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Testing the capacity of clothing to act as a vector for non-native seed in protected areas

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ABSTRACT

Although humans are a major mechanism for short and long distance seed dispersal, there is limited research testing clothing as a vector. The effect of different types of material (sports vs hiking socks), or different items of clothing (boots, socks, laces vs legs) or the same item (socks) worn in different places on seed composition were assessed in Kosciuszko National Park, Australia. Data was analyzed using Repeated Measures ANOVA, independent and paired *t*-tests, Multi-dimensional Scaling Ordinations and Analysis of Similarity. A total of 24,776 seeds from 70 taxa were collected from the 207 pieces of clothing sampled, with seed identified from 31 native and 19 non-native species. Socks worn off-track collected more native seeds while those worn on roadsides collected more non-native seeds. Sports socks collected a greater diversity of seeds and more native seeds than hiking socks. Boots, uncovered socks and laces collect more seeds than covered socks and laces, resulting in 17% fewer seeds collected when wearing trousers. With seeds from over 179 species (134 recognized weeds) collected on clothing in this, and nine other studies, it is clear that clothing contributes to unintended human mediated seed dispersal, including for many invasive species.

1. Introduction

Anthropogenic mass movement of species is one of the greatest environmental challenges faced by conservation organizations (WRI, 1992; IUCN, 2000). Human activities are an important mechanism for long distance dispersal of plants and animals including invasive species (WRI, 1992; IUCN, 2000; Groves et al., 2005; Nathan, 2008; Wichmann et al., 2009). Human mediated dispersal of plants can be deliberate for agricultural and ornamental purposes (Groves et al., 2005; Benvenuti, 2007), or accidental such as through agricultural seed contamination in: soil (Rejmanek, 2000; Benvenuti, 2007), garden waste (Groves et al., 2005; Hulme, 2006), on equipment or even on clothing (Table 1). Both deliberate and accidental introductions have dramatically increased the scale and rate at which plants are dispersed, including many invasive species (Reichard and Hamilton, 1997; Groves et al., 2005; Wichmann et al., 2009).

Limiting human mediated dispersal of non-native plants is important, particularly when they are invasive. Invasive plants can adversely affect flora and fauna, prevent the recruitment of native plants, alter hydrology and nutrient content of soils, change fire regimes, and affect fauna that use the plants for food and habitat (Csurhes and Edwards, 1998; Williams and West, 2000; Mayers and Bazely, 2003). Although there is renewed interest in understanding the invasive process, there is still limited research on the initial dispersal of species, particularly empirical studies (Puth and Post, 2005). For example out of 873 recent articles examining the process of invasion of exotic species, only 15 were empirical studies examining the initial dispersal of species in terrestrial systems.

The initial step in unintended human mediated seed dispersal is seed attachment. Although seeds are commonly observed on socks, laces, boots and trousers there is limited empirical data on clothing as a seed vector (Table 1). The authors have only found nine published empirical studies, and only three involved statistical testing of hypothesis. Seven studies examined seed attached to shoes and/or boots, four examined socks, two examined laces and four examined seed on trousers. Only two of the studies examined dispersal (Bullock and Primack, 1977; Wichmann et al., 2009). Based on the nine studies 139 species of plants have been identified that have seeds that can attach to clothing and hence have the potential to be dispersed by humans over long distances.

Although these studies established that clothing can be an important mechanism for human mediated seed dispersal, research is required to quantify the amount and composition of seeds that can collect on clothing, and determine if factors such as

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Table 1
Details of the current and nine other published studies of clothing as a seed vector.

Source	Country	Type of clothing					Methods used					Diversity collected		
		Shoes	Socks	Laces	Trousers	Other	Design	Rep.	# per item/area	Manip.	Statistics	Fixed # species	# taxa	# species
Woodruffe-Peacock, 1918	England	Yes				Yes	Obs.	No	No	No	No	No	20	20
Healy, 1943	New Zealand		Yes		Yes		Obs.	No	Yes	No	No	No	33	1
Clifford, 1956	England	Yes					Obs.	Yes	No	No	No	No	42	39
Fallinski, 1972	Poland	Yes	Yes	Yes	Yes		Exper.	Yes	No	Yes	Yes	No	32	30
Bullock and Primack, 1977	Costa Rica				Yes	Yes	Exper.	Yes	Yes	Yes	Yes	Yes	3	2
Wace, 1985	Australia	Yes	Yes		Yes		Obs.	Yes	No	No	No	No	38	24
Higashino et al., 1983	Hawaii	Yes					Exper.	Yes	No	No	No	No	16	12
Whinam et al., 2005	Australia	Yes	Yes			Yes	Exper.	Yes	No	No	No	No	81	32
Wichmann et al., 2009	England	Yes					Exper.	Yes	Yes	Yes	Yes	Yes	2	2
This study	Australia	Yes	Yes	Yes	Yes		Exper.	Yes	Yes	Yes	Yes	No	70	50
Total														179

the location the clothing is worn, the type of material it is made of, and if different clothing items, affect the amount and type of seeds collected. For example, the surface area of the item, the location (such as height) of the item and the adhesive quality of the item are all likely to effect seed attachment to clothing (Bullock and Primack, 1977; Whinam et al., 2005). Different combinations of clothing may affect what seeds attach so that someone wearing shorts, socks, shoelaces and boots may collect different seed than if they were wearing trousers which covered the socks, shoelaces and the top of boots. There are also likely to be differences in the seeds collected when hiking through disturbed areas such as roadsides and car parks where there are many non-native plant species, to the seeds collected when hiking in intact native vegetation away from roads and tracks. As hikes can commence from roadsides and car parks there is the risk that people may carry non-native seeds from these areas into the natural vegetation in protected areas.

The objectives of this study were to experimentally test aspects of seed attachment to clothing as part of assessing the risk of human mediated seed dispersal including for non-native plants. Three field experiments were conducted in a popular national park with high conservation values, Kosciuszko National Park, to determine: (1) What seeds are collected on clothing (species and number, native vs non-native); (2) If there are differences in the seeds collected on socks depending on where someone walks; (3) If there are differences in the seeds collected on different types of socks; (4) If there are differences in the seeds collected on different items of clothing (boots, socks, laces and trouser leg) and (5) if wearing trousers reduces the amount of seeds collected.

2. Methods

2.1. Study area

The potential for seed to attach to clothing was assessed in Kosciuszko National Park, in the Australian Alps bioregion of southeast Australia. The Park is a major tourist destination with around three million visitors a year (DEC, 2006). The alpine area around continental Australia's highest mountain, Mt Kosciuszko ($\sim$100 km^2) is very popular for hiking with 79% of the around 100,000 people who visit the area during the snow free period, going hiking (Johnston and Growcock, 2005). Although most hikers remain on the formal trail system, hiking off trail is permitted and is popular to iconic destinations such as glacial lakes and for back country camping (Johnston and Growcock, 2005).

The unique combination of climate and geology in the Park contributes to a high degree of diversity and endemism in the flora. In the alpine zone there are 212 species of vascular plants of which 33 species are rare, and 21 endemic. This is among the highest values for endemism in mountainous regions in the world. Across the whole of the Park there are 852 native vascular species (Costin et al., 2000; DEC, 2006).

Non-native plants are increasing in the Park having been introduced and spread through grazing of cattle and sheep, soil conservation work, mining, the Snowy Mountains Hydroelectric Scheme and activities and infrastructure associated with tourism such as the ski resorts. Approximately two thirds of the 330 non-native plant species in the Park are found in the alpine and subalpine zones (DEC, 2006). The distributions of these species are strongly associated with visitor infrastructure, with a high cover and diversity of non-native species found along roadsides in the Park (Johnston and Pickering, 2001; McDougall et al., 2005; DEC, 2006; Pickering and Hill, 2007a,b).

Three experiments examining clothing as a seed vector were conducted in the Park between late January and mid February 2008 when many plant species in the subalpine and alpine zones of the Park are seeding (Fig. 1). The term "seed" is used here as a general descriptor to represent the dehiscent or indehiscent diaspores produced by a plant species, and hence for some species may refer to fruit. It did not include vegetative propagules. All experiments were conducted when vegetation and soils were relatively dry e.g. no mud was collected on boots. The location and style of hiking in the experiments matched those of general hikers in the region. The number and species of seed on clothing items were assessed after experimental exposure of clothing to vegetation by removing seed directly from the socks, laces, and trousers and from loose material obtained from the leg and boots using tweezers and a dissecting microscope. Fragments of seed and empty infructescenses where excluded from the count. Seed were identified using seed reference collections compiled from seeding species in the field in areas adjacent to, but not trampled, in the experiments, and floras such as Costin et al. (2000), and PlantNET (BGT, 2008). Nomenclature, family, origin (Europe, North and Central America, Africa, Asia, Middle East, Mediterranean or Australia), growth-form (graminoid, herb or shrub) for all species was recorded. Although large numbers of seed from the native herb *Acaena* were collected it was not possible to consistently tell the seed of the common *Acaena novae-zelandiae* (Synonym *Acaena anserinifolia)* from the rare *Aceana* sp. A. as they only differ by 2 mm in the length of spines on the seed, and spines had often fallen off seed that was attached to clothing. Therefore all *Aceana* seed were assumed to be from the more common species, which occurs on roadside and in natural vegetation in the Park.

2.2. Experiment one: effect of location of seed collected on socks

Seeds on socks worn only on roadsides, only in natural vegetation and all day in both roadside and natural vegetation were compared (Fig. 1). At the beginning of each day, for nine days,