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Virve Ravolainen

Vegetation monitoring in Svalbard: implementation plan

Kortrapport / Brief report 54

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– implementation plan

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Preface

In 2007, the Office of the Auditor General of Norway pointed out the lack of long-term studies on vegetation in Svalbard, with particular concern regarding the effects of climate change and increasing human traffic within the archipelago. A pilot project that addressed these two areas of concern was launched as a precursor to implementation of vegetation monitoring (Hansen and Ravolainen 2016). The final report from the pilot project period concluded that there is a need for monitoring vegetation in Svalbard. According to the conclusions in Hansen and Ravolainen (2016) and recommendations in the general assessment of environmental monitoring of Svalbard and Jan Mayen (Ims et al. 2014), the current implementation plan has an ecosystem-based, adaptive approach to monitoring (see Lindenmayer and Likens 2009, Ims et al. 2013).

The white paper Nature for life – Norway's national biodiversity action plan (Meld. St. 14 (2015-2016)) sparked work on describing a "good ecological state" for Norwegian ecosystems (Nybø and Evju 2017). This report was written by a group of experts mandated by the Ministry of climate and environment; it describes a set of indicators for six terrestrial ecosystems. There are 20 indicators for the High Arctic Svalbard Archipelago (Ims et al. 2017). Six of the eight suggested variables for plants and several of the indicators suggested for climate monitoring are included in the current plan. Focus on monitoring variables that will contribute to future quantifications of a "good ecological state" is in line with the tasks given to NPI by the Ministry of climate and environment in 2018. The variables presented in this plan include several of the Focal Ecosystem Components suggested for monitoring by the Circumpolar Biodiversity Monitoring Program (Christensen et al. 2013).

Many people at the Norwegian Polar Institute and in the program COAT – Climate-ecological Observatory for Arctic Tundra – have contributed to discussions about vegetation monitoring while this plan was written. A special thanks to Åshild Ønvik Pedersen, Eva Fuglei, Isabell Eischeid, Kit M. Kovacs, Eeva Soininen, Ingibjörg Svala Jónsdóttir, Mads Forchhammer, René van der Wal, and Jesper Madsen for their input. Also, thanks to other colleagues who have read and revised earlier drafts.

Tromsø, 2 Sep. 2019

Virve Ravolainen
Project leader

Summary

This document outlines a plan for vegetation monitoring in Svalbard. Strategic documents and monitoring agencies have called for such a plan, including the Environmental Monitoring of Svalbard and Jan Mayen (MOSJ), the government white paper *Nature for life – Norway's national biodiversity action plan* (Meld. St. 14 (2015-2016)), the report on "good ecological state" for Norwegian ecosystems following from the white paper, and strategic documents for alien species in Svalbard. Variables to be monitored are outlined, as well as how they will link to monitoring of the environment. Three response targets structure the plan; 1) plant abundance, 2) phenology and 3) distribution.

The variables that will be measured to describe *abundance* are: moss layer, bare ground, biomass of vascular plant species and plant functional types, ice damage *(Cassiope tetragona, Dryas octopetala)*, extent of vegetation types, erosion (de-vegetated area), and productivity at peak growing season (vegetation index). Phenology will be monitored by measuring the variables: timing of the spring green-up and vegetation greenness (time-integrated/maximum vegetation index). Distribution of plant species will be monitored using the variables: occurrence of cow parsley (in Barentsburg), occurrence of alien species in the settlements, and potential occurrences of alien plant species at selected bird cliffs. Red List plant species require a considerable amount of mapping, as well as taxonomic and method development efforts before implementation of monitoring can be achieved. These monitoring elements are thus only briefly discussed below.

The most important environmental and disturbance factors that may drive changes in plant communities are termed predictor targets. These will be monitored by measuring the variables: air and soil temperatures, permafrost thaw depth, snow depth, duration and distribution, soil moisture, precipitation, abundance of the grazing animals (reindeer, ptarmigan and geese), nutrient levels in the soil and in plant leaves, ground-ice formation, damage to *Cassiope* and *Dryas* due to ice, and patches disturbed by permafrost-related processes.

All but two of the variables listed above are included in suggestions for measuring a "good ecological state" within Norwegian ecosystems, and the establishment of vegetation monitoring parallels the on-going development of the national goals of ensuring a "good ecological state". Furthermore, the variables suggested herein are in line with other national and international recommendations for monitoring vegetation. They include measures that will benefit the nature management regime in Svalbard. The COAT – Climate-ecological Observatory for Arctic Tundra – program includes establishment of monitoring for the suggested abundance and phenology variables. COAT will have a fully-operational set-up for monitoring the tundra ecosystem with respect to climate and management impacts by the end of the implementation period (2016-2020). The network of field stations that facilitates the ecosystem-based vegetation monitoring described in this plan involves and facilitates continuation of some of the longest time-series on plants from Svalbard. A system for alien species mapping was created at NPI in 2017 and will be adjusted as required according to future developments for strategies for dealing with alien species in Svalbard. Spatial and temporal organization of the monitoring take a hierarchical approach, using a combination of field monitoring and several types of remote sensing at localities along climatic gradients. Field protocols consistently maximize time used for measurement of multiple variables concurrently, methods proven effective in other geographically spread ecosystem-based monitoring systems. Monitoring will be conducted by a consortium of collaborating researchers that have extensive experience from Svalbard, ensuring effective monitoring of the suite of variables listed above for abundance, phenology and distribution. The majority of the establishment costs will be covered by projects associated with COAT. Additionally, the vegetation monitoring will benefit greatly from contributions from researchers in the consortium. The alien species monitoring requires further development with management agencies and funding must be secured for these project elements.

The vegetation monitoring described herein fulfills the requirement of being ecosystem-based and includes vegetation variables that are selected based on their importance for key functions in the terrestrial food web. Additionally it will monitor the integrity of Arctic biodiversity, with special focus on plant species that are known or expected to be sensitive to climate change and are of high management relevance. The most important drivers of vegetation change are included in the monitoring system because they are necessary for understanding change in biota, relation to climate change and the dynamic herbivore populations in Svalbard. A recent evaluation of the MOSJ terrestrial program suggested that the variables described here should be included in this monitoring program. The practical solution as to how the suite of variables from this multi-faceted monitoring program will be best displayed within the MOSJ framework remains to be decided.

Norsk sammendrag/Norwegian summary

Dette dokumentet skisserer en plan for overvåking av vegetasjon på Svalbard. Strategiske dokumenter og miljøovervåkningsprogrammer har oppfordret til en slik plan, inkludert Miljøovervåking av Svalbard og Jan Mayen (MOSJ), stortingsmeldingen *Nature for life – Norway's national biodiversity action plan* (Meld. St. 14 (2015-2016)), rapporten «Fagsystem for fastsetting av god økologisk tilstand – forslag fra et ekspertråd» (Nybø & Evju 2017) som følger av stortingsmeldingen, og strategiske dokumenter for fremmede arter på Svalbard. Vegetasjonsvariabler som skal overvåkes er skissert, samt hvordan de vil knyttes til overvåkning av miljøet. Tre responsmål strukturerer planen; 1) plantemengde, 2) fenologi og 3) distribusjon.

Variablene som skal måles for å beskrive mengde er: moselagets tykkelse, biomasse av karplantearter og funksjonelle grupper, isskade (på kantlyng *Cassiope tetragona*, og reinrose *Dryas octopetala*), omfanget av vegetasjonstyper, erosjon/område uten vegetasjon, og produktivitet (vegetasjonsindeks i vekstsesongen). Fenologi vil bli overvåket ved å måle variablene: tidspunkt for grønning og vegetasjonens grønnhet (tidsintegrert / maksimal vegetasjonsindeks). Distribusjon av plantearter vil bli overvåket ved hjelp av variablene: forekomst av hundekjeks (i Barentsburg), forekomst av fremmede arter i bosettingene og potensielle forekomster av fremmede plantearter på utvalgte fuglefjell. Rødlistede plantearter krever en betydelig mengde kartlegging samt taksonomisk og metodeutviklingsarbeid før implementering av overvåking kan oppnås. Disse er derfor bare kort diskutert i denne planen.

De viktigste miljø- og forstyrrelsesfaktorene som kan føre til endringer i vegetasjon vil bli overvåket ved å måle variablene: luft- og jordtemperatur, permafrostdybde, snødybde (varighet og fordeling), jordfuktighet, nedbør, mengde av beitedyr (rein, rype og gjess), næringsnivåer i jorda og i planteblader, isdannelse, skader på *Cassiope og Dryas* på grunn av is, og områder forstyrret av permafrost-relaterte prosesser.

De fleste variablene i denne planen er inkludert i forslag til måling av en "god økologisk tilstand" i norske økosystemer. Videre er variablene som foreslås her, i tråd med andre nasjonale og internasjonale anbefalinger for overvåking av vegetasjon. Overvåkingen inkluderer kunnskap som vil være til nytte for miljøforvaltningen på Svalbard. COAT – Klimaøkologisk Observatorium for Arktisk Tundra-programmet – inkluderer overvåking av de foreslåtte mengde- og fenologivariablene. COAT vil ha et fullt operativt oppsett for overvåkning av tundraøkosystemet med hensyn til klima og økologiske variabler innen 2020.

Den økosystembaserte vegetasjonsovervåkingen som er beskrevet i denne planen inkluderer noen av de lengste tidsseriene på planter fra Svalbard. Et system for kartlegging av fremmede arter ble opprettet ved Norsk Polarinstitutt i 2017 og vil bli justert etter behov i henhold til fremtidig utvikling av strategier for fremmede arter på Svalbard.

Romlig og tidsmessig organisering av overvåkingen har en hierarkisk tilnærming, med en kombinasjon av feltovervåkning og flere typer fjernmåling på lokaliteter langs klimatiske gradienter. Feltprotokollene sørger for måling av flere variabler samtidig og bruker metoder som har vist seg effektive i andre økosystembaserte overvåkingssystemer. Overvåking vil bli gjennomført av et konsortium av forskere som har lang erfaring fra Svalbard og sørger for effektiv overvåking av variablene for plantemengde, fenologi og distribusjon. Størstedelen av etableringskostnadene vil bli dekket av infrastruktur-prosjekter tilknyttet COAT. I tillegg vil vegetasjonsovervåkingen ha stor nytte av bidrag fra forskere i konsortiet. Overvåkingen av fremmede arter krever videreutvikling sammen med forvaltningen, og sikring av finansieringen.

Vegetasjonsovervåkingen beskrevet her oppfyller kravet om å være økosystembasert og inkluderer vegetasjonsvariabler valgt ut fra deres nøkkelfunksjoner i det landbaserte næringsnettet. I tillegg vil den overvåke integriteten til det arktiske biologiske mangfoldet, med spesiell fokus på plantearter som er kjent eller forventet å være følsomme for klimaendringer og har stor forvaltningsrelevans. De viktigste driverne for vegetasjonsendring er inkludert i overvåkingssystemet fordi de er nødvendige for å forstå forandringer i vegetasjon i forhold til klimaendringer og beitedyrspopulasjoner, og er i tråd med en evaluering av det terrestriske MOSJ-programmet (www.mosj.no). Det gjenstår å finne praktiske løsninger for hvordan variablene fra dette omfattende overvåkingsprogrammet best formidles innen MOSJ-rammen.

Introduction and rationale

Plants and vegetation have been the subject of a substantial amount of research in Svalbard, but time-series spanning decades or even multiple years are few. Coordinated monitoring that targets vegetation in different environments, and includes factors impacting vegetation, is lacking (Ims et al. 2014, Ravolainen et al. 2020). The longest on-going time-series within plant ecology are found in studies that have been based in Semmeldalen (van der Wal and Stien 2014) and Adventdalen (Elmendorf et al. 2012). Additionally, remote-sensing has allowed for an analysis of overall patterns of productivity throughout the archipelago (Vickers et al. 2016). A science plan for ecosystem-based, adaptive monitoring of the Svalbard terrestrial food web recently identified critical plant variables (Ims et al. 2013), as did recent strategic plans for Red Listed plants (unpublished report, NPI) and alien plants (Lutnæs et al. 2017).

When outlining any monitoring plan, it is essential to follow a simple three step procedure that takes into account the “Why, what and how” of the monitoring (Yoccoz et al. 2001). Strong arguments as to the “Why” and the “What” of vegetation monitoring can be found in recent international and Norwegian summaries of the state of the Arctic plant life (Anisimov et al. 2007, Christensen et al. 2013, Daniëls et al. 2013, Ims and Ehrich 2013, Ims et al. 2013, Ims et al. 2014, Ravolainen et al. 2020) and are only briefly summarized in this document. Herein, the focus is on how NPI will monitor vegetation in Svalbard and how the monitoring fits in with national and international priorities.

Monitoring targets – responses, predictors and units

Plants in the Arctic respond to environmental change fall in three major ways, by changing:

I. abundance,

II. phenology (seasonal development) and

III. distribution.

Due to the multifaceted nature of currently on-going environmental change in the Arctic, monitoring of plant responses requires monitoring of the environment in which they grow. This will enhance understanding of how changes are related to specific environmental changes. Therefore, this implementation plan outlines coordination of the three major responses with a minimum set of environmental variables, termed *“predictor targets”*. Most of the predictor targets will be provided by the COAT program, in which climate variables are monitored alongside relevant components of the Svalbard terrestrial ecosystem.

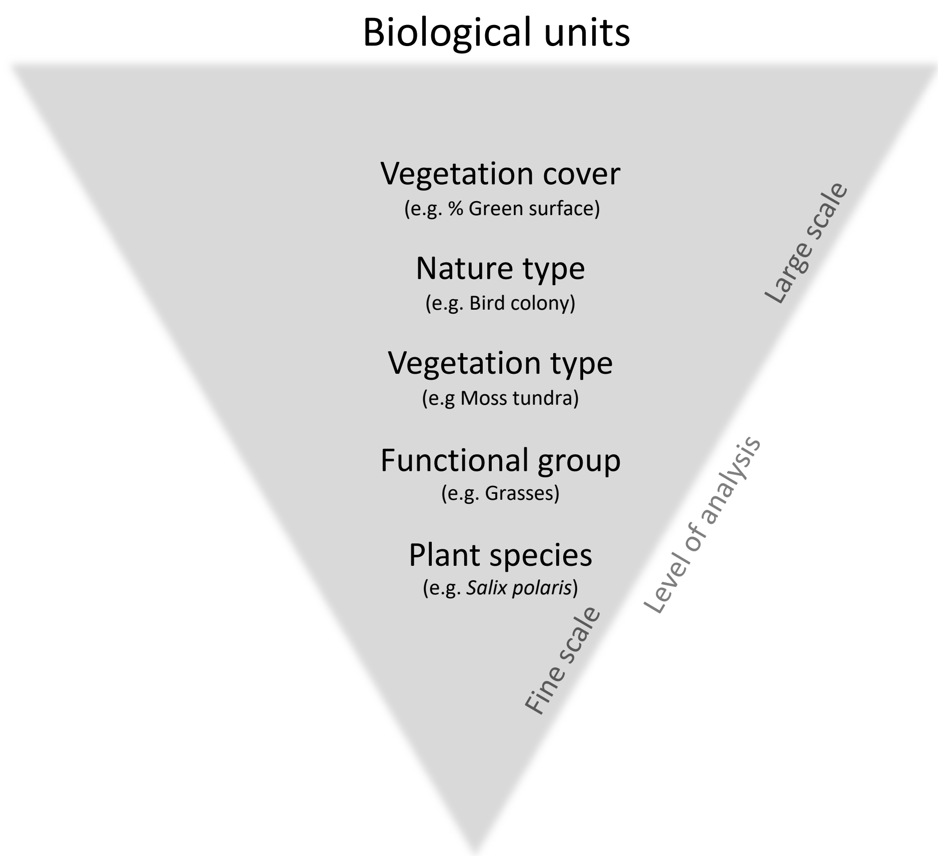

Figure 1. *Biological units in the monitoring plan. Plant species can be grouped together into groups of functionally similar species. Plants can also be described and monitored at the level of vegetation or nature type, or at the most general level, area covered by any kind of vegetation. The current plan involves variables from all these levels of organization.*

Several levels of biological organization need to be included in the monitoring of plants. Hence, "plants" in this document refers to species, functionally similar groups, vegetation and nature types as well as general vegetation cover. Figure 1 illustrates the hierarchical array of these units. Changes in plants at all of these levels of biological organization can greatly affect the function and structure of the ecosystem.

Three strata are identified for monitoring, organized in close vicinity to each other at every location: i) moss tundra (Figure 2), ii) disturbed moss tundra (as evident from visible signs of heavy goose grubbing or permafrost processes causing land surface movement) (Figure 3) and iii) *Dryas octopetala* vegetation (Figure 4). Monitoring plots including these three types of vegetation have been selected along slopes to include several replicates in each of the valleys/peninsulas that will be core sites for long-term monitoring (see chapter 4).

Figure 2. *The vegetation monitoring plan will include assessment of moss tundra, such as here in Adventdalen. Moss tundra is found on slopes and is characterized by the presence of a thick moss layer. Common vascular plants in moss tundra are grasses and forbs. Photo: Jakob Assmann/NPI.*

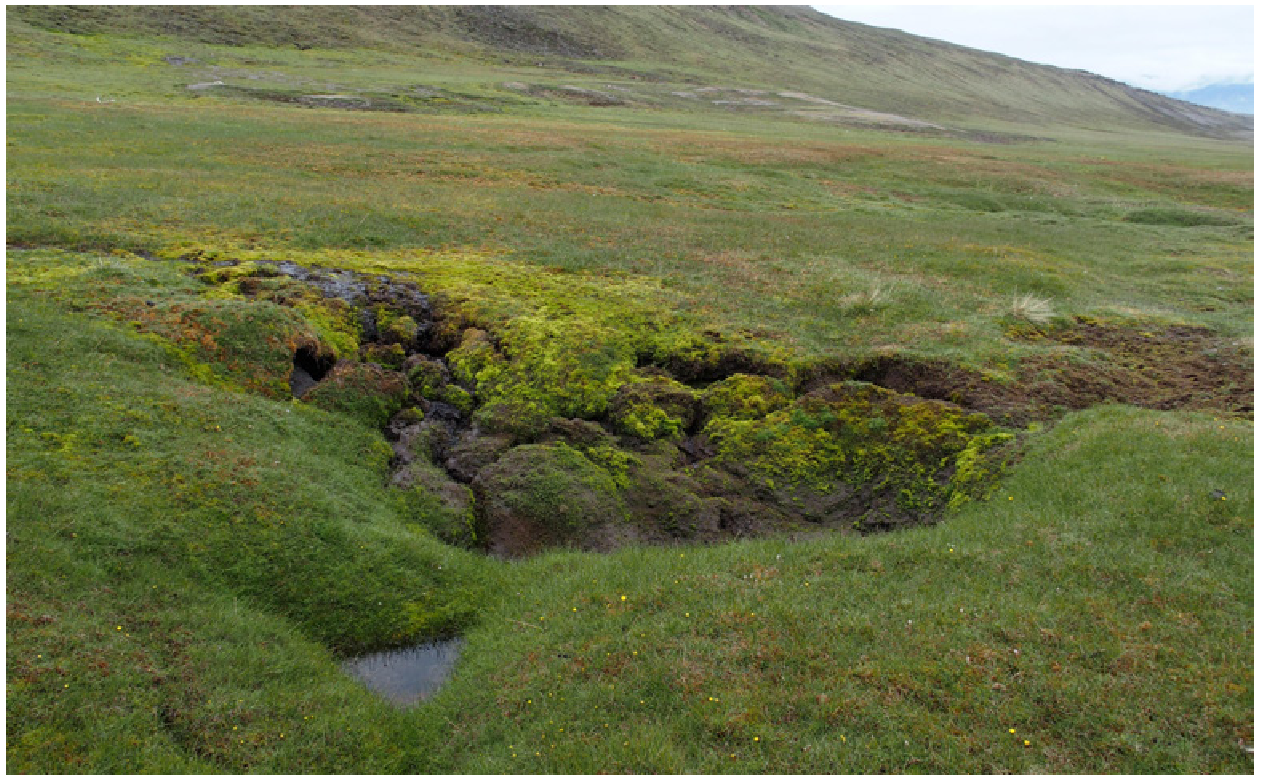

Figure 3. *Moss tundra in Sassendalen visibly disturbed by permafrost-related processes, and the special grazing activity by geese (grubbing), is one of the focus vegetation types in the monitoring. Photo: Ronja Wedegärtner/NPI.*

Figure 4. *Drier upslope ridges with mountain aven* (Dryas octopetala) *vegetation is the third focal vegetation type in the monitoring presented here (from Adventdalen) in addition to the two moss tundra categories. Photo: Stein Tore Pedersen/NPI.*

1. Selected response targets

1.1 Response target: Abundance

Abundance of plants in the Arctic is critical to monitor in the light of on-going global change. Plant species and functional types (groups of plants with similar function and role in the ecosystem) or vegetation types are frequently used to describe the state of whole ecosystems in aquatic and terrestrial ecosystems (Scheffer et al. 2001, van der Wal 2006, van der Wal and Hessen 2009, Scheffer et al. 2014, Ravolainen et al. 2020). This reflects the multiple functions that plant abundance entails in ecosystems, ranging from regulation of soil temperature, moisture and nutrient cycling, to supporting the food web that relies on plants as their basic supply of energy. In the Arctic tundra, familiar examples of plant-defined ecosystem states are the distinctions made between graminoid (grass and sedge) dominated systems and lichen or moss dominated systems (van der Wal 2006). Monitoring the abundance of plant species or functional groups is hence not just useful for understanding the plants themselves but is important for understanding the functions of the plants governing in the ecosystem.

The Norwegian system for classifying habitat types and ecosystems *"Nature types in Norway"* uses plants as essential descriptors of variation along ecological gradients. A Red List for ecosystems and habitat types in Norway was recently compiled (2011), and plant abundance and occurrence descriptions form an essential part of the descriptions of the terrestrial nature types that are on the Svalbard Red List. These types are: Arctic permafrost wetland (Near Threatened), normal Arctic steppe (Vulnerable), poor mires (Near Threatened), bird cliffs (Near Threatened), polar desert (Near Threatened) and hot springs (Vulnerable). These nature types have considerable geographical spread in Svalbard and their occurrence has not been comprehensively mapped. Monitoring all these nature types is beyond the scope of this plan, but the plan does include bird cliffs, hence contributing to knowledge about this particular nature type.

For the monitoring of plant abundance to be efficient, it is necessary to concentrate efforts on a subset of species, vegetation types and nature types present in Svalbard. The rationale used to select which plant species, functional types, vegetation types and nature types to monitor is based in part on those that are expected to respond rapidly to environmental change. A second criterion is the possibility of making predictions regarding the direction of change and the most likely drivers of change (i.e. predictor targets; see description about expected effects in sections below).

It might be thought that none of the Svalbard plants are expected to respond quickly to environmental change (Klimesova et al. 2012a, Klimesova et al. 2012b). However, plants differ greatly in their ability to grow and take advantage of altered growing conditions. Herbaceous plants (forbs, grasses) generally have fast growth rates and shorter generation times than shrubs, for example (Bråthen and Ravolainen 2015). Cryptogams (lichens and mosses) are generally slow growers, but some of the vegetation types with continuous, thick cover of mosses are in fact amongst the most productive in Svalbard (Johansen and Tømmervik 2014). Moss tundra (Figures 2, 3 and 5) is the vegetation type with the greatest number and abundance of plants with an ability to respond rapidly to environmental change and is hence central to the monitoring presented here.

Figure 5. *Moss tundra fertilized by sea birds at Alkhornet. Photo: Lawrence Hislop/NPI.*

Moss tundra is often fertilized by seabirds (Eurola and Hakala 1977, Odasz 1994, Vanderpuye et al. 2002, Zwolicki et al. 2016) (Figure 5). Where seabird colonies do not provide additional nutrients to moss tundra, circulation of nutrients is facilitated by the activities of reindeer and geese (Vanderpuye et al. 2002, Sjogersten et al. 2010). Moss tundra holds high species richness (biodiversity), supports critical ecosystem functions (primary productivity, regulation of permafrost depth), is highly sensitive to climate change and is "management relevant". Moss tundra is sensitive to disturbance from humans (Hagen et al. 2014) and grazing animals (Speed et al. 2009) and is highlighted as a potential stratum for the spread and establishment of alien plant species (Alsos et al. 2015) (Figure 6). Furthermore, moss tundra vegetation, particularly when found under seabird colonies, hosts a number of Red Listed plant species (2011). Additionally, moss tundra is considered a focal stratum that holds potential for rapid change under the influence of global warming and hence is a priority for monitoring (Ravolainen et al. 2020).

Figure 6. *Moss tundra below a sea bird cliff at Alkhornet with soil exposed due to permafrost-related processes. Such productive habitats are prone to change in the existing vegetation as well as hold potential for establishment of new species. Photo: Jakob Assmann/NPI.*

Shrubs abundance is another priority for Svalbard vegetation monitoring. The common species Arctic bell-heather (*Cassiope tetragona*) and mountain avens (*Dryas octopetala*) are slow-growing, evergreen shrubs. Dryas is an important food source for the herbivores in the late winter and early spring. These two shrub species are dominant plants in less productive vegetation groups and suffer severely from the formation of ground-ice in the winter (Bjerke et al. 2017) (Figure 7 and 8). The results of this sort of damage are currently unknown.

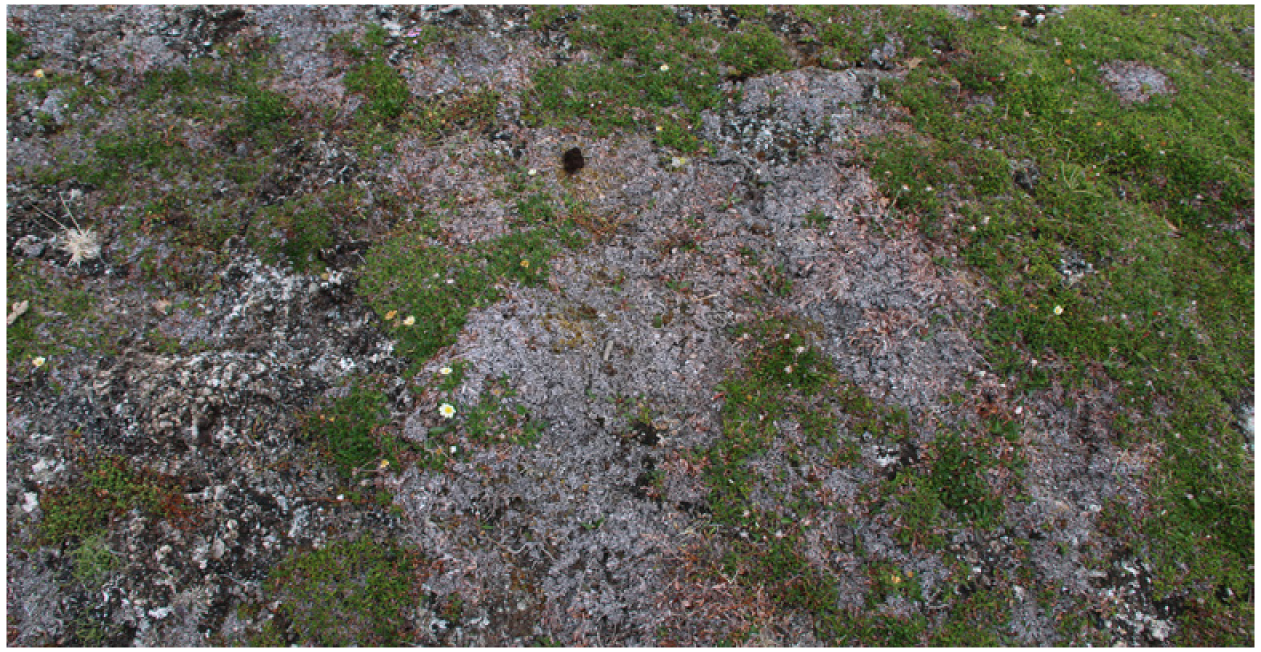

Figure 7. *Dryas vegetation damaged by extreme winter weather. The reason for damaged vegetation can be ground-ice, freeze-thaw events or frost-damage caused by lacking snow cover under extreme cold temperatures. Photo: Virve Ravolainen/NPI.*

Figure 8. *Temperature fluctuations around 0°C and precipitation as rain followed by cold periods lead to formation of thick ground ice that can cover large landscapes and damage the vegetation. These ice-layers prevent the herbivores from accessing their food resources such as presented here in Adventdalen. Photo: Jennifer Forbey/NPI.*

Variables for abundance and correspondence with national and international priorities

The core sets of variables measured in the field (Figure 9), with their corresponding indicator and ecosystem trait in the "good ecological state" system, are listed below each variable (Ims et al. 2017) is:

- moss layer, bare ground
  - indicator mosses for ecosystem trait functionally important species and biophysical structures
  - indicator area of bare ground for ecosystem trait abiotic conditions
- biomass of vascular plant species and plant functional types
  - indicator plant community in moss tundra, mountain aven, ridge and bird cliff vegetation for ecosystem trait biomass at trophic levels
  - indicator plant growth forms in moss tundra, mountain aven, ridge and bird cliff vegetation
- ice damage (*Cassiope, Dryas*)
  - indicator plant community in moss tundra, mountain aven, ridge and bird cliff vegetation for ecosystem trait biomass at trophic levels

Figure 9. *Field measurements include moss layer thickness, plant species and functional group biomass and damage due to winter processes. Photo from Brøggerhalvøya. Photo: Fredrik Samuelsson/NPI.*

Selected variables for plant or vegetation type abundance in landscapes or at larger scales with their corresponding indicator and ecosystem trait in the "good ecological state" system are listed below each variable (Ims et al. 2017):

- extent of vegetation types, erosion (de-vegetated area)
  - indicator nature type with restricted area for ecosystem trait landscape-ecological patterns (rare nature type "bird cliff")
  - indicator area of bare ground for ecosystem trait abiotic conditions

- productivity during peak growing season (NDVI)
  - indicator vascular plant community for ecosystem trait primary production

1.2 Response target: Phenology

Phenology describes the timing of events. For plants the start of the growing season in the spring marks the start of primary production and the end of the growing season marks the termination of primary production for the winter season. In the High Arctic, the growing season is short, and plants have to make optimal use of the summer to grow and reproduce. Species have different strategies for optimizing the growth season, such as having overwintering green tissue (e.g. mountain aven), or producing green tissue under the snow in the spring (Körner 2003). Generally, plants in Svalbard start to grow as fast as

conditions in the spring allow. The start of the growing season for common plant species in Svalbard is determined by snowmelt date (Semenchuk et al. 2016). Development seems to be regulated by temperature in the early parts of the season (greening, flowering), but the end of the season is not regulated by temperature. This supports the suggestion of a fixed-length for the growing and reproduction seasons for High Arctic plants (Prevéy et al. 2017). Hence, although Arctic plants can start to develop earlier in the spring they may not be capable of extending their growth period in the autumn.

The plasticity in the early season and the periodicity in the late season have implications for the plants themselves and for the interactions between the herbivorous animals and the plants. While plants can start growing earlier, herbivorous animals like reindeer and ptarmigan may not be able to adjust their reproductive events to a forward shift in the spring season. This could lead to a potential mismatch in timing of the reproduction in the animal species and availability of good quality food in the critical late winter/early spring period (Figure 10). More detailed descriptions of the expectations for future interactions between plants and Svalbard reindeer and Svalbard rock ptarmigan are outlined in the science plan for COAT (Ims et al. 2013).

Figure 10. *Early spring snow melt and green-up is critical factor for the vegetation as well as an important period for reproductive events for herbivores such as Svalbard rock ptarmigan that rely on wind-swept ridges for foraging during the mating in early spring. To predict how timing of vegetation green-up and reproductive events in the ptarmigan and reindeer develop in the future is one of the challenges for ecosystem-based monitoring. Photo taken in Adventdalen. Photo: Jennifer Forbey/NPI.*

Variables for phenology and correspondence with national and international priorities

The following variables will be measured in order to monitor phenological response targets (their corresponding indicator and ecosystem trait in the "good ecological state" system given below each variable, see (Ims et al. 2017),

- phenology (plant development over the seasons, spring green-up)
  - indicator vascular plant community for ecosystem trait primary production
  - indicator plant community in moss tundra, mountain aven, ridge and bird cliff vegetation for ecosystem trait biomass at trophic levels
  - indicator plant growth forms in moss tundra, mountain aven, ridge and bird cliff vegetation for ecosystem trait functional groups

- vegetation greenness (time-integrated/maximum measure)
  - indicator vascular plant community for ecosystem trait primary production
  - indicator plant community in moss tundra, mountain aven, ridge and bird cliff vegetation for ecosystem trait biomass at trophic levels
  - indicator plant growth forms in moss tundra, mountain aven, ridge and bird cliff vegetation for ecosystem trait functional groups

In addition to corresponding with the recent work on a "good ecological state" in Arctic tundra (Meld. St. 14 (2015-2016); Ims et al. 2017), these variables were suggested for monitoring in the evaluation of the MOSJ terrestrial plan (Ims et al. 2014), they are outlined in the COAT science plan (Ims et al. 2013) and they include several of the Focal Ecosystem Components suggested for monitoring by the Circumpolar Biodiversity Monitoring Program (Christensen et al. 2013). Phenology variables have been selected for continuation beyond the Svalbard vegetation monitoring pilot project (summarized in Hansen and Ravolainen 2016).

1.3 Response target: Distribution

Alien species

Alsos et al. (2015) presented an update on the status regarding the occurrence of alien plant species in Svalbard adding to the information that was considered in the previous national treatment of alien species (Gerderaas et al. 2012). Subsequently, Norwegian management authorities have summarized the situation regarding alien species in Svalbard, and for definitions and descriptions of the status the recent action plan by Lutnæs et al. (2017) should be consulted.

The goals of the action plan for alien plant species in Svalbard are: 1) species considered as "black-listed" with high risk of impact on Svalbard nature are to be eradicated; 2) new alien species should not be allowed to establish and; 3) alien species already present in Svalbard should not be permitted to spread to new locations. Amongst the priority actions that are specified for alien species (Lutnæs et al. 2017) mapping and monitoring alien species is considered to be the most important.

Most alien plant species in Svalbard have been recorded in central Spitsbergen, and all nine alien plant species that have been recorded in a reproductive state occur in or near settlements (Ravolainen 2017). Cow parsley, which is the only plant for which eradication actions currently are being undertaken, is found only in the Russian settlement of Barentsburg. During a mapping campaign conducted by NPI in

Figure 11. *A number of alien plant species are found in the settlements, such as here in Barentsburg. On this site the alien plant cow parsley has been successfully removed and has not been observed since 2017. The other alien species in the picture (such as* Veronica longifolia *in the foreground) have not spread to nearby areas.*

2017 no individuals were found, for the first time since the eradication measures started (Figure 11). Other alien plant species were found in the settlements but were not found spreading to nearby areas from previously known locations.

Spread of alien species from settlements to natural habitats is a concern, particularly so for bird cliff vegetation and in other types of moist moss tundra in areas with relatively high soil nutrient content (Alsos et al. 2015). Alien species are mentioned alongside climate as one of the important stressors of high Arctic bird cliff tundra in Svalbard (Ims et al. 2017).

Variables and measurement for response target distribution: Alien species

As a routine part of the monitoring of plant abundances in COAT, alien species occurrences will be surveyed at selected bird cliffs according to methodology developed during the survey of 2017 (Ravolainen 2017). The selected variables are in line with the action plan written for alien species in Svalbard (Lutnæs et al. 2017), as well as with other recent strategies for dealing with alien species in the Arctic (CAFF and PAME 2017, Thomassen 2017) and with the "good ecological state" system (Ims et al. 2017).

Variables selected for monitoring alien species are:

- cow parsley in Barentsburg
- alien species in Barentsburg, Pyramiden and Longyearbyen
- any potential occurrences at bird cliffs at five-year intervals (2017-2022-2027, etc)
  - a stressor for the indicator bird cliff moss tundra for ecosystem trait landscape-ecological patterns

Discussion: Distribution of species on the Red List

Most plant species on the Svalbard Red List are considered threatened based on the criteria "small population size". In a strategy document for rare plant species in Svalbard (Anonymous 2014, unpubl), mapping activities were prioritized. Such mapping activities are considered outside the scope of the basic plan for monitoring plants in Svalbard described herein. A separate process is required to plan activities to follow up on suggested Red List activities.

Data on rare plant species exist for thermophilic plant species in Colesdalen. This work was conducted as part of a pilot project for vegetation monitoring in 2009-2014 (summarized in Hansen and Ravolainen 2016). As could be expected based on the life-history traits of the species the forbs show large variation in frequency while shrub frequency is quite stable. None of the monitored species had directional changes, or trends, in the pilot project sampling areas, but rather they varied from year to year. This is similar to results of yearly monitoring of abundance of plants in many different vegetation types in Semmeldalen (van der Wal and Stien 2014). Thus far in Colesdalen and Semmeldalen there are no directional trends in plant abundance over the years of registration.

The method that was used for monitoring of rare plants in the pilot project in Colesdalen must be changed, as monitoring distribution or occurrence changes in the landscape is the goal. For instance have *Euphrasia wettsteinii* and *Campanula rotundifolia* ssp. *gieseckinia* spread to new locations within Colesdalen in the period from 2000 to 2014 (Arnesen et al. 2014), and this was poorly captured by the method used in the pilot project. Moreover, the large size of individual shrubs did not match the small size of the analysis plots. During the five-year implementation period of COAT (until 2020), monitoring of landscape-scale plant occurrence and vegetation type extent will be further developed, combining field and remote sensing methods. The feasibility of landscape scale monitoring of the distribution of plants for use, for instance for the thermophilic plants in Colesdalen, can then be evaluated based on more efficient methods that can cover the area necessary for monitoring population level changes.

The evaluation of the MOSJ terrestrial ecosystem plan suggested a thematic program for Red List species, which included all plant species with the exception of one goose species (Ims et al. 2014). Development of a monitoring program focusing on rare plant species that are widely distributed in Svalbard will require considerable resources, including specialized taxonomic capabilities that are not currently hosted at NPI, and is hence not feasible at this time.

2. Selected predictor targets

Plant abundance can increase or decrease, which are sometimes popularly termed "greening" and "browning" of the Arctic, respectively. These two directions of change are driven by different environmental factors. Warming of Arctic vegetation (experimentally) can increase the abundance of herbaceous plants (forbs, graminoids) and shrubs, while cryptogams (lichens, mosses) are more likely to decrease (Elmendorf et al. 2012). Biomass of the common vascular plants in Svalbard closely follows summer temperatures, displaying high inter-annual variation (van der Wal and Stien 2014). Hence, summer temperature is a critical environmental variable to include on the list of monitoring targets that will be used as predictors of plant change.

Considering the fact that herbivores (reindeer, different species of geese) are practically omnipresent and abundant in Svalbard, it is not possible to outline climate change predictions for plants without taking into account the impact of grazing animals. Grazing animals can promote forbs and grass-characterized vegetation, while they generally impact woody plants and/or cryptogams such as lichens negatively (van der Wal 2006). The degree of herbivore activity will have a strong influence on the direction and magnitude of plant change. For instance, mosses can benefit from some herbivore activities, such as nutrient inputs as they can readily acquire nutrients over their whole surface (Sjogersten et al. 2010), but they do not tolerate high levels of trampling. Contrary to the temperature effects, which are expected to be slow, grazing animals can transform vegetation from one type to another rapidly (van der Wal 2006, Speed et al. 2009, Ravolainen et al. 2020).

Milder winters, with more frequent rain-on-snow events, cause extensive ground-ice damage to shrubs (Bjerke et al. 2017). *Cassiope tetragona* and *Dryas octopetala* are particularly prone to damage due to ice, and vegetation type development after severe damage to these plants is not known. Primarily in moss tundra, but also in other vegetation types, geese grazing activity and especially their grubbing behavior (removal of below-ground plant parts) can leave areas de-vegetated. The only study that has looked at disturbance at landscape scales in Svalbard quantified this type of disturbance, and concluded that the majority of moss tundra is highly likely to be affected by goose grubbing (Speed et al. 2009). Human trampling can also reduce vegetation cover. This type of damage is usually very local in extent, mainly around highly visited sites such as cultural remains, where the trampling effect can be considerable (Thuestad et al. 2015, Barlindhaug et al. 2017). Disturbance of plants by geese and human activities is spatially variable, but currently geese seem to induce the greatest landscape scale impacts (Ravolainen, unpublished data).

Snow distribution greatly affects moisture regimes in the spring/early summer and thermal insulation during the winter (Figures 8 and 10). The amount of snow and its distribution is changing along with the other climate changes in Svalbard. Changes in seasonal duration of snow cover, distribution and depth can be expected to change growing conditions for plants rapidly. This can determine which plants are able to survive at a given spot. Increased summer precipitation can destabilize the soil and lead to increased soil movement or landslides.

Variables for climate, disturbance (herbivores and human trampling), and nutrient input

Climate variables are of major importance for understanding future vegetation changes, and will be fully integrated into the vegetation monitoring program. The relative importance of temperature change, grazing, trampling disturbance and changes in nutrient availability are not currently known. The suite of predictor variables will therefore be broad and cover the environmental factors that are most likely to be important. Additionally, replicated monitoring in multiple landscapes will be accompanied by experiments addressing causality between selected variables, following national and international recommendations for effective monitoring.

The focus predictor targets for the monitoring, with their corresponding indicators and the ecosystem trait described in the "good ecological state" system (Ims et al. 2017) are,

- air and soil temperatures
- permafrost thaw depth
  - indicator permafrost for ecosystem trait abiotic conditions
- snow depth, duration and distribution
  - indicator snow cover for ecosystem trait abiotic conditions
- soil moisture
  - indicator bare ground for ecosystem trait abiotic conditions
- precipitation
- abundance of the grazing animals (reindeer, ptarmigan and geese)
  - indicator Svalbard rock ptarmigan for ecosystem trait biodiversity
  - indicator Svalbard reindeer for ecosystem trait functionally important species and biophysical structures
  - indicator pink-footed goose for ecosystem trait functionally important species and biophysical structures
- nutrient levels in the soil and in the plant leaves
- ground-ice formation
  - indicator bare ground for ecosystem trait abiotic conditions
- damage to *Cassiope* and *Dryas* due to ice
  - indicator plant community in moss tundra, mountain aven, ridge and bird cliff vegetation for ecosystem trait biomass at trophic levels
- disturbed patches due to permafrost-related processes

The evaluation of terrestrial components of MOSJ recommended integration of climate and disturbance-related variables (herbivores and human trampling) in the plant monitoring regime (Ims et al. 2014). National and international monitoring plans also suggest integration of measurements of the environmental factors expected to have the most influence on the biological monitoring variable (Christensen et al. 2013, Ims and Ehrich 2013, Ims et al. 2013, Hansen and Ravolainen 2016). The combination of climate monitoring and herbivore monitoring is seldom incorporated into plant time-series, and the current set-up should provide a valuable addition to the understanding of climate change impacts on vegetation in the context of the Circumpolar Arctic.

3. Organization and methods

3.1 Spatial and temporal study design

The spatial study design will make use of a multi-scale approach, where the intensity of the measurements will be adjusted to the spatial scale and extent of the variables (Figure 12). Remote sensing allows for monitoring at all scales from the whole of Svalbard down to patches of a certain vegetation type, while field monitoring will take place in several selected areas (valleys and peninsulas) (Figures 13 and 14).

Spatial units are, in increasing size: plots (0.5 x 0.5 m), ecologically different types of vegetation at 30 x 30 m sites, groups of sites, sections (parts of valley/peninsula), locality that corresponds to a valley or peninsula, region, the whole of Svalbard. The spatial set up includes several replicates of focal vegetation type patches in the landscapes where the monitoring will be done (Figures 13 and 14).

The temporal set up for the monitoring includes different intensities (Figure 12). Multiple field measurements within a growing season are only feasible close to Longyearbyen (such as Endalen sites, Figure 14), and will be restricted to a small subset of phenology measurements to validate remote sensing imagery that will be acquired repeatedly as the growing season proceeds.

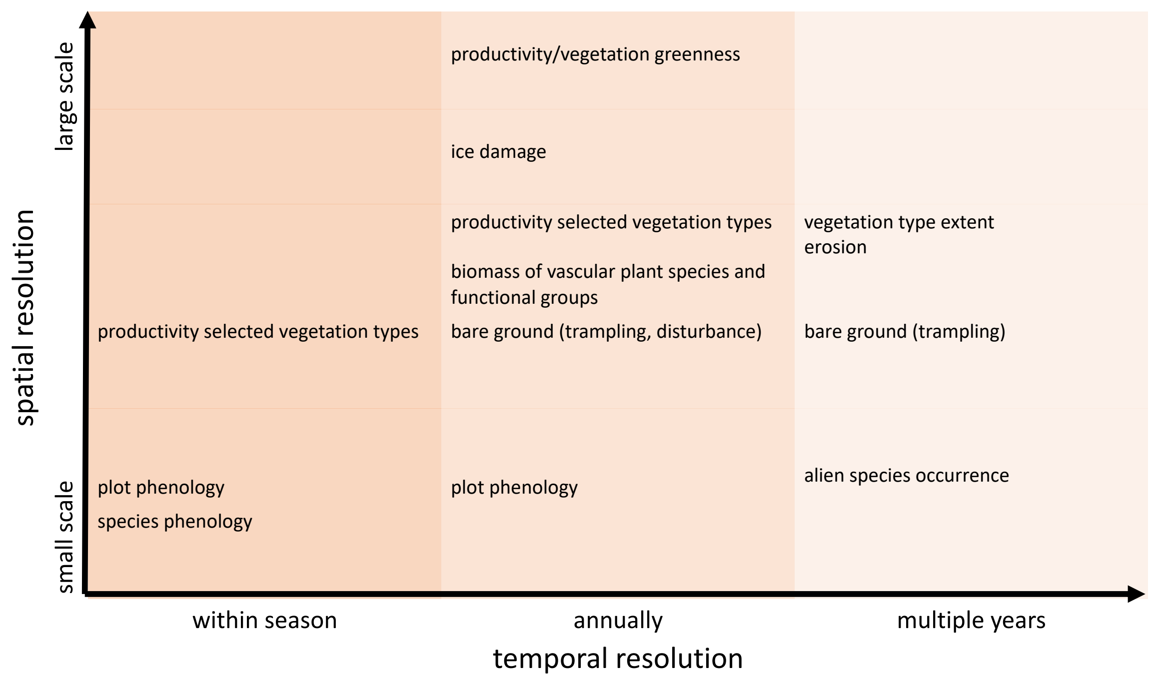

Figure 12. *The spatial and temporal set up for monitoring. The most intensive monitoring is field-based monitoring conducted at individual sites. The annual field monitoring includes the spatial scales of plots up to landscapes and remote sensing at the scale of region/whole Svalbard. Some variables, such as the alien species and vegetation type extent are expected to change slowly and will be monitored at five-year intervals.*

The core of the monitoring for plant abundance variables are the focal i) *Dryas*, ii) moss tundra and ii) disturbed moss tundra sites (Figure 15). All landscape scale monitoring is organized around the focal areas in order to make fieldwork effective. Landscape scale assessment of variables related to disturbance and the vegetation type extent (at five-year intervals) will be done along altitudinal transects that cover different vegetation types and varying degrees of current disturbance.

Areas for monitoring sites are Adventdalen, Sassendalen, Colesdalen, Semmeldalen, Alkhornet, Brøgger Peninsula, and Sarsøyra (Figures 13 and 14). More than 20 valleys/peninsulas along the west coast of Spitsbergen have been surveyed for potential inclusion and initial data has been gathered that will be used for final site choices (Ravolainen et al unpublished data; Bjerke et al. 2017, Ravolainen et al. 2018). The few sites in Svalbard where long-term field-based time-series on plants have been collected (Adventdalen and Semmeldalen sites, see e.g. Dollery et al. 2006, van der Wal and Stien 2014) will be continued in future monitoring.

At each combination of temporal and spatial scales, appropriate predictor variables will be monitored. For example, at the focal moss tundra sites where vascular plant biomass will be monitored, counts of grubbing events will be made (Figure 15). Accordingly, the larger scale records of productivity on a valley/peninsula scale will be supported by the annual assessments of reindeer population size by NPI/COAT.

Figure 13. *Remote sensing with a coarse spatial resolution will be used to assess vegetation greenness on whole Svalbard scale (inset figure), while higher resolution remote sensing and field measures will be obtained from valleys and peninsulas on the central west coast of Spitsbergen. Alien plant species will be monitored in the settlements. The highlighted areas denote approximate areas that high resolution remote sensing and field work will cover. Monitoring of climate and herbivores is obtained from the COAT program in these areas and will facilitate analysis and interpretation of results of the vegetation monitoring.*

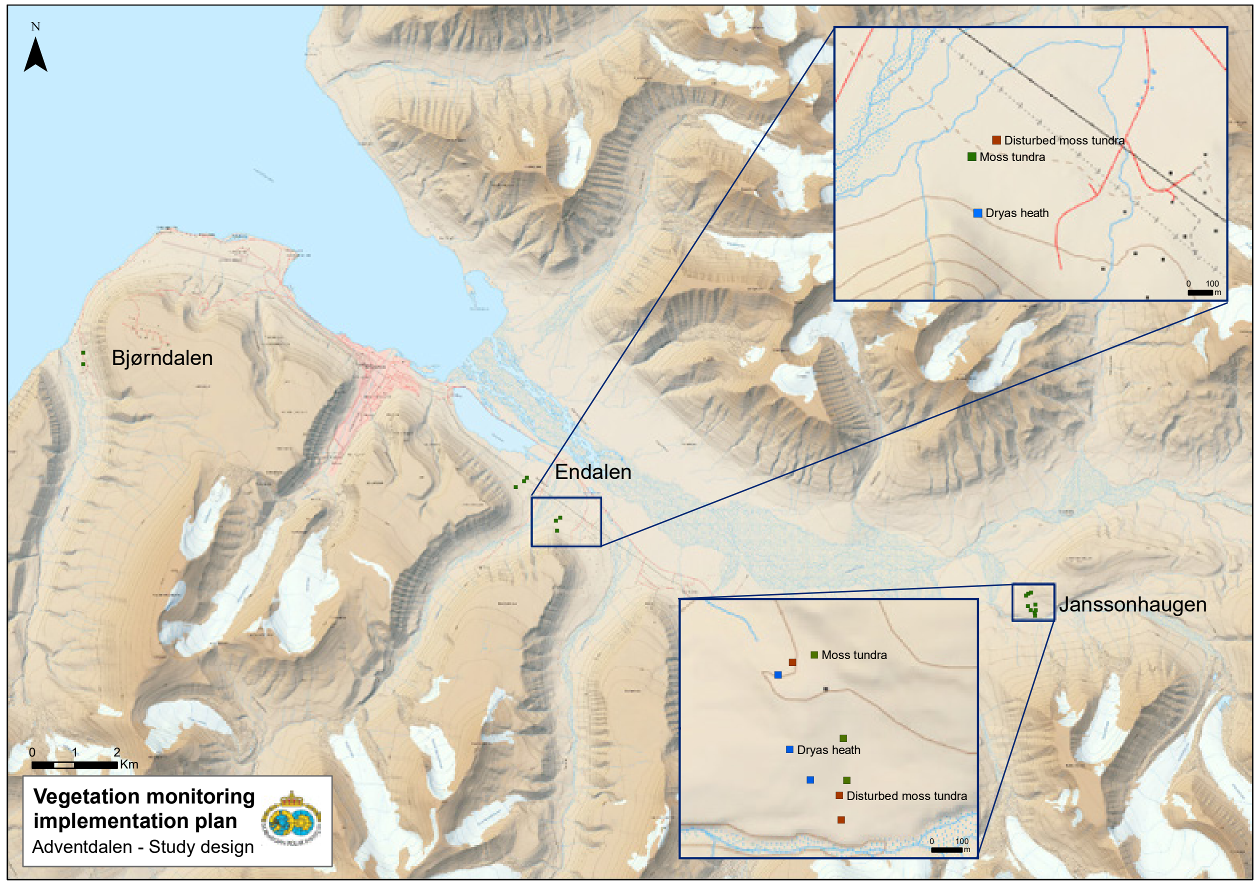

Figure 14. *The monitoring will focus on moss tundra and mountain aven (*Dryas octopetala*) vegetation. Inserts show examples of sites in the different sections of Adventdalen. Monitoring sites are distributed in different parts of the valleys and penisulas. Similar distribution of sites is used in the other areas too, to achieve adequate spatial coverage along environmental gradients, in particular climate and the herbivores. Monitoring of the variables that cover larger areas of the landscape is organized around the field sites. The colored square symbols correspond to the sites (30x30 m) in Figure 15.*

Climate variables will be monitored within a multi-scale set-up, similar to the biological variables, using a combination of many replicates of small stations in various landscape types, medium size stations at fewer sites, and the fully instrumented meteorological stations at key selected sites. The Norwegian Meteorological Institute is currently developing the COAT climate portfolio. Climate monitoring in COAT utilizes regional (coastal-continental, north-south) and landscape scale gradients (inner-outer valley, altitudinal gradients) of climatic variability. Productivity measures monitored along altitudinal transects and in the Isfjorden and central west coast regions are examples of plant variables that will benefit from the COAT climate monitoring. By 2020, time-series information will exist for reindeer, ptarmigan and geese, as well as for climate variables from a series of meteorological stations. The list of existing variables for all the biological monitoring targets in COAT are under evaluation during the implementation period to ensure sufficient climate monitoring is conducted. The plant monitoring will greatly benefit from the data collection in the COAT program, to which over 20 researchers from multiple institutions contribute.

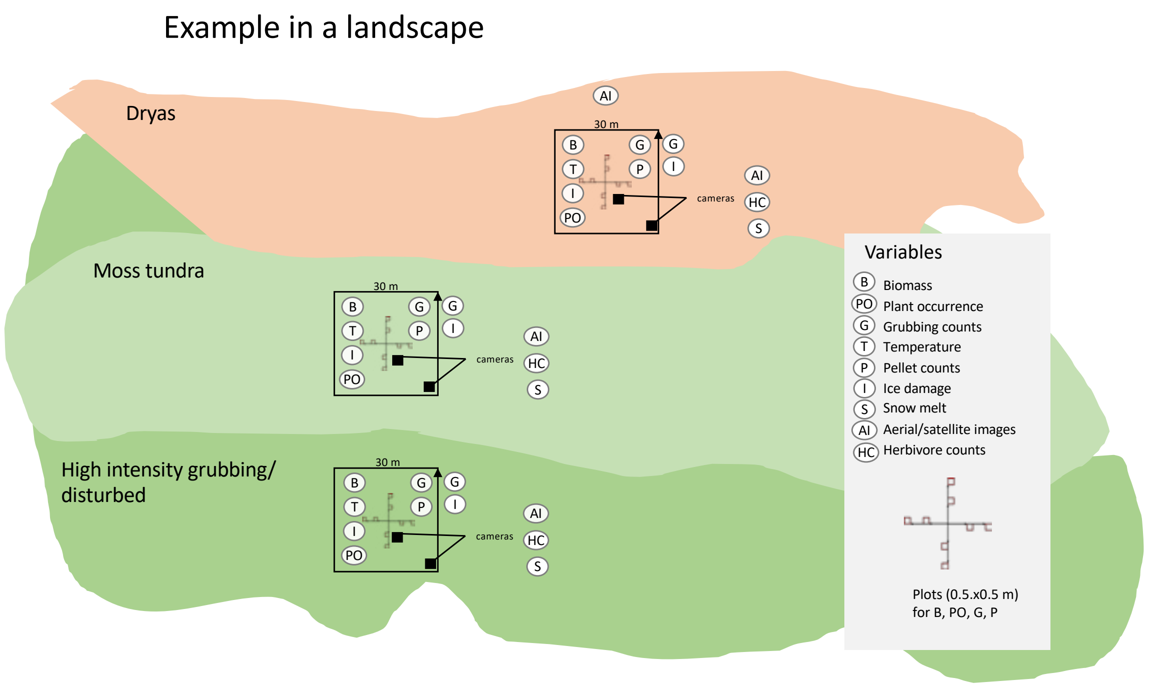

Figure 15. *The study design of the monitoring will ensure that variables measured with different intervals and methods can be linked to each other in the analysis of the time-series. Monitoring is organized around sites (30x30 m), in the different vegetation types in the landscapes. Field measures of vegetation are taken in small squares (plots of 0.5x0.5 m size) in the middle of the site, signs of winter damage (ice and/or frost damage) and geese grubbing are counted along one of the sides of the square and quantified from imagery obtained using drones. While full-scale climate stations will provide data from the general area, soil surface temperature and soil moisture will be measured on site with a set of small loggers. Such co-location and coordinated distribution of measurements will ensure that the results will not only give us information about vegetation change but also likely the causes of it.*

3.2. Methods

A variety of field and remote sensing methods will be combined to provide variables at the adequate spatial and temporal intensity. Field methodologies for the abundance variables will follow methods found effective in corresponding landscape and regional scale field monitoring of plants in other Arctic areas from the Norwegian and the Russian Arctic (Ravolainen et al. 2013, Ravolainen et al. 2014, Bråthen and Ravolainen 2015, Baubin 2017, Bjerke et al. 2017, Bråthen et al. 2017). Point intercept method will be used for field measurements of plant biomass as it is non-destructive and adjustable to desired efficiency and accuracy (Figure 16). Counts of ice-damaged area along 30 x 0.5 m transects at the sites will be conducted. Moreover, image-based methods will be used to delineate areas of vegetated and non-vegetated ground, as well as ice-damaged vegetation. Once all the sites have been marked (after 2020) they will be described using the Norwegian system for classifying nature types.

The need to quantify the impact of herbivores on Arctic vegetation was emphasized in the recent work on a "good ecological state" (Ims et al. 2017) that followed from the Government white paper *Nature for life – Norway's national biodiversity action plan* (Meld. St. 14 (2015-2016)). At a subset of the most

Figure 16. *Small field plots where the point intercept method is used form the basis for many of the field based variables, such as here in Adventdalen. Photo: Jakob Assmann/NPI.*

accessible sites from Longyearbyen and Ny-Ålesund, long-term experimental exclusion of geese and reindeer will be conducted, in order to disentangle effects of climate change from effects of grazing animals, separating the well-known effects of geese (Kuijper et al. 2006) and reindeer (Dormann and Skarpe 2002, Cooper 2006) from each other. Experimental exclusion of different-sized herbivores has proven important in other Arctic areas, although such studies are few (Ravolainen et al. 2011, Ravolainen et al. 2014, Baubin 2017). Coupling an experimental approach to the monitoring is the only way to assess causality in the situation where Svalbard plants are influenced by both herbivores and climate change. For example, the rate of nutrient cycling can be correlated with the activities of herbivores yet determined by climate change. Without monitoring the herbivore effects in controlled experiments, we will not be able to understand future changes.

Figure 17. *Images from Unmanned Aerial Vehicles (UAVs) will be combined with field and satellites measures to ensure landscape scale coverage as well as ground validation of the remote sensing data. Images will be obtained so as to cover the moss tundra types (upper panel) as well the drier upslope* Dryas *ridges and the* Cassiope *vegetation of the intermediate slopes (lower panel). Images from Sassendalen. Photo: Isabell Eischeid/NPI.*

Effects of human trampling will be assessed at the COAT sites where plant monitoring is done, which are areas assumed to have low human visitation levels compared to some of the most frequently visited sites in central Spitsbergen. Additionally, selected sites with known high rates of human visitation in addition to research activities (e.g. Alkhornet) will be assessed. Repeat imagery will form the basis for monitoring trampling effects.

The variables “vegetation greenness” and “phenology” will be monitored using a combination of satellite images, images from Unmanned Aerial Vehicles (UAV) and images from fixed cameras mounted on poles (Figure 17). This combination of platforms will ensure large spatial coverage (satellite imagery) and high enough resolution for understanding of the ecological significance of the results (UAV and fixed camera data from the field). Sensors onboard MODIS and Sentinel satellites will be used for calculating vegetation indices (Normalized Difference Vegetation Index and/or Enhanced Vegetation Index) for Svalbard. The red, green and blue and near infrared bands from cameras carried by UAVs and from cameras attached on fixed poles will be used to calculate greenness indices at resolutions higher than those possible with the Sentinel imagery. High resolution images will also be used for obtaining data on flowering and goose grubbing. NPI’s remote sensing unit will process the Sentinel and MODIS satellite imagery. Additional fixed cameras in Adventdalen will be deployed by COAT in 2018-2020 to complement existing camera stations, and plant species and functional type phenology will be acquired from the images for the most common species (such as *Dryas octopetala, Salix polaris*, graminoids, forbs; see next section for further detail on methods). Spectral properties of the vegetation and the soil will be collected both in situ in the field, using direct sampling as well as via the use of several types of sensors and cameras. Near Infra-Red Spectrometry (Smis et al. 2014) will be used to monitor nutrient level changes in plants and soil. Substrate nutrient properties will be incorporated into the current monitoring.

Method development

Method development is on-going to improve the monitoring of phenology using manual measures, fixed cameras and satellite images from the Sentinel satellite. The work is coordinated by the Norwegian Polar Institute and involves colleagues associated with COAT from the partner institutions UiT– The Arctic University of Norway, University Centre in Svalbard (UNIS), Norwegian Institute for Nature Research (NINA) and The Norwegian Meteorological Institute. Colleagues from the High-Latitude Drone Ecology Network Darthmouth College, University of Idaho and University of Edinburgh are also involved in development work. There is a particular emphasis on developing the links between the fine-scale camera measurements and the larger resolution drone and satellite image measurements of vegetation green-up. Work on scaling of the measurements is required for efficient monitoring and is in high demand from the international remote sensing community.

New development of image processing and analysis will be implemented as needed. Within the COAT consortium, the informatics and physics environment dataflow will be streamlined via the project COATTools. The technological development of remote sensing variables will benefit from the associated COAT Tools+ project (Tromsø Forskningsstiftelse), where automatic processing of images acquired from multiple platforms is tailored for the needs of ecosystem monitoring focusing on the vegetation component. NPI researchers Ravolainen and Pedersen are supervising a PhD student (started in 2018) working specifically on vegetation-permafrost-herbivore linkages using aerial imagery.

3.3. Resources

The implementation period (until 2020) and running the monitoring will require different resources. In the years until 2020 a substantial amount of work will be done to establish the full set of sites and routines. Special tasks in the implementation period include: accurate positioning of the sites, establishing camera stations and the herbivore exclosure experiment, as well as completing the routine for handling remotely sensed information. Furthermore, logistics regarding field cabins will be streamlined, and safety and field equipment will be purchased for NPI’s basic equipment pool.

The vegetation monitoring program will benefit from the establishment of the climate monitoring network, the digital infrastructure and logistics upscaling (field stations, vehicles, equipment) within the COAT program. The COAT INFRASTRUCTURE and the INFRANOR projects will provide substantial resources needed for establishing the vegetation monitoring that complement the staffing and monetary resources available from NPI base funding. In the running phase, the field monitoring in the spring and summer will be undertaken by NPI research and technical staff (Virve Ravolainen and Stein Tore Pedersen) and will be facilitated by researchers in the COAT consortium. In particular the concerted efforts of researchers with existing vegetation time-series from Semmeldalen, Adventdalen and Sassendalen will complement the NPI team. The in-kind contributions of the ecological and climate monitoring in the COAT consortium add up to several man-months a year and the inclusion of existing, decade-long time-series to the current vegetation monitoring is invaluable.

In the monitoring phase the main field work period will take place around the peak of the growing season, mid-July to mid-August. Additionally, camera-based monitoring of snow melt and plant green-up will require a week of field work effort spread over the period April to mid-June. COAT technical personnel at NPI will service data loggers and cameras at the field sites (temperature, moisture etc). At NPI Virve Ravolainen and Stein Tore Pedersen will contribute with a month of field time annually and the time needed for getting the data in to database formats. A similar set up used in the low Arctic tundra, with a geographically spread and effectively executed field program in combination with use of remote sensing information, has proven a powerful tool to assess landscape and regional scale patterns and processes in the terrestrial food web (Ravolainen et al. 2013, Ravolainen et al. 2014). Researchers within the COAT consortium will share data collection responsibilities according to the science plan.

The biological variables will be collected within the COAT framework and stored in both COAT and at NPI databases. These are developed to be compatible with the Svalbard Integrated Observation System database that is under construction. The Norwegian Meteorological Institute is responsible for climate measurements from the full-scale meteorological stations, and data quality will be checked and the quality-secured data subsequently deposited in the national climate database. Climate variables collected at the field stations using smaller loggers will be maintained by COAT biologists and technical staff.

As climate is warming rapidly in Svalbard and the populations of herbivores are changing and influencing the abundance and phenology of vegetation, their monitoring is prioritized over the monitoring of alien species because recent assessments suggest that the alien plant situation is quite stable. However, every fifth year an “extensive” cycle is planned during which alien species will be monitored in the settlements; this work depends on further development of the implementation plans for alien species (CAFF and PAME 2017, Lutnæs et al. 2017, Thomassen 2017).

There is a need to access additional funds to complement the current level of funds allocated to vegetation monitoring at NPI’s Research Department if the whole monitoring package outlined in this document is to be implemented.

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