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Non-stochastic colonization by pioneer plants after deglaciation in a polar oasis of the Canadian High Arctic

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Abstract

Initial plant colonization is critical in determining subsequent ecosystem development. In a High-Arctic oasis showing atypical "directional primary succession", we quantified the microhabitat characteristics associated with colonization by pioneer vascular plants of a bare moraine. The study moraine, formed during the Little Ice Age, is located within the proglacial area at the southern front of Arklio Glacier, Ellesmere Island, Canada. We established two line-transects on this moraine to quantify microhabitats for vascular species. Microsites favorable for plants were concave depressions, probably increasing the likelihood of colonization. At microsites distant from stable boulders, which probably protect seeds/seedlings from wind desiccation, plant colonization was less likely. Furthermore, favorable microhabitat properties differed depending on topographical location within the moraine, suggesting that, even within a single moraine, microhabitats favorable for plant colonization are heterogeneously-distributed. This moraine was characterized by two major pioneer species, *Epilobium latifolium* and *Salix arctica*. Their species-specific microhabitat requirements highlight the importance of biotic factors in colonization processes. Favorable sites for plants are generally distributed at random in harsh environments. However, we showed that initial plant colonization is a deterministic process rather than random, indicating the possibility of non-stochastic processes even during the early phase of ecosystem development in High-Arctic ecosystems.

Keywords: Community development; Deglaciated moraine; Glacier foreland; Microhabitat characteristics; Primary succession

1. Introduction

Primary plant succession and ecosystem development are important aspects of ecology, and have been the subjects of extensive study. Irrespective of ecosystem, region, and succession pattern (primary or secondary), initial plant colonization is the most critical phase in the succession process, determining subsequent long-term ecosystem development and shaping various ecological processes during each ensuing phase of succession (Cooper et al., 2004; Elmarsdottir et al., 2003; Gill et al., 2006; Jumpponen et al., 1999; Ledger et al., 2006; Matthews and Whittaker, 1987; Mori et al., 2008; Robbins and Matthews, 2009). Knowledge of community ecology also sheds light on the significant role of early events including a priority effect (e.g., Chase, 2010; Fukami and Nakajima, 2011), which can lead to unexpectedly high variability in community structure

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among similar sites. Cutler et al. (2008) noted that even in a subarctic ecosystem characterized by stressful abiotic environments, the initial phase of colonization is of substantial importance for subsequent ecosystem development. The initial phase of primary succession is dominated by stochastic processes (del Moral, 2009; Marteinsdóttir et al., 2010; Robbins and Matthews, 2009), including the random distribution of pioneers relative to the distribution of suitable sites (Cutler et al., 2008). Consequently, identifying the causal factors that determine the colonization success of pioneer plants has major implications for understanding the subsequent shift to a gradual dominance of deterministic processes through succession.

Lévesque (2001) showed that plant recruitment in a High Arctic desert is spatially nonrandom as a result of the limited availability of microhabitats that can trap seeds and favor their germination and subsequent plant growth. This is attributable to the specific succession pattern in the polar region. As a consequence of the overwhelming effects of marginal physical conditions and the lack of biological interactions in the High Arctic, successional patterns differ greatly from those in lower latitude areas (Svoboda and Henry, 1987). In High Arctic deserts the typical succession pattern is generally referred to as 'non-directional, non-replacement (of species) succession', which means that a very low number of species survive and maintain their status, while fluctuating in terms of cover, abundance, and productivity (Svoboda and Henry, 1987). Thus, the conceptual models of directional ecosystem development (reviewed by Cutler et al., 2008) may not be applicable to systems in extremely harsh environments, such as those in High Arctic ecosystems.

The High Arctic region is generally characterized by vast expanses of barren or sparsely vegetated terrain without significant populations of land animals, or by ice fields (Freedman et al., 1992). Nevertheless, uncommon well-vegetated areas referred to as "polar oases" (Muc et al., 1992) occasionally occur. In these oases primary plant succession can sometimes exhibit directional succession involving directional addition of species over time (Svoboda and Henry, 1987), although this is very atypical (Breen and Lévesque, 2006; Hodkinson et al., 2003; Jones and Henry, 2003; Mori et al., 2008). Given that biotic factors and processes have a significant effect on vegetation development in the glacier forelands of High Arctic oases (Mori et al., 2008), plant colonization patterns in these areas may differ from those observed in typical polar deserts dominated by marginal abiotic environments. Despite the importance of microscale environmental conditions for plant occurrence on deglaciated forelands (Jones and del Moral, 2005; Jumpponen et al., 1999), the physical properties of such favorable microsites have not been well quantified for the polar oases of the High Arctic. This study focused on a High Arctic oasis on a relatively new moraine on Ellesmere Island (Canada); this oasis formed during the Little Ice Age (LIA) (Mori et al., 2006, 2008; Okitsu et al., 2004). By characterizing the attributes of microhabitats favorable for the colonization of pioneer plants in the bare terrain, this study aimed to provide information on the initial process of directional succession following glacial retreat in a High Arctic environment.

2. Materials and methods

2.1. Study site

The study site (80°52′N, 82°50′W) is located within the proglacial area at the southern front of Arklio Glacier in the Krieger Mountains near Oobloyah Bay, Ellesmere Island, Nunavut, Canada. Climate data from the nearest weather station (Eureka; 80°00′N, 85°56′W; 130 km south of Oobloyah Bay) show that the study area has a polar climate (Okitsu et al., 2004). The mean temperature in the warmest month (July) is 3.3 °C, and is −38.0 °C in the coldest month (February), while the mean annual temperature is −19.7 °C and the mean annual precipitation (1951–1980) is 64 mm. The geological features of the study site have been described previously (King, 1981; Okitsu et al., 2004).

The Arklio Glacier has glacial moraines that have developed over different periods since the Last Glacial Period (King, 1981). The vegetation characteristics of the deglaciated moraines in this area have been described previously (Mori et al., 2008; Okitsu et al., 2004). Among the moraines formed during different periods of glacial advance, the youngest moraine (located at the front of the glacier) is estimated to have formed during the LIA (400–250 years ago; Mori et al., 2008; Okitsu et al., 2004). Although both the occurrence and abundance of plants are very low, several plant species have colonized and become established on this moraine (Mori et al., 2006).

2.2. Moraine features

A morphological description of the study moraine is provided in Fig. 1. Topographical features within the moraine were categorized as the moraine ridge (Ridge site; Fig. 2); the upper part of the moraine side slope,