SESS REPORT 2024

The State of Environmental Science in Svalbard – an annual report

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Contents

Terrestrial and freshwater invertebrate science in Svalbard in a changing world: from regional to pan-Arctic scales (STAFIEN - Svalbard Terrestrial and Freshwater Invertebrate Ecology Network)

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1. Introduction

This chapter covers invertebrates, a group that consists of a large and diverse range of taxa including worms, water bears, springtails, mites, spiders, insects and Crustacea of various types (Figure 1). The invertebrate community plays a central role globally in many key terrestrial ecosystem processes (Figure 2) such as decomposition, nutrient cycling, energy flow, herbivory, pollination, parasitism and as prey items (Losey and Vaughan 2006; Wagner 2020), and this is also believed to be the case in the polar regions (Thomas et al. 2008; Gillespie et al. 2020; Aronsson 2021). In a generally still understudied Arctic, Svalbard stands out as having over a century of terrestrial biology research dating back to Summerhayes and Elton (1923). Many invertebrate species were first described from the archipelago (Seniczak et al. 2020) and Svalbard remains one of the benchmark locations for the study and knowledge of Arctic invertebrate biodiversity. While much remains to be learnt about the terrestrial diversity of Svalbard's invertebrates and their precise ecosystem roles, the levels of species endemism already apparent (i.e., species only known from the archipelago) further emphasise the great conservation value of the archipelago in the context of key international agreements such as the Convention on Biodiversity (CBD 2024) and, hence, the need for its effective and informed management.

Svalbard's invertebrate fauna includes many taxa and 1 091 recorded species (Coulson et al. 2024a,b). The terrestrial and freshwater invertebrate fauna of Scandinavia and Svalbard is of global interest because it possibly has great geological age, for instance with rotifers displaying distinct genetic lineages suggesting their presence precedes the Quaternary (> 2.58 mya) (Shain et al. 2024). Given the general lack and widely inconsistent level of detailed knowledge of terrestrial and freshwater ecosystems across the Arctic, Svalbard also stands out for its high potential both as an exemplar, or sentinel, of research in Arctic environmental change, and to provide a foundation to upscale to the pan-Arctic (e.g., Bischoff et al. 2019; Gillespie et al. 2020; Pedersen et al. 2021).

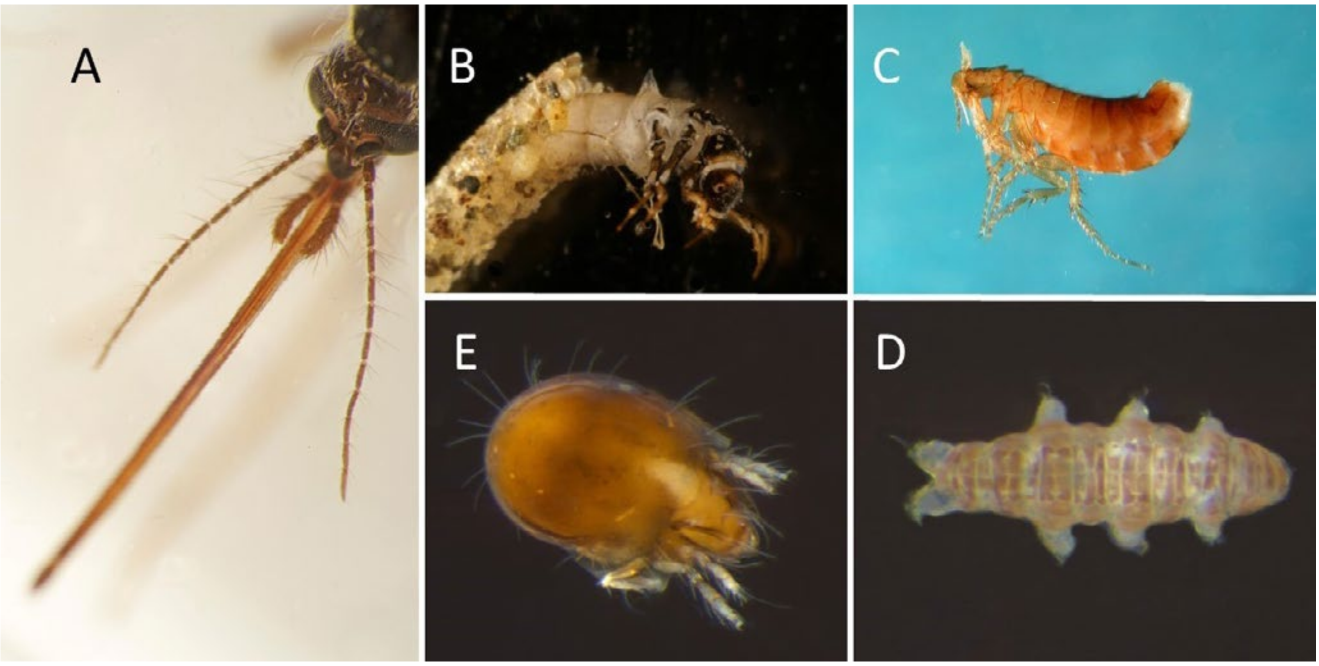

Figure 1: Examples of some invertebrate groups present in Svalbard; A=Diptera (mosquito) (P Hermansen), B=Trichoptera (caddisfly) (SJ Coulson), C=Siphonaptera (flea) (SJ Coulson), D=Tardigrade (water bear) (K. Zawierucha), E=Oribatida (mite) (SJ Coulson).

With the very noticeable recent environmental and climatic changes in the Arctic generally, and Svalbard specifically (ACIA 2005; Pedersen et al. 2021), the role of invertebrates as bioindicators becomes crucial in identifying and understanding the responses and resilience of polar ecosystems. However, despite their recognised importance and the research already done in Svalbard, there currently remains a disproportionate lack of focus on invertebrate ecology compared to other less diverse taxonomic groups. This deficiency has not previously been considered in a State of Environmental Science in Svalbard (SESS) report. Society is demanding that researchers provide information on biodiversity, ecosystem function and the rapid changes that we are experiencing to underpin adaptation to, and mitigation of, their wide-ranging impacts. Nonetheless, the latest Conservation of Arctic Flora and Fauna (CAFF) status report and the evidence of trends in Arctic terrestrial biodiversity that it describes (Aronsson et al. 2021) clearly highlights the lack of information concerning the terrestrial and freshwater invertebrate fauna across the Arctic. In particular, the extreme paucity of studies providing repeated information over time (time series data) is a striking feature of invertebrate research in Svalbard. Further, there is a lack of knowledge on species-specific responses to both abiotic and biotic variables, as well as on species interactions across invertebrate taxa and with other species groups such as plants, vertebrates and microorganisms. Anthropogenic perturbations in Arctic regions are increasing, as for example stressors such as pollution, introduction of non-native species, infrastructure construction and land use change. Research is desperately needed to fill knowledge gaps before irreparable damage prevents a complete understanding of Svalbard's unique invertebrate fauna. Without this understanding it is difficult to fully comprehend terrestrial and freshwater ecosystems, their functioning, or project how they will respond to ongoing environmental change.

This report sets out to (a) describe the current state of knowledge of the terrestrial and freshwater invertebrate fauna in Svalbard, (b) the role of Svalbard in the Arctic as a wider region, and

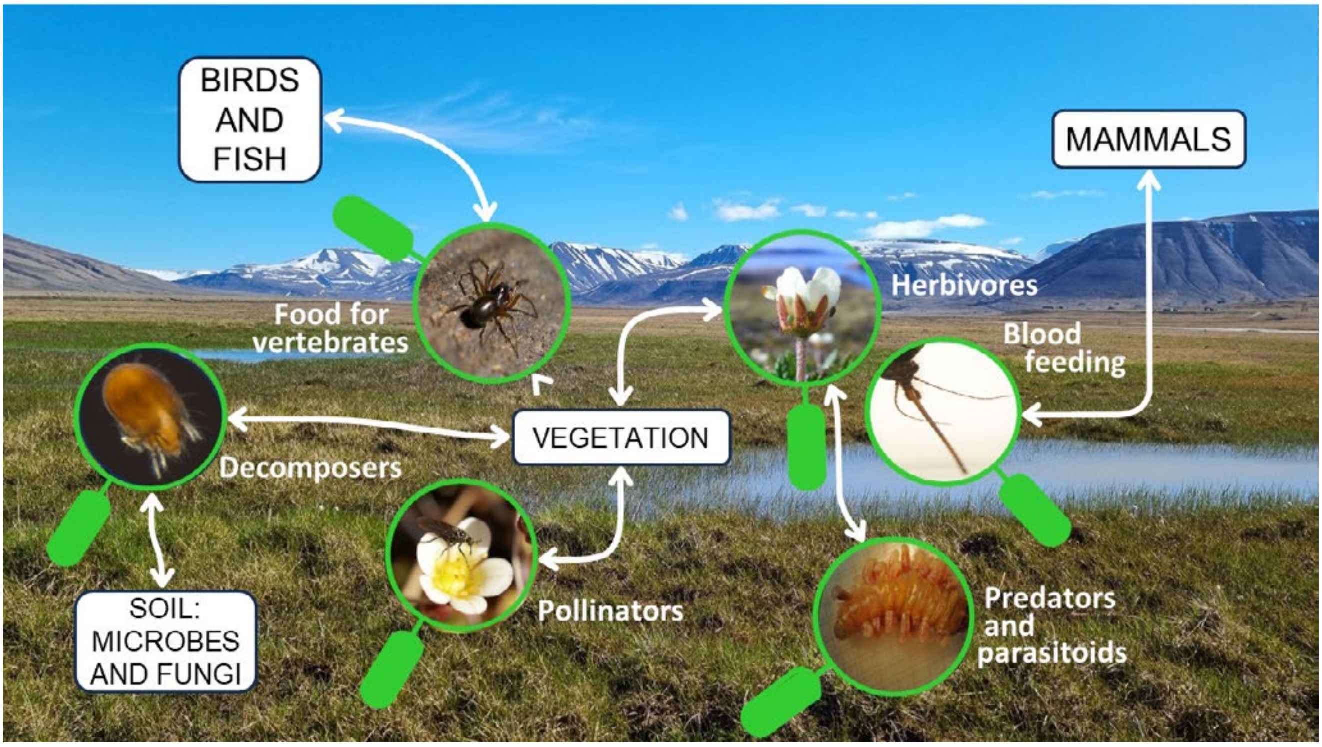

Figure 2: Simplified conceptual model of the Focal Ecosystem Components (FECs) defined in the Arctic Terrestrial Ecosystem Monitoring Plan (Christensen et al. 2013) and the State of the Arctic Terrestrial Biodiversity Report (Aronsson et al. 2021), and processes mediated by more than 2 500 species of Arctic arthropods known from Greenland, Iceland, Svalbard, and Jan Mayen (based on Aronsson et al. 2021).

(c) identify key knowledge gaps, opportunities and data requirements to provide the required understanding, including (d) how the Svalbard Integrated Arctic Earth Observing System organisation (SIOS) might contribute to invertebrate ecology, for example by facilitating novel sample acquisition opportunities.

2. Overview of existing knowledge

The terrestrial and freshwater invertebrate diversity of Svalbard is one of the best known for any region in the Arctic (Coulson et al. 2014) and the recent publication of a critically assessed species inventory with 1 091 species is a significant advance (Coulson et al. 2024a, Table 1). Moreover, the resultant inventory has been matched to molecular sequence data currently available in the Barcode of Life Data Systems (BOLD), revealing that approximately 51% of these species have NCBI GenBank entries and providing a shortlist of 522 species to target for DNA sequencing. New species are regularly recorded from the archipelago, especially when studies address the less-accessible eastern and northern regions. For example, after only a brief visit to Edgeøya, Ávila-Jimenez et al. (2019) reported 140 invertebrate species belonging to 69 genera of which 16 were new records for Svalbard and six were new to science. Given that the number of publications featuring Svalbard invertebrates has increased exponentially since the first records in 1869, new findings are likely to occur more frequently, including those of "invasive alien species" – species for which anthropogenic assistance plays a key role in arrival and establishment in Svalbard. This is exemplified by Coulson (2015), who surveyed the literature and identified 15 species of terrestrial invertebrate considered to be recent anthropogenic introductions. While no invertebrate species are currently known to have spread beyond synanthropic environments (i.e., settlements and sites of direct human activity), many of the species identified in the anthropogenic soils in Barentsburg (Coulson et al. 2013) or Pyramiden (Coulson et al. 2015) are known to be resident in both the potential source regions (former Soviet Ukraine and Svalbard). The possible impact of introduced conspecifics on genetic diversity of native Svalbard populations remains to be studied.

While knowledge of Svalbard species diversity matches that of some other Arctic locations, such as Greenland (Bøcher et al. 2015), and is more advanced than many other locations (Gillespie et al. 2020), a detailed inventory provides only one perspective on invertebrate ecology. Far less is known about geographical distributions, species interactions, relative abundance, community and age structure, population dynamics or trends and the relative importance of different species to ecosystem functions. It is clear that, in general, we lack spatial and temporal data relating to different invertebrate species. These aspects of invertebrate ecology are vital to understanding the impacts of environmental changes to invertebrate biodiversity and the functions they perform (Aronsson et al. 2021). The knowledge gaps are partly due to the challenges involved in accessing varied invertebrate habitats in Svalbard, which result in knowledge of many aspects of invertebrate ecology being heavily skewed towards the west, particularly around Longyearbyen and Ny-Ålesund, and to certain taxa (Figures 3, 4). For instance, while the oribatid and mesostigmatid mite communities have been recently reassessed based on new sampling and up to date taxonomies (Seniczak and Seniczak 2020; Seniczak et al. 2020; Coulson et al. 2024a), the same cannot be said for other important taxa, such as nematode or enchytraeid worms.

In addition to geographical bias, studies of Arctic invertebrate ecology are commonly too limited in time and space to generate high-quality, generalisable information. For example, Gillespie and Cooper (2022) provided the first study of plant and insect pollinator interactions for Svalbard, revealing tight links between flower visitation by insects and the timing of snow melt. Nevertheless, this study was restricted in scope due to limited

Table 1: Species diversity in Svalbard. Number of species total = total number of valid species, synonyms removed; numbers in bold font indicate the total number of species in the phylum; in italics the total number of species in the class; in normal font the number of species in the sub-classes or orders.

Phylum	Class	Sub-class	Order	Total number of species
Rotifera 				**184**
	Eurotatoria			*184*
Gastrotricha 				**50**
	Chaetonotida			*50*
Nematoda 				**136**
	Adenophorea			*4*
	Chromadorea			*95*
	Enoplea			*37*
Platyhelminthes 				**29**
	Cestoda			*23*
	Trematoda			*6*
Annelida 				**41**
	Oligochaeta			*41*
Tardigrada 				**99**
	Heterotardigrada			*17*
	Eutardigrada			*82*
Chelicerata 				**212**
	Arachnida			*212*
		Acari		194
		Araneae		18
Mandibulata  				**290**
	Collembola			*67*
	Insecta			*223*
			Hemiptera	3
			Thysanoptera	1
			Phthiraptera	35
			Coleoptera	16
			Hymenoptera	33
			Trichoptera	1
			Lepidoptera	3
			Siphonaptera	2
			Diptera	129
Crustacea 				**50**
	Branchiopoda			*16*
	Copepoda			*20*
	Malacostraca			*4*
	Ostracoda			*10*
			Sum	1 091

species identification ability, plot-level observations which do not necessarily scale up to the broader landscape, and covered only a single season and location. Year-to-year and spatial variability may impact both plant flowering and insect abundance: future studies will require support to be broader in scope (Gillespie et al. 2020). Many reports from Svalbard, such as that of Ávila-Jiménez et al. (2019) referred to above, also represent a snapshot in time, albeit identifying important results. Generally, there is a lack of long-term data throughout the Arctic with suitable spatial and habitat coverage and species-level identifications, with the best available currently being from Zackenberg (Høye et al. 2021) and Nuuk (Topp-Jørgensen et al. 2015) as part of the Greenland Ecosystem Monitoring programme (GEM). Without long time-series data it is impossible to disentangle the considerable

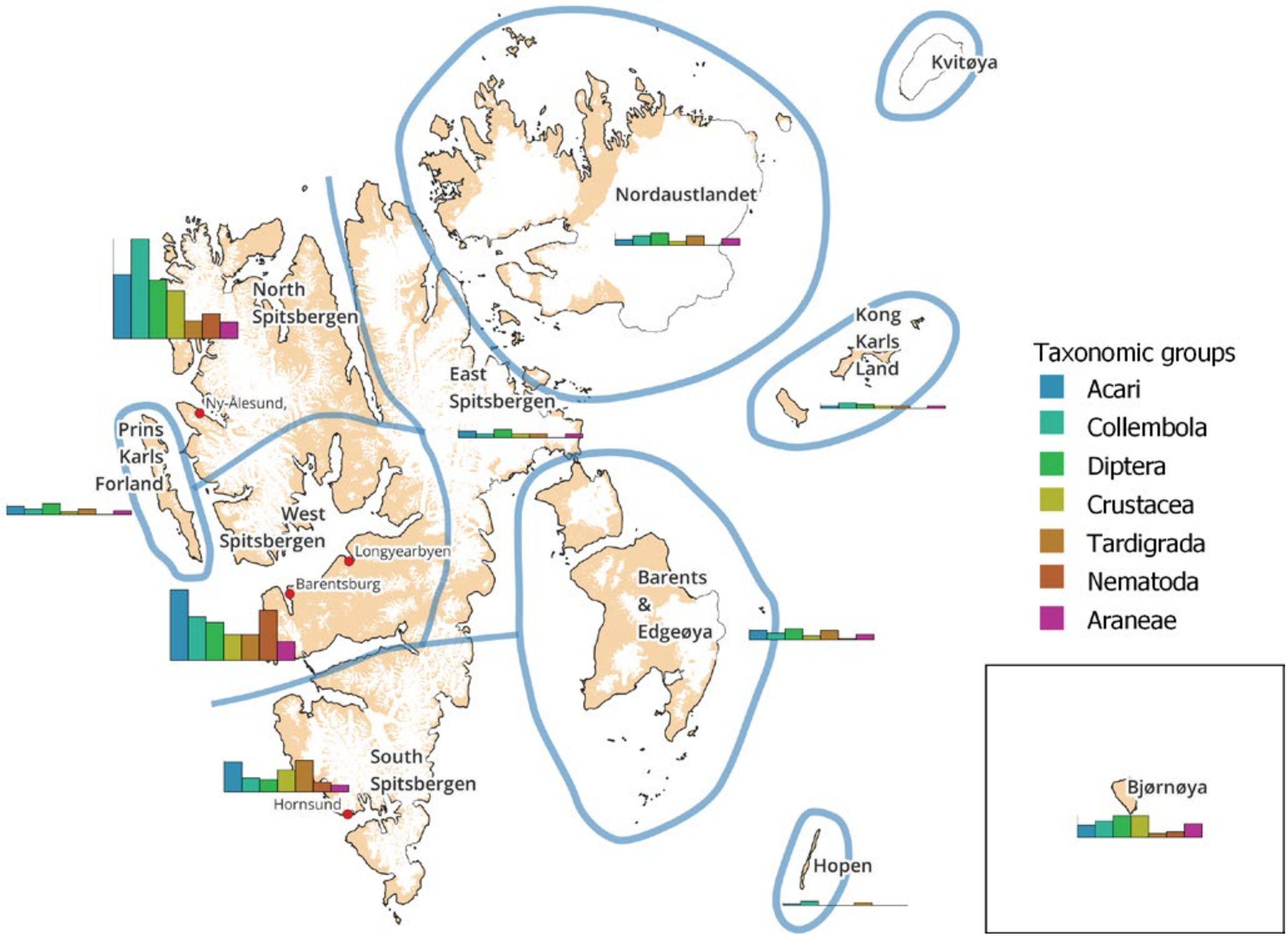

Figure 3: Bar charts showing the regional bias in the numbers of papers considering the top seven most studied taxonomic groups of the terrestrial and freshwater fauna of Svalbard. This figure is created from 460 papers published between 1869 and 2023 which listed specific locations and taxonomic information (see Coulson et al. 2024b) and were not general review articles. Articles covering more than one region/taxa are counted more than once. For reference, the tallest bar (Collembola in North Spitsbergen) has a value of 73 papers.

intra- and interannual fluctuations in abundances that are characteristic of many invertebrates, from long-term population responses to environmental change.

There is also incomplete understanding of how different abiotic and biotic stressors interact to affect different Arctic terrestrial invertebrates, or whether these responses can be generalised across taxa (Høye et al. 2021). For example, recent studies have suggested that Arctic arthropods respond negatively to longer term exposures to moderate to high temperatures (e.g., Sørensen et al. 2024; Christoffersen et al. 2024) and that changes in humidity may exacerbate these effects (Christoffersen et al. 2024). Follow-up research is required to determine whether these effects are general or species-specific, and what their consequences will be. Furthermore, environmental change may also have cascading effects that require deeper understanding. For example, parasitic gut nematodes are believed to play a role in suppressing the fecundity of their host, Svalbard reindeer (*Rangifer tarandus platyrhyncus;* Albon et al. 2002). The free-living stages of the parasitic gut nematode *Ostertagia gruehneri* have recently been shown to avoid desiccating conditions by potentially moving deeper into the vegetation profile and, should this happen, are less likely to be ingested and re-infect the host (Moerman et al. under revision). To better comprehend the resilience of significant taxa to environmental change there

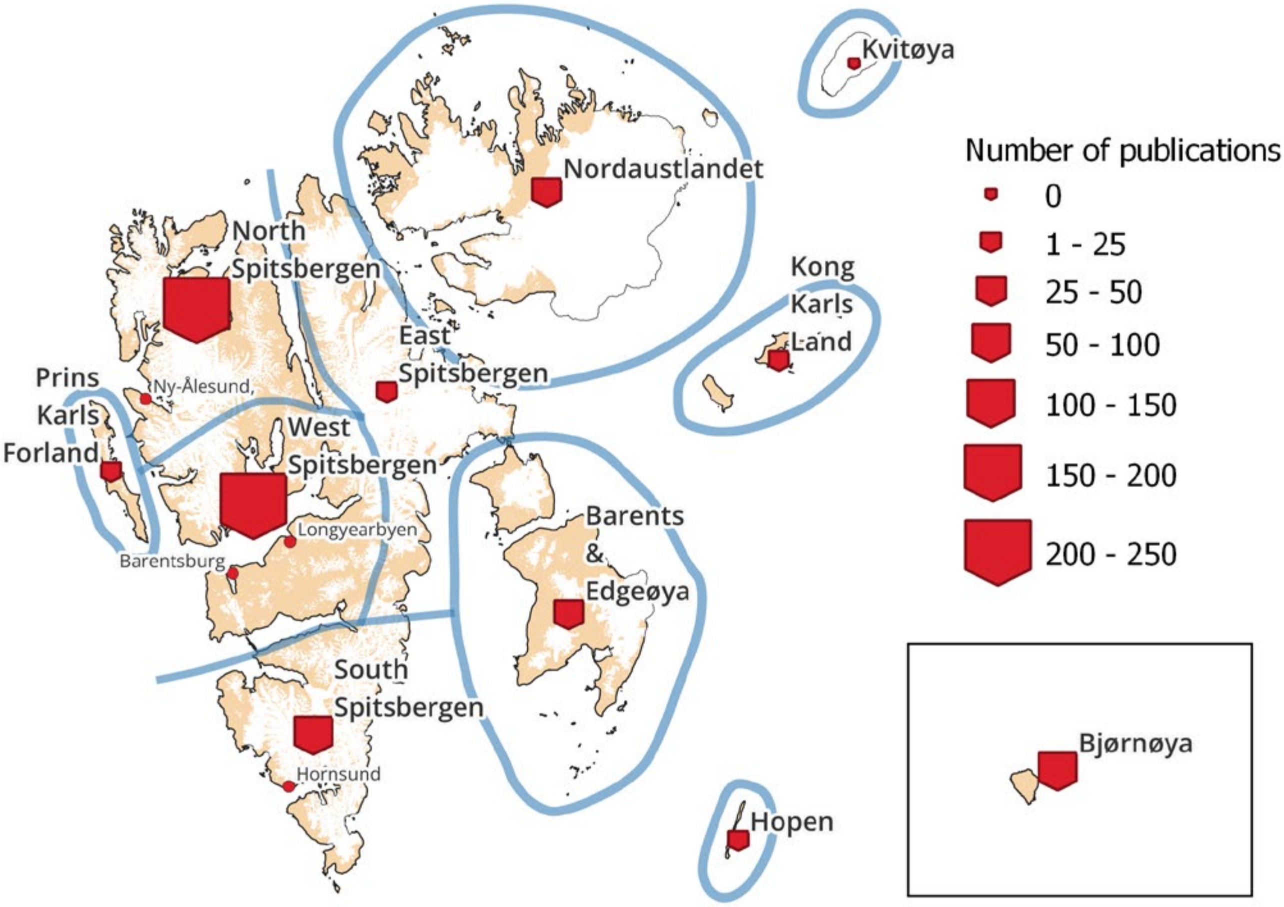

Figure 4: Numbers of papers considering the terrestrial and freshwater fauna of Svalbard in various regions. This figure is created from 472 papers published between 1869 and 2023 which listed specific locations (see Coulson et al. 2024b) and were not general review articles. Articles covering more than one region are counted more than once.

is an urgent requirement for baseline data and structured inventories, particularly at key locations, and a focus on key gradients and variables.

It is well understood that invertebrates have many functions in the terrestrial and freshwater ecosystems. For example, beyond Svalbard, much is known about important species of flower pollinators (e.g., Hallett et al. 2017) and decomposers (e.g., Ott et al. 2012). In Svalbard, however, knowledge of the presence, abundance and frequency of species interactions is insufficient to establish the roles and importance of invertebrates to ecosystem functions such as pollination and nutrient cycling. Nevertheless, the concept of the Functional Ecosystem Component (FEC) has been developed as part of the Arctic Terrestrial Biodiversity Monitoring Plan produced by the CAFF programme, together with associated "parameters" and "attributes" (Christensen 2013; Gillespie et al. 2020; Aronsson et al. 2021). Focal Ecosystem Components were defined in the Circumpolar Terrestrial Biodiversity Monitoring Plan (Christensen 2013) as key and indicative elements of biodiversity identified for each Arctic ecosystem considered. Changes in status of FECs likely indicate changes in the overall environments that require further attention and study. In the original terrestrial biodiversity plan five FECs were identified for the terrestrial and freshwater invertebrate fauna: Decomposers, Pollinators, Herbivores, Food for vertebrates, and Blood feeders. A sixth FEC, Predators and Parasites, was identified by Gillespie et al. (2020), and is included in the most recent CAFF Status and Trends of Arctic Terrestrial Biodiversity report (Aronsson et al. 2021) (Figure 2). Note that the State of the Arctic Freshwater Biodiversity Report (Lento et al. 2019) identified two FECs relevant to this SESS chapter, Zooplankton and Benthic Macroinvertebrates, but these are not included in Figure 2 for simplicity and are here considered as within the six FECs described. It has been recommended that monitoring efforts focus on the status and trends of these FECs (e.g., species diversity, abundance, ecosystem function of key species in each FEC), but as a recent review found, we lack even the most basic information for the vast majority of species and regions (Gillespie et al. 2020). Furthermore, this conceptual classification of species is based on a combination of knowledge of ecosystem service provision by invertebrates from more temperate and tropical locations (e.g., Losey and Vaughn 2006), and scant observations of actual Arctic ecological roles (e.g., Gillespie and Cooper 2022). While all of the FECs identified for invertebrates by the Arctic Council's Circumpolar Biodiversity Monitoring Programme (CBMP) are well represented in Svalbard (Gillespie et al. 2020), no studies to date have confirmed the species involved in those functions, their effectiveness and their resilience to environmental change. Even within a single FEC subclass, such as "Prey for birds", studies of invertebrates in bird diets rarely identify invertebrates to species-level and generally report overall biomass figures. Although some studies are starting to employ sequencing techniques to identify taxa (Stolz et al. 2023), expansion of such sampling would provide a huge resource to invertebrate researchers (see section 3). In general, much research is required to confirm many species' FEC membership and, therefore, to identify the most important species providing key functional roles. Thus, for future coordinated monitoring efforts to be most effective, an extensive initial research effort is required in Svalbard and beyond, maybe expanding the national Norwegian insect monitoring programme, based on DNA-metabarcoding of Malaise traps (NINA 2024).

In addition to the general lack of data, there is also a concerning dearth of studies addressing topics crucial to Svalbard biosecurity. Ninety eight alien vascular plant species are recorded from Svalbard (Artsdatabanken 2018), 27 which are considered established or "door-knocker" species (Artsdatabanken 2023), while Bartlett et al. (2021) in a recent survey identified 36 alien plant species exclusively associated with areas of human activity. Moreover, climate modelling studies indicate that 19 of 27 established alien door-knocker species were considered to have the climate potential to spread to 75% of non-glaciated areas (Speed et al. 2024). Analogous studies addressing invasive alien invertebrates are largely lacking, but the potential for establishment of these species in Svalbard is likely to be great. Evidence from the Antarctic overwhelmingly points to the national operators being the primary source for introduced species, followed historically by trade and exploitation industries in the periods when they were active, with tourism as yet being less important (Hughes et al. 2019; Siegert et al. 2023). In Svalbard such colonisation records are focused on sites such as Barentsburg and Pyramiden (Coulson et al. 2013, 2015) and the active settlements and research stations of Longyearbyen, Ny-Ålesund, Barentsburg and Hornsund. Together with climate change, the spread and impacts of alien and invasive species on native Arctic ecosystems and species may be particularly significant (Speed et al. 2024) and information is urgently needed on which to base future planning, mitigation measures, and environmental management of Arctic terrestrial ecosystems. Enhanced collaboration with other disciplines and actors can provide a profitable approach to make this a reality.

3. Contributions to interdisciplinarity

The Svalbard research community has long recognised the existence of multiple key interconnections between taxonomic groups (Aronsson et al. 2021; Pedersen et al. 2021) and these are exemplified by the six Arctic terrestrial FECs of the Arctic Terrestrial Biodiversity Monitoring Plan (Christensen et al. 2013; Gillespie et al. 2020), all of which imply multi-trophic

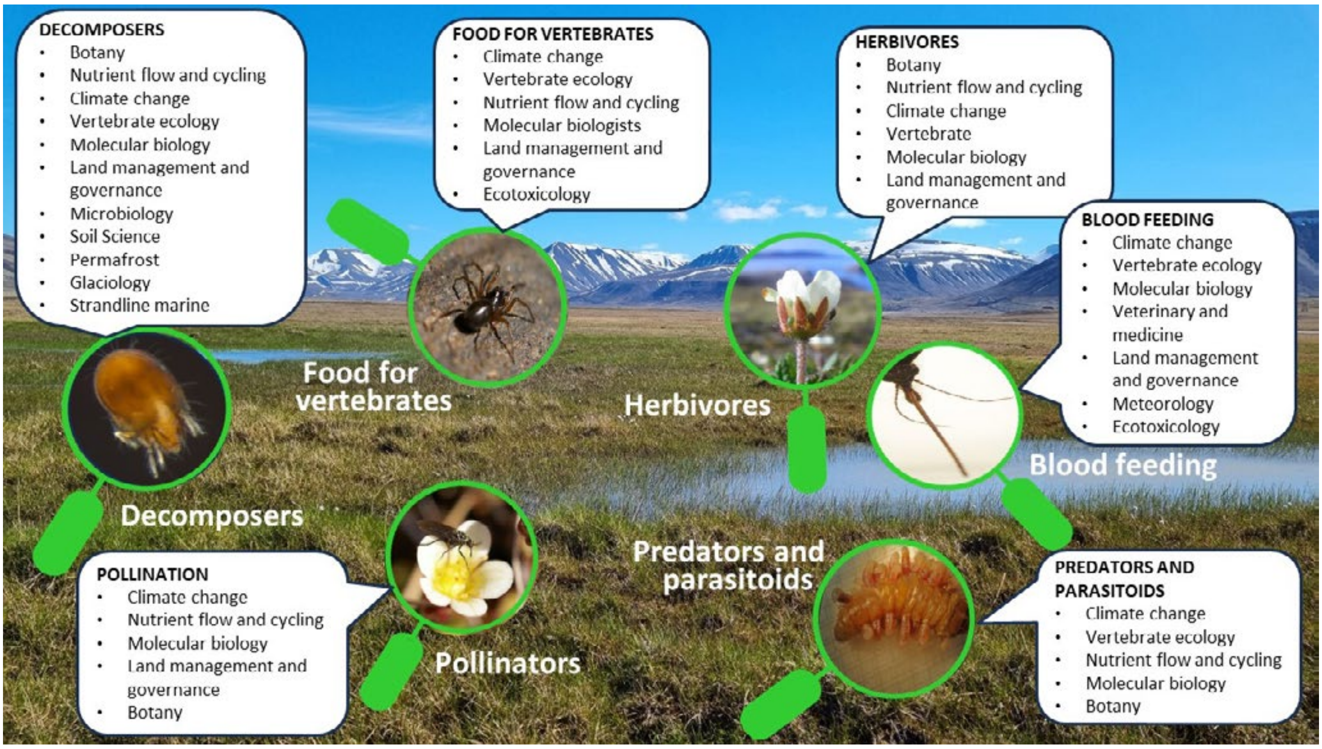

Figure 5: Conceptual model of the FECs and processes mediated by more than 2 500 species of Arctic arthropods known from Greenland, Iceland, Svalbard, and Jan Mayen and the interconnections with other science disciplines in Svalbard (based on Gillespie et al. 2020).

interactions (Figure 5). Each of the FEC groupings are functional components because they link to other species groups and demonstrate that invertebrates have interactions with many other taxa and themes (see the example of Figure 5). For instance, invertebrates play vital roles in plant pollination and seed set (Gillespie et al. 2016), in decomposition of dead organic matter and nutrient cycling (Koltz et al. 2017), in herbivory of plants (Strathdee and Bale 1996; Gillespie et al. 2007), and in vertebrate blood feeding and potential disease transmission (Müllerová et al. 2018). They also have impacts on reindeer fecundity via gastrointestinal parasites (Albon et al. 2002), serve as prey items for nesting birds and affect fledging success (Bolduc et al. 2013; Wirta et al. 2015; Schmidt et al. 2017; Stolz et al. 2023), All of these areas of overlap between trophic levels highlight opportunities to combine research effort and resources across ecological disciplines, and when pursued, have resulted in some excellent cross-disciplinary research initiatives. In addition to these, there are further areas of interdisciplinary need or opportunity beyond biology that are yet to be explored.

1. Climate changes causing, for example, glacial retreat or alterations in the timing and pattern of snowmelt, create new environmental conditions including revealing new land surfaces for colonisation. These events can be monitored using invertebrates as bioindicators. In this way, it is possible to follow succession processes and community assembly from single pioneer species arriving to more complex communities consisting of many taxa and individuals. Even wingless invertebrates have relatively large dispersal abilities (spreading) using anemochory (wind), hydrochory (ocean currents) or zoochory (animal) including the special case of anthropochory (via human actions). This type of research requires cooperation between taxa specialists, for example acarologists, entomologists and ornithologists as well as physical scientists including meteorologists, glaciologists and permafrost and soil specialists. There are opportunities for tighter collaboration with, for example, vegetation and microbial ecologists who study the same successional patterns (e.g., Yoshitake et al. 2011; Těšitel et al. 2014; Masumoto et al. 2023; Rola et al. 2023), or other fields such as geology (Kim et al. 2022)

and efforts could be combined more often to reveal co-occurring plant and invertebrate successional changes.

2. The species composition of invertebrate communities is often closely related to the quantity and type of food available. For many species of soil invertebrates, soil fungi, algae and bacteria are the main–or the only–food and, therefore, determine the structure of invertebrate communities. Separately, high springtail (Collembola) abundance can have a negative effect on nitrogen-fixing cyanobacteria and hence nitrogen fixation (Birkemoe and Liengen 2000) and vascular plant performance in the nutrient-limited ecosystems characteristic of Svalbard (Jónsdóttir 2005) and other parts of the Arctic. Thus, opportunities for collaboration between ecologists and soil scientists abound.
3. Invertebrates form a key prey item for various taxa including breeding migratory birds in the Arctic (Chagnon-Lafortune et al. 2024) and freshwater fish (Svenning et al. 2024). A snow bunting monitoring project has collected data on snow bunting breeding success in Adventdalen since 1998 (Fossøy et al. 2015) and includes trapping of arthropods since 2014. Arthropods represent the main food source for snow bunting nestlings, and the project aims to understand how climate change affects arthropod availability within and among years, and in turn how this affects snow bunting breeding success. Trapping data includes collection of insects from pitfall traps every fourth day from early June to mid-July every year, in order to estimate the phenological change in total biomass of arthropods throughout the snow bunting breeding period (Stolz et al. 2023; Jöesaar 2024).
4. Linkages with human impacts could, and need to be, further explored. Local sources of direct impacts, such as tourism and industry, can have severe implications for ecosystem functioning. Not only are there direct effects of human activities in these regions, for example ground trampling and introduction of pollutants, but there is a risk that introduced species may establish and, over time, colonise more widely within Svalbard. While the presence of introduced plants is reasonably well documented (Ware et al. 2012; Governor of Svalbard 2014), introduction of invertebrates, including hidden genetic diversity, is less well understood even though known to have occurred (Coulson et al. 2013, 2015).
5. To better understand the overall functioning of the ecosystem it is necessary for ecologists from various disciplines to approach the problem from their own respective taxonomic and/or functional expertise but with a focus on integration through the system. The TERRA project provides one example of a project focused on the effects of a combination of abiotic (surface icing) and biotic (goose grazing and soil nitrification) factors on the soil system (TERRA 2024).
6. The outcomes of invertebrate studies (e.g., bioindicators, parasitology) need to be readily available to environmental managers and those involved in governance. It is critical to share timely and accessible knowledge on Svalbard invertebrates with all relevant parties, to improve public understanding of the complexity of ecological processes and of our impacts on these processes (for example the possibilities to limit spreading of invasive alien species). Inherent in this is a need to engage with citizen science practitioners and outreach activities to develop and disseminate knowledge about the invertebrate fauna, its role and threats.
7. Many other disciplines carry out one-off or regular fieldwork activities in less visited parts of the Svalbard archipelago. At the same time, many invertebrate or habitat sampling methods are simple, fast and effective. By actively linking more closely with other disciplines and actors, such as the tourist industry in Svalbard, as is increasingly happening in other parts of the Arctic (e.g., Greenland) and Antarctic, sample collection opportunities can be considerably enhanced, developing the currently lacking crucial knowledge of the invertebrate (and, indeed other) communities from these locations. Such integration and cooperation will also contribute to addressing the often-stated aim of minimising the human footprint of research and other activities in Svalbard.

8. Traditional "on-the-ground" approaches to invertebrate survey and research are currently irreplaceable. There is a need to further integrate the traditional approaches by engaging with and increasing application of cutting-edge technological disciplines, such as remote sensing through drones and satellite imagery, eDNA, and Large Language Models and AI. These technologies offer new possibilities for sample and/or data collection, as well as enhancing specimen identification and sample analysis. However, due to the general poor knowledge base within the field of ecology these techniques require institutional support and external expertise.
9. There are direct linkages to social science, public understanding of science and the role of Svalbard science in a global context. Greater outreach can be encouraged, for example via Svalbard Environmental Fund funding. Increased data and knowledge transfer to governance organisations, including the Governor of Svalbard, the Norwegian Ministry for Climate and Environment, and the Arctic Council and its bodies, is essential as a foundation for knowledge-based governance decision making and actions. Here we see an important role for SIOS in enhancing the visibility of invertebrate science in Svalbard internationally to ensure Svalbard data are employed globally.

Such interdisciplinary collaboration could be enhanced by SIOS by creating and hosting online protocol handbooks or guidance for recommended data and types of samples and how to collect them. Other key SIOS actions identified include connecting researchers studying invertebrates in Svalbard with researchers involved in other disciplines and raising awareness of possibilities for synergy and assistance in sample collection during fieldwork activities related to other scientific disciplines, for example, collection of soil/vegetation cores for invertebrate community/biodiversity analyses.

4. Unanswered questions

In summary, while research on Arctic invertebrates in Svalbard has a long history and the current inventory is amongst the best available and quality-assured for any Arctic region, the Arctic generally, and many regions of Svalbard specifically, remain desperately understudied. To a large extent there is lack of coverage in terms of spatial and temporal patterns of biodiversity at all levels and in the application of integrated approaches linking trophic levels and energy and nutrient fluxes. Specifically, while lists of species recorded and described are available, the abundance, community age structure and functional significance of these species and populations are largely undocumented or unknown. Finally, there is a general lack of understanding of the sensitivity of most species to changes in climate, land use and other anthropogenic drivers, and the consequent cascading effects on linked biological systems.

Specific knowledge gaps include:

1. Baseline documentation of the invertebrate biodiversity of Svalbard including temporal and spatial descriptions of the distribution and abundance of this biodiversity (i.e., alpha, beta, gamma biodiversity) and a description of community structure and genetic variation in, and between, invertebrate populations. A comprehension of the great differences in species composition across relatively small geographic scales is lacking.
2. Improved understanding is required of the origin and history of colonisation of invertebrate species and populations and the potential for genetic exchange with other populations across geographical scales. Monitoring of potential invasive alien species and their likely effects on native biodiversity is lacking (e.g., through direct competition, vectoring of disease, parasitism).

3. Identification of taxa that respond to, or are vulnerable to, change and/or have possible range shifts. There is a clear lack of understanding of the local adaptation of species/populations and their resilience to climate change, changes in land use, pollution and other anthropogenic and biotic drivers. This includes the ability of species to adjust their physiologies or life histories sufficiently to enable them to show resilience to projected environmental change.
4. The ecological roles of species and linkages across trophic levels, for instance nutrient cycling, pollination and seed production, population dynamics of birds and reindeer through parasitism and food, are very far from understood. The same is true of links across the marine/terrestrial biospheres.
5. Knowledge, dynamics and challenges from Svalbard need to be translated across other Arctic systems (and vice versa), allowing Svalbard to act as an early warning system, or sentinel, for wider global patterns and effects of change. The upscaling of data from Svalbard to other parts of the Arctic is largely unaddressed.
6. There is no monitoring of invasive alien species or the potential threat that these species may represent to the native Svalbard flora and fauna communities. A risk assessment is currently lacking for Svalbard, and the archipelago must be incorporated fully into the current invasive alien species risk assessment toolkits.
7. It is necessary to develop procedures for how these data and conclusions can be used in management and policy frameworks.

5. Recommendations for the future

To enhance invertebrate ecological research in Svalbard, and address many of the important gaps highlighted above, we provide five key recommendations, including how SIOS can contribute to terrestrial and freshwater invertebrate science.

- *Develop and implement a sustained effort to document biodiversity and drivers of biodiversity change over time.*
- Invertebrates are key indicators of environmental change and are crucial in identifying and understanding the responses and resilience of polar ecosystems. There is an urgent requirement to collect baseline data and to establish future data collection foci, such as the key measurable attributes of Arctic invertebrate biodiversity. In the context of determining resilience to environmental change future data collection should focus preferably on taxa that: (a) are relatively well-studied with existing data; (b) respond to, or are vulnerable to, change; (c) face possible range shifts; d) are important for ecosystem services; and e) are or may be defined as invasive alien species, in which case their potential routes of entry should also be studied.
- *Engage with other actors and researchers to promote and enhance collaboration opportunities within Svalbard.*
- The logistics of working in the Arctic require that scientific disciplines collaborate and that science opportunities are exploited in an efficient manner. Here there are clear opportunities for collaboration with other actors, such as the tourist industry, the Governor of Svalbard's officials or research institutions involved in environmental monitoring of Svalbard (for instance MOSJ 2024) to enable access to less visited regions and to boost data collecting possibilities.
- *Build connections within and beyond the Svalbard research community to secure a pan-Arctic synthesis.*
- The above datasets should not be pursued in isolation, as other Arctic regions and disciplines face the same challenges. There is a need to establish strong cross-disciplinary and pan-Arctic connections to ensure coordination in the collection of time-series data, identification of focal key drivers, completion of molecular libraries, and assessment of the risks of invasive

alien species.

- *Create and make available online collaboration tools to facilitate enhanced data collection.*
- Tools such as a frequently updated online protocol handbook and a catalogue of recommended equipment, will enable the acquisition of the standardised samples required for efficient and accurate collection of key data. Such tools can be employed by ecologists and non-ecologists alike and could help raise the profile of invertebrate science in Svalbard, enabling data collection that would otherwise be impossible.
- *Leverage SIOS in Svalbard to raise the profile of invertebrate science and unlock new research opportunities.*
- With a focal role in Svalbard science, SIOS can play an important part in enhancing the visibility of invertebrate science in Svalbard, coordinating biogeographic analyses and data archiving, providing infrastructure support, including funding, and enabling time series data to be collected, samples to be processed, and analysis pipelines to be developed (e.g., large-scale computing). Moreover, SIOS can facilitate collaboration with current data collection and monitoring programmes such as the Greenland Integrated Observing System (GIOS.org) or the Isaaffik Arctic Gateway (isaaffik.org), and make data public via the SIOS Data Portal (sios-svalbard.org/Data) and other outreach activities.

6. Data availability

Dataset	Parameter	Period	Location	Metadata access (URL)	Dataset provider
Svalbard invertebrate inventory	Species occurrence	1869 to 2024	Svalbard	https://www.gbif.org/dataset/443d4938-8d5a-4e2e-a5b8-53fd139bb1d6	Coulson SJ stevec@unis.no

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