulation to evaluate the chosen sampling plan from the current sampling frame in Olympic National Park (ONP). We drew 1000 simulated samples of 25 clusters (the sample size necessary for the preferred sampling variant *b* with a sample universe of 61 clusters; Table 1) and for each

Table 1. Evaluation of four sampling designs for monitoring Olympic marmots

Required sample size was based on Eqns 1 and 2 in the text

Sampling design	No. of polygons	No. of polygons per cluster		Required sample size	
		Mean	s.d.	No. of clusters	No. of polygons
66 clusters	310	4.7	1.20	29	136[A]
61 clusters	292	4.8	1.13	25	120[A]
33 clusters	292	8.8	1.58	17	150[A]
Simple random sampling	292	–	–	–	62

[A] Calculated as a product of the mean number of polygons per cluster and number of clusters.

simulation computed the proportion of occupied polygons in the sample, constituting an estimate of population occupancy. The histogram of sampling distributions of occupancy estimates (Fig. 4) shows that cluster sampling gives accurate estimates, centred around the true proportion of occupied polygons ($\bar{x} = 0.71$, s.d. = 0.05).

Detectability assessment

To assess the detectability of marmots during presence–absence surveys, survey trials were conducted in June, July and August 2006 by a naïve observer with no previous experience with any species of marmots or in the park. The observer was accompanied by one of the authors (JW) to provide guidance of where to sample, although JW was careful to give no clues as to occupancy status. To keep the naïve observer from having an expectation of finding marmots, we sampled both the 94 polygons determined to have been occupied by marmots in at least one of the previous seasons 2002–2005, as well as an additional 30 polygons known (by JW) to be unoccupied. The observer determined plot status based primarily on the most-reliable signs (marmots or marmot pellets), using burrows or other occupancy signs as necessary (see Accessory Publication on *Wildlife Research* website).

The detection accuracy of the naïve observer was very high. On 92% (87 of 94) of polygons previously determined as occupied, the presence of marmots was recorded or signs of current marmot occupancy were found (Appendix 1). Importantly, this raw detectability rate may have been biased low for two reasons. First, previously occupied polygons may have been abandoned since the last survey. Second, all seven of the previously occupied sites where the naïve observer did not find marmots were atypical in that they were not on meadows but rather on rocky sites that may have been peripheral habitats that were inconsistently occupied or perhaps infrequently visited without permanently used burrows. Thus, 92% detectability for a naïve observer can be considered a minimum estimate. Figure 5 shows the proportion of different cues used by the naïve observer as the most important for occupancy determination. In the majority (85%) of polygons the preferred, undeniable clues were found – marmot sightings or scats found on the burrow porches; on the remaining polygons the observer determined occupancy based on fresh digging or vegetation condition (e.g. visible paths) around burrows. For the 30 surveyed polygons known to be unoccupied, the naïve observer correctly assigned the polygon status in all cases, indicating that false positives are unlikely.

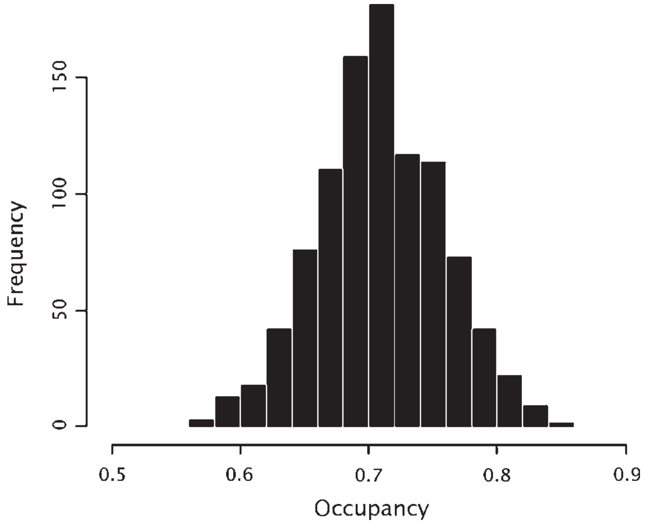

Fig. 4. Histogram of occupancy estimation for 1000 simulated samples of the required size (25 clusters containing 120 polygons) for monitoring variant *b* with a sampling universe of 61 clusters. The true proportion of occupied polygons is 0.72.

Sampling plan implementation and timing of surveys

Based on our simulations the preferred sampling approach would be variant *b* of the cluster sampling. Thus, to begin a park-wide monitoring program, park staff would randomly select 25 clusters (containing ~120 polygons) from the list of 61 clusters of polygons in the sampling universe (the full list of polygons grouped into clusters would be provided to the park). The same clusters would be surveyed annually (Mackenzie *et al.* 2006), and the trend in occupancy over time estimated via approaches analogous to those used to estimate trend in abundance (e.g. Thompson *et al.* 1998; Mills 2007). To specifically monitor for new colonisations, each year a new set of 15 polygons will be randomly selected from polygons not included in the sampling frame but constituting suitable marmot habitat (from the model developed by Griffin 2007); up to five of these could be deleted each year due to inaccessibility. Snow conditions on trails, road openings, and other factors affecting access will dictate the order that polygons are surveyed each year.

Each polygon would be visited at approximately the same time (season, time of day) across years to control for factors such as phenology of vegetation and seasonal changes in activity patterns that could affect observability. Presence should be estimated based on direct sightings, pellets, calls and active burrows (see Accessory Publication on *Wildlife Research* website). All monitoring activities should target the activity peak period, when the probability of observing marmots on the colony area

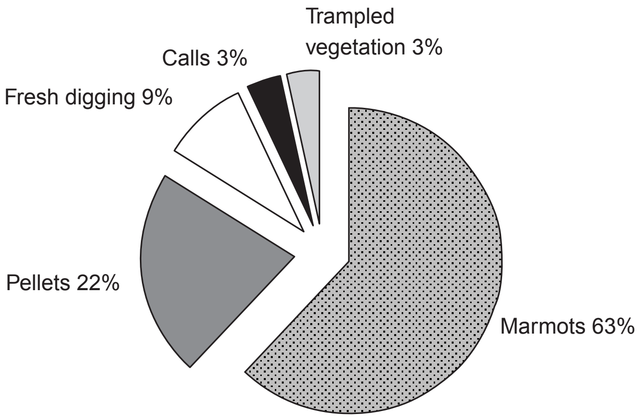

Fig. 5. Primary cues used for determining presence or absence in polygons sampled for Olympic marmots ($n = 87$).

is the highest (Cortot *et al.* 1996; Leontieva *et al.* 1997; Bryant 1998; Lenti Boero 1999).

Marmot daily activity patterns depend on the season and weather (Barash 1973; J. Witczuk, pers. obs.). During the summer marmot activity is bimodal with the mid-day being a period of resting below ground. Therefore, optimal times for summer surveys are morning and late afternoon hours (before 1100 and after 1600 hours; mid-June to mid-September).

Personnel

Critical pieces of information for the monitoring design include the type and number of personnel that will be available (seasonal rangers, biologists, volunteers, park interns). For monitoring purposes there are advantages to using inexperienced amateur observers as well as experienced park personnel to conduct the repeated surveys across years. A presence–absence survey of backcountry alpine meadows throughout the park is feasible for inexperienced observers and constitutes an attractive project for recruiting volunteers. Amateurs do not know previous marmot distributions, thereby eliminating a potential source of bias. By contrast, observers experienced in sampling marmots in the park can unconsciously put less effort into areas where marmots were absent in previous periods, thereby failing to record colonisations of new sites or identification of previously undetected colonies. On the other hand, inexperienced observers may have higher error rates in determining polygon occupancy status (failure to distinguish between marmot and mountain beaver (*Aplodontia rufa*) burrows, inadequate searching behaviour, etc.). Therefore, adequate training is necessary (see Accessory Publication on *Wildlife Research* website).

Conclusions

The example of the critically endangered Vancouver Island marmot, where dramatic decline was recognised just in time to avert extinction (Bryant and Page 2005), underscores the importance of long-term studies. Although intensive monitoring of numerical trend and vital rates at particular sites are necessary to illuminate specific drivers of population dynamics (Mills 2007; Griffin *et al.* 2008), occupancy monitoring is a useful complement to demographic monitoring because it efficiently tracks extinction and recolonisation dynamics across a large spatial scale. We have developed a protocol for annual sampling of the presence–absence of Olympic marmots across their range, based on a random sampling of 25 clusters and supplemented by sampling 10–15 never-occupied polygons. Although optimised for Olympic marmots, our approach could easily be extended to other species, many of which are vulnerable (e.g. *Marmota camtchatica* and *Marmota sibirica*; Bibikov 1999; Karels *et al.* 2004). More broadly, we believe our protocol may be a useful case study addressing general on-the-ground issues that must be dealt with to monitor any species with logistical challenges.

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Appendix 1. Results of the pilot polygon surveys for the detectability assessment

Status determined: 0, unoccupied 1, occupied 2, abandoned

Survey number	Polygon ID	Status determined	No. of marmots seen	Calls	Active burrows confirmation				
					Pellets	Fresh digging	Trampled vegetation	Paths between burrows	Marmot smell
1	56	1				+			+
2	128	1			+				
3	172	1	2						
4	183	1	2						
5	189	1	2						
6	199	1	2						
7	518	1		+	+		+		
8	523	1				+			
9	524	1			+				
10	559	1			+				
11	575	2							
12	594	1				+			
13	598	0							
14	600	1	1	+					
15	650	1			+		+	+	
16	657	1					+		
17	674	1			+				
18	731	1	1		+				
19	790	1			+				
20	791	1			+				
21	803	1			+				+
22	830	1	1						
23	831	1	2						
24	859 W	1	4						
25	859 E	1				+		+	
26	876	1	1	+					
27	980	1			+			+	
28	983	1	1						
29	1009	1	1						
30	1031	1	1						
31	1040	1	2						
32	1043	1			+				
33	1086	1	1						
34	1106	0							
35	1116	1	1						
36	1132	1		+					
37	1133	1	2						
38	1154	1					+	+	+
39	1164	1			+				
40	1170	1		+				+	+
41	1173	1	1	+					
42	1177	1			+				
43	1178	1	5	+					
44	1210	1				+			
45	1250	1	1						
46	1264	1				+			
47	1273	1	1						
48	1322	1			+				
49	1331	1	1		+				
50	1370	1	1						
51	1404	1	1						
52	1434	1	1	+					
53	1544	1	1		+				
54	1545	1	1		+				
55	1823	1	5						
56	1882	1			+				

(*continued next page*)

Appendix 1. (*continued*)

Survey number	Polygon ID	Status determined	No. of marmots seen	Calls	Active burrows confirmation				
					Pellets	Fresh digging	Trampled vegetation	Paths between burrows	Marmot smell
57	2045	1	2						
58	2147	1			+				
59	2232	0							
60	2259	0							
61	2318	1	1						
62	2442	1	1						
63	2531	1	1						
64	2566	1	1						
65	3587	1	1						
66	3615	1	3						
67	3643	1	6						
68	3688	1	3						
69	3785	1			+				
70	3815	1			+				
71	3913	1	1						
72	3996	1	3						
73	4066	1	1						
74	4202	1	6						
75	4290	1	5						
76	4318 W	1	2						
77	4318 E	1	1						
78	4600	1	2	+					
79	5038	1	1						
80	5521	1	1						
81	5607 E	1	1						
82	5607 W	1	1						
83	5620	1					+		
84	6005	1	1						
85	6051	1			+				
86	6287	1				+			
87	11285	0							
88	11313	1	1						
89	11341	1	1						
90	11342	1				+		+	
91	11357	1	1	+					
92	11394	1	2	+					
93	11401	2							
94	Lena Lake	1			+				