The alien terrestrial invertebrate fauna of the High Arctic archipelago of Svalbard: potential implications for the native flora and fauna

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Abstract
Experience from the Antarctic indicates that the establishment of alien species may have significant negative effects on native flora and fauna in polar regions and is considered to be amongst the greatest threats to biodiversity. But, there have been few similar studies from the Arctic. Although the terrestrial invertebrate inventory of the Svalbard Archipelago is amongst the most complete for any region of the Arctic, no consideration has yet been made of alien terrestrial invertebrate species, their invasiveness tendencies, threat to the native biology or their route of entry. Such baseline information is critical for appropriate management strategies. Fifteen alien invertebrate species have established in the Svalbard environment, many of which have been introduced via imported soils. Biosecurity legislation now prohibits such activities. None of the recorded established aliens yet show invasive tendencies but some may have locally negative effects. Ten species are considered to be vagrants and a further seven are classified as observations. Vagrants and the observations are not believed to be able to establish in the current tundra environment. The high connectivity of Svalbard has facilitated natural dispersal processes and may explain why few alien species are recorded compared to isolated islands in the maritime Antarctic. The vagrant species observed are conspicuous Lepidoptera, implying that less evident vagrant species are also arriving regularly. Projected climate change may enable vagrant species to establish, with results that are difficult to foresee.

The Arctic ecosystem is often described as undisturbed, or even pristine. However, this region is currently subject to extremely rapid environmental change and is experiencing faster changes, and of greater magnitude, than many other global regions (AMAP 2012; IPCC 2014). Environmental change is resulting in dramatic widespread alterations in species distribution. Human activities are also introducing alien species to polar regions (Frenot et al. 2005; Chown et al. 2012; Coulson et al. 2013a). The establishment of such alien species often has complicated effects on the resident ecology (Ricciardi et al. 2013), including species loss and disruption of key ecological processes (Richardson & Ricciardi 2013). Because invasive species are considered among the main threats to biodiversity in Antarctic terrestrial ecosystems (Hughes & Convey 2010; Hughes et al. 2010; Kennicutt et al. 2015) it is important to develop a fuller understanding of the current alien fauna of the Arctic.

The archipelago of Svalbard lies in the European High Arctic and is centred around 78°N, 15°E (Fig. 1). Attempts have been made to document the introduced flora and fauna of the archipelago (Gjertz & Lønø 1998; Lisška & Soldán 2004; Belkina et al. 2013; Governor of Svalbard 2014). However, there has been no consideration of the
alien species element of the invertebrate community, even though the invertebrate fauna of Svalbard is considered to be amongst the best known for any region in the Arctic (Hodkinson 2013) and the invertebrate fauna comprises a fundamental component of the tundra ecosystem. The unique governance status of Svalbard and its limited commercial history has resulted in one of the least disturbed regions in the Arctic. This status has been further supported by the Norwegian government with recent legislation—the Svalbard Environmental Protection Act of 2002—created to manage and conserve this environment, including provision for climate change science.

Natural dispersal to Svalbard is an ongoing process and results in new species establishing in the terrestrial environment (Coulson et al. 2002; Alsos et al. 2007; Ware et al. 2012; Coulson et al. 2014; Governor of Svalbard 2014). The current inventory of the terrestrial and freshwater fauna of Svalbard includes close to 600 microarthropod species names (Coulson 2007a), although some care must be taken with exact numbers because of the large number of potential synonyms, misidentifications and other taxonomic confusion (Coulson et al. 2014). All are considered to have colonized the archipelago since the retreat of the ice after the last glacial maximum approximately 11 000 years ago (Coulson et al. 2014). It is difficult to assess the rate at which invertebrate species arrive and colonize the archipelago since direct observation is impossible. Estimates of the rate of establishment of plant species, and the subsequent arrival of further individuals, have been made using sequencing techniques (Alsos et al. 2007; Eidesen et al. 2013), but this approach remains to be applied to the invertebrate fauna.

The environment of Svalbard is now under strict management and the Svalbard Environmental Protection Act forbids deliberate introduction of new species. However, in the past several vertebrate species were introduced as attempts to conserve species (muskox [Ovibos moschatus]), improve sport hunting and fishing (e.g., Arctic hare [Lepus arcticus] and trout [Salmo trutta]; Gjertz & Lønø 1998), or greening of the tundra initiatives via the deliberate introduction of plants (Belkina et al. 2013). Accidental introduction of alien species has also occurred, for example, the sibling vole (Microtus levis; Fredga et al. 1990), which now forms an established population centred on the abandoned mining town of Grumant (Fig. 1). Moreover, 78 species of alien plant are now recorded in Svalbard (Governor of Svalbard 2014), the majority believed to be accidental introductions.

The alien terrestrial invertebrate species of Svalbard have been assessed from reports in scientific and grey literature and are summarized here with comments on introduction routes, invasive risk and potential ecological consequences. Three categories of alien species have been defined: (i) established in natural environment; (ii) vagrant species occasionally seen naturally dispersing to Svalbard; and (iii) observations, those species with sporadic recordings associated with human activities, that is, synanthropic. Invasive potential is assessed based on food requirements, life history strategies and physiology to survive on the natural Arctic tundra.

**Results and discussion**

Only 15 alien invertebrate species are known to have established in the Svalbard environment (Table 1, Supplementary Table S1), while 10 species are considered as
vagrants and a further seven classified as observations. No invertebrates have been deliberately introduced into the environment yet several species are believed to have been introduced with hosts or soils (Henttonen et al. 2001; Coulson et al. 2013a). Recently permission has been granted by the Governor of Svalbard after a risk assessment to import the earthworm *Eisenia fetida* (Savigny 1826) as part of a composting project but with strict conditions to avoid accidental release into the natural environment. The majority of the introduced alien invertebrate species have been accidentally introduced along with imported soils for either the greenhouse in Barentsburg or as a part of the greening project in Pyramiden (Coulson et al. 2013a; Coulson et al. 2015) (Fig. 1), including the only earthworms recorded in Svalbard (Coulson et al. 2013a). Two species of invertebrates—*Laelaps hilaris* and *Echinococcus multilocularis*—appear to have been introduced with their mammalian host. The host, the sibling vole (*M. levis*), is thought to have arrived in Svalbard along with foodstuffs for the horses working in the coal mines in Grumant (Fredga et al. 1990) or the farm animals in Barentsburg (Governor of Svalbard 2014). *Echinococcus multilocularis* has the potential to infect humans resulting in alveolar echinococcosis (Atanasov et al. 2013).

### Table 1

| Species | Status in Svalbard | References |
|---------|-------------------|------------|
| Cestoda | *Echinococcus multilocularis* Leuckart, 1863 | Established | Henttonen et al. 2001 |
| Oligochaeta | *Cognettia glandulosa* (Michaelsen, 1888) | Established | Coulson et al. 2013a, b |
| | *Enchytraeus dichaetus* Schmelz & Collado 2010 | Established | Coulson et al. 2013a, b |
| | *Dendrodrilus rubidus* (Savigny, 1826) | Established | Coulson et al. 2013a, b |
| | *Dendrobaena hortensis* (Michaelsen, 1890) | Established | Coulson et al. 2013a, b |
| Acanthocephala | | |
| | *Heterocotyle taenia* Steenstrup 1872 | Established | Henttonen et al. 2001 |
| | *Heterocotyle castellator* Steenstrup 1872 | Established | Henttonen et al. 2001 |
| | *Heterocotyle multicirrus* Steenstrup 1872 | Established | Henttonen et al. 2001 |
| | *Heterocotyle abyssorum* Steenstrup 1872 | Established | Henttonen et al. 2001 |
| | *Heterocotyle luciae* (Savigny, 1826) | Established | Henttonen et al. 2001 |
| | *Echinococcus multilocularis* Leuckart, 1863 | Established | Henttonen et al. 2001 |
| | *Alaria elegans* (O. F. Müller, 1776) | Established | Henttonen et al. 2001 |
| | *Alaria expansa* (O. F. Müller, 1776) | Established | Henttonen et al. 2001 |

*aEstablished denotes in natural environment; vagrant denotes occasional natural dispersal to Svalbard; observation denotes sporadic recordings associated with human activities.*
and suitable sanitary precautions should therefore be exercised when visiting locations where the vole is known to occur.

Few of these alien invertebrate species are considered to be invasive and none have been recorded far from beyond the probable point of entry. However, there is the potential for two Collembola, Folsomia fimetaria (L. 1758) and Deuteraphorura variabilis (Stach 1954), to spread beyond their current locations and they may represent a threat to the rich Collembola assemblages in similar nutrient enriched habitats beneath bird cliffs (Supplementary Table S1; Zmudczynska et al. 2012) and which are considered characteristic of the Svalbard environment (Jónsdóttir 2005). In Iceland, F. fimetaria is often found in organic soils along seashores (Fjellberg 2007) and D. variabilis is common in enriched organic soils along the coasts of the White Sea (Pomorski & Skarżyński 2001).

Many of the observations here relate to individual recordings of invertebrates associated with imported fresh produce in the supermarket of the main settlement, Longyearbyen (Fig. 1), for example, Coccinella septempunctata L. 1758 (Insecta, Coleoptera). Other species may be observed infrequently in Longyearbyen or Barentsburg and represent synanthropic species such as Ephesia kuehniella. None of these appear to be able to establish in the natural environment and probably present little threat to the native biology. Few vagrants have been recorded. This is likely because of the difficulty with observing occasional and sporadic invertebrate visitors to the archipelago, especially in the absence of systematic monitoring programmes. However, seven species of vagrant Lepidoptera have been observed, with, for example, Plutella xylostella typically arriving with southerly winds (Supplementary Table S1; Coulson et al. 2002). This implies that considerable numbers of smaller and less obvious invertebrate species are likely to be arriving irregularly and, while the current environment hinders establishment of these species, projected environmental change may permit colonization of Svalbard by vagrant species.

The mosquito Ochlerotatus nigripes (Zetterstedt, 1838) (Aedes nigripes) is often cited as an imported species arriving in drinking water barrels with the phosphate miners working at Kapp Thordsen (Fig. 1) in 1918 (Hoel 1967). This theory of introduction is likely to be incorrect for two reasons. Firstly, this species was recorded in Isfjorden by both Boheman (1865) and Holmgren (1869) many years prior to the arrival of the phosphate miners and, secondly, this mosquito has a broad distribution throughout the Arctic region, including Greenland and the Norwegian mainland, suggesting an ability to disperse naturally to Svalbard. This mosquito therefore does not appear in the inventory presented here.

There is an awareness that alien species in, or arriving to, Svalbard have the potential to be highly disruptive to the native flora and fauna. The Office of the Governor of Svalbard is taking active measures to eradicate four human introduced alien species in the archipelago because of their potential to cause negative environmental impacts: two rodents (M. levis and Mus musculus), the plant Anthriscus sylvestris (Apiaceae) and one invertebrate, the cestode E. multilocularis. Measures to control the intermediate host, the sibling vole (M. levis), will reduce the occurrence of the parasite but as yet there is no defined plan of action.

Overall, the current alien invertebrate fauna of Svalbard consists of relatively few species and none have yet displayed invasive tendencies. This is in contrast with the maritime Antarctic, where alien species, such as the carabid beetle Merizodus soledadinus [Guerin-Meneville, 1830], may have dramatic effects on the native flora and fauna (Convay et al. 2011; Greenslade & Convay 2012; Hidalgo et al. 2013). The relatively scarcity of alien species in Svalbard could possibly be a result of the greater connectivity in the Arctic, where extensive regions of continent and numerous islands facilitate natural dispersal. However, with projected climate change there is a likelihood that additional alien species will be able to establish, both those naturally dispersing to the archipelago and those imported accidently by humans. Current biosecurity measures prevent the deliberate import of alien invertebrates to Svalbard, but there remains the threat of species introductions by anthropochory.

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