



# Effects of errors in range maps on estimates of historical species richness of mammals in Canadian national parks

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## Abstract

**Aim** Tests for faunal relaxation in reserves, particularly for mammals, have relied on comparisons of current species richness with estimates of species richness derived from historical range maps. However, any range map reflects the *extent of occurrence* of species and not necessarily the *area of occupancy*. Thus, estimates of historical species richness might be prone to error introduced by ‘false positives’, that is, a species might be considered to have been present in locations where it actually was not. The effect of such ‘false positives’ could bias statistical tests of faunal relaxation to type I error, and result in estimates of the extent of faunal relaxation in reserves greater than was actually the case. We evaluated the potential for errors in historical range maps to generate inflated estimates of historical species richness of mammals at sites that are reserves today.

**Location** Canadian national parks in the Canadian portion of the Alleghenian–Illinoian mammal province in south-eastern Canada (the maritime region and parts of southern Québec, Ontario and Manitoba).

**Methods** The effect of varying levels of error in range maps on estimates of historical species richness was tested using geographical information systems (GIS)-based statistical sampling of simulated historical ranges. Species’ areas of occupancy were simulated to be only 25%, 75% and 95% of published historical species ranges. For each reserve, estimates of historical species richness from these simulated species ranges were then compared with similar, previously published estimates of richness based on published historical species ranges.

**Results** Previous estimates of historical species richness for reserves were inversely and linearly related to the degree of inaccuracy of species ranges. If species ranges were, on average, 5% smaller than the accepted ranges, then estimates of historical species richness agreed with previous estimates in *c.* 90% of cases. However, if historical ranges were, on average, 25% smaller than those used in previous analyses, then previous historical estimates of species richness may be overestimates in *c.* 40% of cases.

**Main conclusions** Estimates of the extent of faunal relaxation in reserves that use historical range maps to quantify past species richness appear to be sensitive to even small errors in the degree to which range maps may overestimate ‘area of occupancy’.

## Keywords

Canadian national parks, historical mammal distributions, faunal relaxation, range maps.

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## INTRODUCTION

Terrestrial reserves have been shown to undergo faunal relaxation consistent with the principles of island biogeography. Small parks that have become isolated from their surrounding habitat matrix have been shown to have lost more of their historical complement of disturbance-sensitive mammals than large parks that are surrounded by intact habitat (Glenn & Nudds, 1989; Newmark, 1995; Gurd & Nudds, 1999; Brashares *et al.*, 2001; Gurd *et al.*, 2001; Wiersma & Nudds, 2001). Tests for extinctions of mammals from Canadian reserves have used two approaches to estimate historical baselines of species richness. Species richness has been estimated from species–area curves generated from historical range maps assumed to represent species ranges prior to widespread European settlement (e.g. Glenn & Nudds, 1989; Gurd & Nudds, 1999). Species richness has also been directly sampled from these maps using geographical information systems (GIS) (e.g. Wiersma & Nudds, 2001). Estimates of the numbers of species that might have been present in reserves prior to insularization were compared with current species richness (Glenn & Nudds, 1989; Gurd & Nudds, 1999; Gurd *et al.*, 2001; Wiersma & Nudds, 2001) to estimate the extent of faunal relaxation that each park had undergone.

Estimates of past species richness from historical range maps may be prone to error because of inaccuracy in those maps. Range maps are typically derived from a series of point observations and delineate the ‘extent of occurrence’ of a species (van Jaarsveld *et al.*, 1998). Different methods may be used to extrapolate range boundaries (extent of occurrence) from observations of species (areas of occupancy), giving very different impressions of the ‘extent of occurrence’. Authors of original range maps, for instance, may have had different confidence in the locations of observations on which they based their maps, and delineated species historical ranges accordingly.

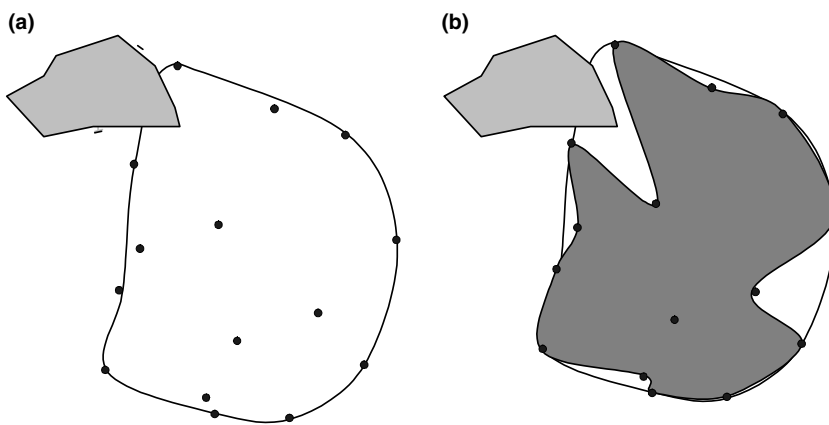
For example, the mammal range maps in Banfield (1974) used previously to test for faunal relaxation in Canadian parks (Glenn & Nudds, 1989; Gurd & Nudds, 1999; Gurd *et al.*, 2001; Wiersma & Nudds, 2001) were based on observations

and collected specimens documented in records maintained in museums. These kinds of data may reflect favoured transport routes, hunting areas or collection localities (Lawes & Piper, 1998). Further, because historical records are typically fewer, and historical estimates of species ranges thus cruder, the discrepancy between the ‘extent of occurrence’ of a species and the actual ‘area of occupancy’ (van Jaarsveld *et al.*, 1998) may be even greater for historical data than it is for current distribution data.

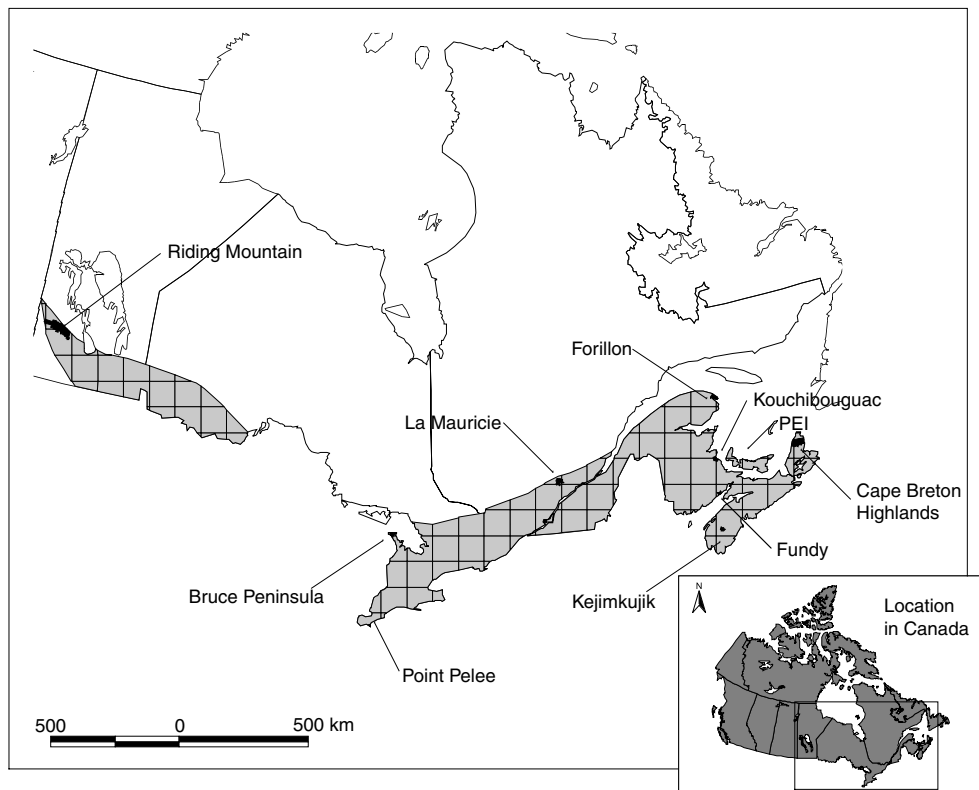
Thus, Robinson & Quinn (1992) cautioned that species might be designated as historically present in an area that is currently a reserve, when they actually were not (Fig. 1) and the effect of such ‘false positives’ has implications for tests of faunal relaxation. If a reserve was never as species rich as assumed, then formal statistical tests for faunal relaxation would be biased to type I error, that is, to detecting relaxation when it has not actually happened (Gurd & Nudds, 1999; Wiersma & Nudds, 2001). This criticism has intuitive appeal, but we are unaware of any formal evaluation of how poor the match between ‘extent of occurrence’ and ‘area of occupancy’ would have to be before we might consider statistical tests for faunal relaxation based on historical data to be unreliable.

## METHODS

We evaluated the effect of potential inaccuracies in historical ranges of mammals on estimates of historical species richness for a subset of mammals (see below for selection criteria) identified as historically present by Wiersma & Nudds (2001) in Canadian national parks. For each species, we simulated reductions in ‘area of occupancy’ within the historical ranges (extents of occurrence) by randomly placing ‘holes’ (simulated unoccupied areas) within each range. New estimates of historical species richness for each park were derived using the simulated ranges following methods of Wiersma & Nudds (2001), wherein GIS was used to count directly the number of species historically present in areas that are currently national parks. The new estimates of historical species richness were compared with Wiersma & Nudds’ (2001)



**Figure 1** Two possible ways to connect the same set of points to delineate an historical species range with different implications for assessment of historical presence of a species in a reserve. (a) The reserve (stippled) intersects with the ‘extent of occurrence’ of the range; the species is recorded as historically present in the reserve. (b) The reserve intersects the ‘extent of occurrence’ of the range, but not the actual ‘area of occupancy’ (shaded); the species was not actually present in the reserve.



**Figure 2** The Canadian portion of the Alleghenian–Illinoian mammal province (after Hagmeier, 1966), showing the ten national parks used in the analysis. Superimposed is the range grid for the mammal province used in the analysis, from which the ranges for each of the six species used were clipped.

previous estimates of historical species richness to test how robust the estimates were to the simulated inaccuracies in the historical ranges.

We used maps digitized from historical distributions of native, terrestrial mammals in Canada depicted in Banfield (1974) to generate simulated historical ranges in a GIS. Analysis was restricted to disturbance-sensitive mammal species (defined by Glenn & Nudds, 1989, *sensu* Humphreys & Kitchener, 1982) in the Canadian portion of the Alleghenian-Illinoian (AI) mammal province (Fig. 2) (Hagmeier, 1966), the region where faunal relaxation by mammals consistent with theory has been previously and consistently detected (Glenn & Nudds, 1989; Gurd & Nudds, 1999; Gurd *et al.*, 2001; Wiersma & Nudds, 2001). Parks composed of archipelagoes (Georgian Bay Islands National Park, St Lawrence Islands National Park, and Mingan Archipelago National Park) were excluded to study the effects of insularization on terrestrial isolates alone, leaving ten parks for analysis (Fig. 2).

The six species deemed to be historically present across all ten national parks by Wiersma & Nudds (2001) were used in this analysis: *Castor canadensis* (beaver), *Lynx canadensis* (lynx), *Microsorex hoyi* (pygmy shrew), *Tamiasciurus hudsonicus* (red squirrel), *Glaucomys sabrinus* (northern flying squirrel), and *Lontra canadensis* (river otter). Five of these

six are not currently resident in at least one park; therefore, if their historical presence in a park is an example of a ‘false positive’, then Wiersma & Nudds’ (2001) conclusion that these species were extirpated from the parks may be sensitive to type I error.

The shape of the AI province was clipped from each mammal range using ArcView™ 3.1 (Environmental Systems Research Institute, Redlands, CA, USA) and used as the ‘base ranges’ from which to simulate ranges with different degrees of ‘area of occupancy’. The base historical range of each species was gridded with 10,000 km<sup>2</sup> cells using ArcView™ Sample 3.03 extension (Quantitative Decisions, Merion Station, PA, USA) (Fig. 2). This cell size was chosen somewhat arbitrarily, but with the intent of compromising between two potential sources of error. Overly large cells might have reduced the resolution of the analysis to the point that effects of a simulated small percentage reduction in ‘area of occupancy’ would be too hard to detect, as it would reduce the simulated range by only one or two cells. This might result in false confidence in the use of historical range maps. On the other hand, overly small cells might have created an unrealistic level of patchiness in the simulated ‘area of occupancy’.

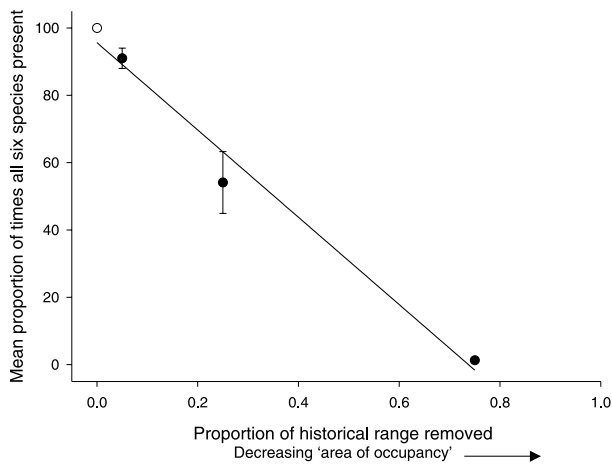
A list of cells that comprised the simulated historical ranges, and the parks that intersected each cell, was generated in

ArcView™. This list was exported to SPSS 10.0 (SPSS Inc., Chicago, IL, USA) and cells were deleted at random to create, for each species, 300 historical ranges – 100 each of 25, 75 and 95% ‘area of occupancy’ of the historical ranges used in past studies (Glenn & Nudds, 1989; Gurd & Nudds, 1999; Wiersma & Nudds, 2001) – for a total of 1800 iterations. For each iteration, species were scored as present or absent in each area that is now a national park based on whether they intersected with the simulated ‘area of occupancy’. Thus, a simulated ‘gap’ in the interior of the ‘extent of occurrence’ represented an unoccupied area and a species would not be considered historically present in a park that coincided with that gap.

For each park, we calculated the proportion of 100 iterations in which all six species were detected as present historically, and therefore in agreement with Wiersma & Nudds (2001). We calculated the mean proportion of agreement ( $N = 10$  parks) at each simulated percentage ‘area of occupancy’ ( $N = 3$ ). The proportion of those simulated results that agreed with the original estimates by Wiersma & Nudds (2001) was fitted against the simulated area of occupancy by linear least squares regression.

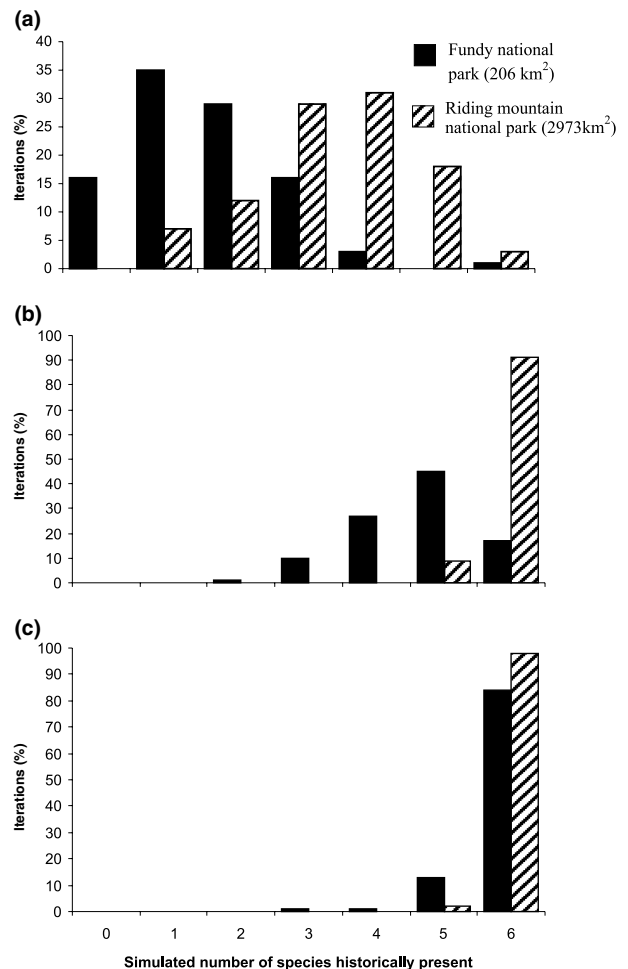
## RESULTS AND DISCUSSION

The numbers of species estimated to have been historically present in parks varied with simulated variation in ‘area of occupancy’ of historical ranges (Fig. 3). If actual historical



**Figure 3** Data points [●; ○ indicates Wiersma & Nudds (2001) baseline value] and linear regression ( $y = 95.6 - 12.9x$ ,  $r^2 = 0.98$ ,  $P = 0.0095$ ) illustrating rate of change of the probability of all six species being historically present as the ‘area of occupancy’ is reduced. Decreasing the ‘area of occupancy’ of a historical range by 5% results in a 90% agreement with the baseline value which assumed that ‘area of occupancy’ = ‘extent of occurrence’. Thus, if historical range maps overestimate ‘area of occupancy’ by 5%, then estimates of faunal relaxation may be biased by ‘false positives’ in 10% of cases. Note that standard error for 75% historical range removed is too small for error bars to be displayed on the scale of graph.

ranges were on average only *c.* 5% smaller than those depicted by Banfield (1974), then Wiersma & Nudds’ (2001) estimates of historical richness may be accurate in *c.* 90% of cases (Fig. 3). That is, if historical range maps overestimated the ‘extent of occurrence’ by 5%, then there is a 10% chance that a species detected at a specific location will be a false positive. If, however, historical ranges were, on average, 25% smaller than those used in previous analyses, then Wiersma & Nudds’ historical estimates of species richness may have been overestimated by one to four species in *c.* 40% of cases (Figs. 3, 4). The estimate of the slope suggests that a 10% decrease in the actual ‘area of occupancy’ results in a 13% decrease in agreement with estimates of historical species richness compared with estimates generated under the assumption that the ‘area of occupancy’ is also the ‘extent of occurrence’ (i.e. the historical species range).



**Figure 4** The number of species estimated to have been present historically in a small park (Fundy National Park; solid bars) and a large park (Riding Mountain National Park; striped bars) at three simulated ‘areas of occupancy’: (a) 25%, (b) 75% and (c) 95% of historical ranges.

At the smallest simulated 'areas of occupancy' (25%), parks were estimated to have one to six fewer species than Wiersma & Nudds (2001) reported, and this effect varied among parks of different sizes. Typically, estimates of species richness for larger parks were more robust to variation in the 'areas of occupancy' than were estimates for smaller parks (Fig. 4). However, because most reserves are small [e.g. see Fig. 3 in Gurd *et al.* (2001)], the problem of 'false positives' for identification of faunal relaxation could be particularly acute. These results suggest that studies which sample historical range maps at a large grain size may be more robust to errors in the 'extent of occurrence' than studies which conduct sampling at a finer resolution or grain size. In any case, future inventories of biodiversity could be strategically directed towards sampling to resolve to what degree 'extent of occurrence' actually differs from 'area of occupancy' for species ranges.

Further, accuracy of historical ranges may also vary by species. Better historical records exist for game species than for smaller mammals. For example, the beaver was heavily trapped following European colonization, and therefore has more point observations. Conversely, the pygmy shrew was not only ignored by trappers, but was probably rarely sighted because of its small size. Historical range maps may also be more accurate for generalist species that can live in a variety of habitats. For example, the red squirrel is considered to occupy a variety of habitats; therefore, its historical range may more nearly reflect its 'area of occupancy' than the pygmy shrew, which is considered a habitat specialist, suggesting a smaller 'area of occupancy' than indicated by its historical range. In general, studies that use historical range maps for abundant, charismatic, or commercially important species should be more reliable than those using maps of rare, shy or non-game species. In our analysis, most of the six species used were generalists, and three of them (river otter, beaver and lynx) were heavily trapped by Europeans.

Our analysis speaks of the question of the reliability of estimates of faunal relaxation when historical range maps overestimate the 'areas of occupancy' of species. It is also possible that historical range maps may underestimate species 'areas of occupancy'. Thus, a species recorded as historically absent from a current park would be a false negative, and would be considered to have appeared in the park over the interval. In this case, an increase in species richness would be detected, when, in fact, the correct conclusion would be that no decrease occurred. While this type of error would bear directly on estimates of faunal turnover, it does not bear on assessments of faunal relaxation. In that respect, error from historical range maps that underestimate 'areas of occupancy' is conservative when the emphasis is on stemming losses of species from reserves; a park manager is more concerned with missing a local extinction than detecting a colonization that did not happen.

## CONCLUSION

So far as we are aware, this is the first formal assessment of the implications of 'false positives' for historical data

used to test for faunal relaxation in reserves, but it concurs with the intuitive logic of Robinson & Quinn (1992), who expressed concern that variation in 'area of occupancy' affects estimates of historical species ranges in present-day reserves. Nevertheless, although it is generally accepted that historical range information is often difficult to obtain and of questionable accuracy, it is difficult to evaluate how inaccurate historical ranges are likely to be, and so, how significant this source of error might be for evaluating the extent of faunal relaxation. In any case, Aplet & Keeton (1999) argued that historical data ought not to be simply dismissed or ignored because of the difficulties it presents. Certainly, historical range maps are often based on opportunistically collected data, such as trapping records, and there is no single acceptable standard against which the maps can be judged (Williams, 1996). Often, they are the only data available with which to work (van Jaarsveld *et al.*, 1998). Thus, the outcomes of analyses using historical range data are somewhat conditional on the accuracy of the historical data. Where the accuracy of the data is not known, there is no option other than to accept the assumption that the majority of the range maps used are accurate, at least within the range of effects detectable in analyses, and supply appropriate caveats. At large scales of spatial analysis, perhaps more error in historical range maps might be tolerated than at finer scales. Thus, we remain in somewhat of a quandary, requiring appropriate historical baseline data for species richness, but perhaps unsure of the quality of the data. Gurd & Nudds (1999) and Wiersma & Nudds (2001) may have reported inflated rates of faunal relaxation, especially in the smallest parks; however, from a conservation perspective, the effect of overestimating historical species richness in present-day parks is a conservative error. Our caveat is this: if Banfield (1974) depicted historical ranges larger than they actually were, then faunal relaxation in some Canadian parks may not be as great as previous work suggested. It will never be possible to know with certainty, but extremely large discrepancies between 'extents of occurrence' and 'areas of occupancy' seem unlikely given that many of the species that are presumed extirpated from parks are large, charismatic, game species whose ranges were probably quite well known. Overall, we concur with others (van Jaarsveld *et al.*, 1998) who suggest that range maps are a useful tool for large scale ecological and biogeographical analyses, so long as their limitations are acknowledged.

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