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Searching for rare species: A comparison of Floristic Habitat Sampling and Adaptive Cluster Sampling for detecting and estimating abundance

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A B S T R A C T

Surveys of rare species are challenging owing to the difficulty of detecting them on a landscape. Survey methods vary, often to achieve different goals. Thus when different survey methods are used in different locations and/or years, it is difficult to compare abundance data between regions or for assessing population trends through time. In many jurisdictions, forest legislation or policy may require managers to carry out surveys to assess presence or confirm absence of rare species. This then can inform forest management decisions that may impact these species, particularly when the rare species is listed for protection, for example under species-at-risk legislation. Because species surveys can be time consuming as managers want to be confident in their ability to detect species (or confirm that observed absences are likely true), survey protocols should be as efficient and effective as possible. Floristic habitat sampling (FHS) is often applied for botanical surveys and focuses on generating a list of species present in a region (sometimes referred to as the relevé method) by inventorying an area as thoroughly as possible, including potential microhabitats. The Adaptive Cluster Sampling (ACS) method assumes that rare species are clustered in space and delineates sample plots non-randomly to increase accuracy of abundance estimates. Here, we compare FHS and ACS methods to detect rare lichens in two landscapes on the Avalon Peninsula in Newfoundland, as well as to generate species lists of arboreal lichens in a region. We also carry out a novel field simulation using artificial lichens to test how well ACS estimates known abundance. Finally, we demonstrate the utility of ACS to make new detections of an IUCN red-listed species (*Erioderma pedicellatum*) in a real-world setting and suggest how survey methods can be chosen to meet different forest management requirements.

1. Introduction

Forest management requires making decisions to balance sustainable extraction of resources with competing needs for recreation and biodiversity conservation (Wiersma et al., 2015). When a forest is habitat for a rare species, management must be carried out to minimize negative effects of forest activities on the organism. Effective forest management for rare species requires reliable inventory information of the location and abundance of rare species (e.g., Hannon et al., 2004; MacKenzie and Royle, 2005; Guisan et al., 2006; Wolseley et al., 2017). However, due to their rarity, such species can be difficult to sample and reliably estimate their abundance (Thompson, 2004; Guisan et al., 2006; Dorey et al. 2017) or distribution (Allen and Lendemer, 2017). Thus, understanding which methods efficiently and effectively detect rare species within an ecosystem is valuable for forest managers, as reliable detection is a first step for decision making about management that will not adversely impact the persistence of these rare species.

In vegetation surveys, there are a number of well-established survey methods. Plot sampling (PS) has been widely used since the earliest days of modern ecology, whereby sample plots of a fixed size are randomly placed within a study area and the species within them are inventoried and their abundance/cover recorded (Bonham, 1989). Data gathered from such plots are considered representative of the larger region (Newmaster et al., 2005), but may miss detections of rare species (Guisan et al., 2006). An alternative approach is the relevé method (Braun-Blanquet, 1932) which has been widely used in Europe (Chytrý and Otýpková, 2003; Peterka et al., 2015), including for lichens (Gombert et al., 2004). There is some confusion over what the unit of study the relevé refers to. In some studies, the relevé has been considered "the plot" (e.g., Knollová et al., 2005), although properly, the

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Table 1
Past and current survey efforts for the rare boreal felt lichen, *Erioderma pedicellatum* in Newfoundland. Note that the McCarthy survey included a suite of lichens, and the Big Triangle Pond and Bay du Nord surveys were part of an Environmental Assessment for proposed linear developments. Survey methods include the Floristic Habitat Survey (FHS, equivalent to an "intelligent meander"), the Wildlife Division Protocol (WLD), and the Adaptive Cluster Sampling (ACS) method.

Survey location	Year	Person-days	Area surveyed	Survey method	# trees surveyed	# thalli detected	Thalli per person day	Reference
Avalon Peninsula	2008	153	75 1-ha plots	FHS	9141	25	0.16	McCarthy (2010)
Big Triangle Pond	2010	9	29 x 100 m	WLD	1116	5	0.56	Gov't of NL (2015)
Kagudeck Lake	2014–2015	12	120 1-ha plots	ACS	n/a	398	33.17	Unpublished
Bay du Nord	2015	30	~27 plots 40 m wide	n/a	80	242	8.07	NL Hydro (2015)
Central Avalon	2016	12	16 moraines (~0.5–1 ha each)	ACS	n/a	52	4.33	This study

term "relevé" is French, meaning "list", "statement" or "summary". The relevé method in vegetation sampling refers to the list of plants in a delimitated area (Poore, 1955; Minnesota Department of Natural Resources, 2013), with estimates of relative cover. Surveys within a defined area closely examine as many meso and microhabitats as possible with the goal of inventorying all possible species. Newmaster et al. (2005) called this approach Floristic Habitat Sampling (FHS) and compared diversity of bryophytes captured with FHS and PS approaches. They found FHS (i.e., relevé method) was more efficient, and detected twice as many species as PS. FHS detected more rare species, but did not estimate abundance well. Thus, there is a trade-off; if the goal is to detect rare species, then FHS/relevé methods are more appropriate, but for statistical inference or robust estimates of abundance, a PS method is more appropriate. This trade-off makes it difficult to decide which method is most efficient and effective when it is necessary to both detect rare species and estimate their abundance.

An alternate method is adaptive cluster sampling (ACS) (Thompson, 1990, 1991). ACS involves initial selection of plots based on a probability sampling procedure. Detection of the species of interest triggers additional survey efforts in adjacent plots (Thompson, 1990). This takes advantage of the tendency for rare species to cluster together (Acharya et al., 2000; Ostling et al., 2000; Pacifici et al., 2015). ACS is a slightly different approach than randomly assigned plots, as in the PS method. As a result, ACS is hypothesized to more reliably estimate abundance (Thompson, 1990). It has been successfully applied to detect rare lichens in Italy (Giordani et al., 2015), rare plants in China (Pacifici et al., 2015) and rare trees in Nepal (Acharya et al., 2000).

Boreal felt lichen (*Erioderma pedicellatum* (Hue) P.M.Jørg.) is a globally rare species that is listed as "Critically Endangered" by the International Union for Conservation of Nature (Scheidegger, 2003) and "Special Concern" in Canada by the Committee on the Status of Endangered Wildlife (COSEWIC, 2014). Approximately 95–98% of the global distribution is found on the island of Newfoundland (Keeping and Hanel, 2006). Lichens can be useful indicators of old-growth forest status (Selva, 2003; Nascimbene et al., 2010) and detection of this particular species triggers development of a management plan, as its presence on the landscape may have implications for forest management and other land use activities (Government of Newfoundland and Labrador, 2014). Efficient detection of this species through cost-effective surveys is important for understanding its distribution which is a critical component of both forest and rare species management, particularity when resources for survey work and management are limited.

Boreal felt lichen is extirpated from New Brunswick and has very small populations in Nova Scotia (Keeping and Hanel, 2006; Cameron and Neily, 2008; Cameron and Toms, 2016) and a few localities in Scandinavia (Holien, 2006; Reiso and Hofton, 2006). More recently, there was a large population discovered in Alaska consisting of more than 2035 thalli (Stehn et al., 2013). On the island of Newfoundland it is known from three localities (Keeping and Hanel, 2006), though it is believed to be more widely distributed (Wiersma and Skinner, 2011; A. Arsenault & C. Hanel, pers. comm.). Its cryptic coloration means that it is likely to be overlooked unless it is the focus of targeted surveys conducted by individuals trained to recognize it.

Currently, the distribution of boreal felt lichen is not fully understood in the province, and is difficult to predict (Wiersma and Skinner, 2011). Thus, forest managers are required to spend time searching for the lichen to confirm its presence or absence, and estimate its abundance. The survey method most used in the province was developed by the Wildlife Division of the Department of Environment and Conservation (detailed in Appendix C of Government of Newfoundland and Labrador, 2015). This method is similar to FHS, in that survey effort is targeted to specific meso and microhabitats within a constrained area. The survey involves traversing a 100 m transect in suitable habitat and closely examining at least 40 suitable balsam fir (*Abies balsamea* L. (Mill.)) trees, with an additional 100 m/40 trees to search when the searcher encounters the associated liverwort *Frullania asagrayana* or one of the five indicator lichens (*Coccocarpia palmicola, Erioderma mollissimum, Fuscopannaria ahlneri, Lichinodium sirosiphoideum, Lobaria scrobiculata*). Searchers must also examine additional trees within 20 m of every thallus of *E. pedicellatum* found. In lichenology, this approach of subjectively examining meso and microhabitats (FHS) to try to create as complete a species list for an area as possible has also been termed an "intelligent meander" (e.g., Selva, 1994, 2003; McMullin et al., 2008; McCarthy et al., 2015; McMullin and Wiersma, 2017).

Forest managers have found the currently used methods (which follow more of the FHS approach) to be time- and labour-intensive, and potentially inefficient. For example, a recent survey found only 5 thalli with a survey effort at Big Triangle Pond of 12 person-days (0.16 thalli per person day) that covered 29 sample transects (100 m each), and 1116 trees (Table 1) (Government of Newfoundland and Labrador, 2015). Even methods designed to be biased to likely localities for the target species can be time-consuming. For example, McCarthy (2010) used a stratified random approach to select survey areas that met criteria of forest cover which matched *E. pedicellatum* habitat requirements. He surveyed 75 1-ha plots across the Avalon Peninsula over the course of 51 days and found 25 *E. pedicellatum* thalli (0.56 thalli per person day). Sixty-two of the surveyed plots did not contain *E. pedicellatum* (Table 1). In contrast, the ACS method was applied in a second known hotspot for *E. pedicellatum* in Newfoundland, Kagudeck Lake, and resulted in the location of 398 thalli in 9 person-days of survey work (33.17 thalli per person day; B. Adams, unpublished data; Table 1). These data illustrate the difficulty in determining whether different lichen densities observed is real, and due to habitat conditions (the above surveys did not overlap spatially, although two were in the same region), or whether it is an artifact of sampling differences.

Our objective was to compare sampling methods for rare species to better understand the relative strengths and limitations of each. We realized this objective through three approaches. First, we compared the FHS and ACS method (described in additional detail below) in their ability to detect rare lichens. We predict that they will detect presence of rare species equally well, but that the ACS method will be more efficient because it has a time constraint and focuses on clusters of rare species, thus avoiding sampling in areas where the species is unlikely to occur. Second, we experimentally tested how closely the ACS method