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Dry Calcareous Grasslands – Using Monitoring Methods to Detect Effects From Management Actions

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Abstract

1. The grim fact is that biodiversity in ecosystems across the globe are rapidly declining due to anthropogenic activities. On the other hand, focus on actions that may halt this loss is on the rise. Ecological restoration is frequently used as a management tool to increase the quality of degraded habitats. Management actions used in ecological restoration are numerous, though invasive plant removal is the most common target. However, due to lack of documentation, there is still little knowledge of what the outcome from management actions are, and this presents a global knowledge gap in most of the earth's ecosystems.

2. In this thesis I have investigated how monitoring methods can be used to detect effects from management actions in localities of dry calcareous grassland, in the inner Oslofjord region, Norway. I have through four monitoring methods analyzed difference in locality condition and biodiversity between ten managed- and ten unmanaged localities. In addition, I also visited four localities that underwent first-time management actions summer of 2022.

3. The four different monitoring methods (NatStat, NiN, calcareous grassland reduced, and calcareous grassland complete) vary in the level of detail and scale variables are estimated. Two of the methods detected significant results in locality condition; higher abundance of invasive species in the unmanaged localities. Further significant results were found in biodiversity; one method detected higher richness of habitat-specific species in the managed localities and another method found the same for red listed species.

4. Results from this thesis points to the importance of adapting scale of sampling to type of effect wished to study. Both number- and size of sampling plots influence the result. Limiting monitoring of effects to variables management actions have targeted and doing so in a practical spatial scale, may not only provide more useable data for management, but also reduce the financial costs and contribute to sustainable monitoring of effect programs. Closing the gap between scientific research and practical management actions, may provide a key solution to increase documentation of management work and effects from such actions.

Sammendrag

1. Et trist faktum er at det biologiske mangfoldet i økosystemer over hele kloden er i rask nedgang på grunn av menneskelige aktiviteter. På den annen side øker fokus på handlinger som kan stoppe dette tapet. Økologisk restaurering brukes ofte som verktøy for å øke kvaliteten på forringede naturtyper. Forvaltningstiltak som brukes i økologisk restaurering er mange, selv om fjerning av fremmede karplanter er det vanligste fokus. Men på grunn av mangel på dokumentasjon er det fortsatt lite kunnskap om hva resultatet av slike forvaltningstiltak er, og dette står fram som et globalt kunnskapsgap i de fleste av jordens økosystemer.

2. I denne oppgaven har jeg undersøkt hvordan overvåkingsmetoder kan brukes for å oppdage effekter fra forvaltningstiltak i lokaliteter av åpen grunnlendt kalkmark, i indre Oslofjordregion, Norge. Jeg har gjennom fire overvåkingsmetoder analysert forskjell i lokalitetstilstand og biologisk mangfold mellom ti skjøttede og ti uskjøttede lokaliteter. I tillegg har jeg også besøkt fire lokaliteter som gjennomgikk forvaltningstiltak for første gang sommeren 2022.

3. De fire ulike overvåkingsmetodene (NatStat, NiN, grunnlendt kalkmark redusert, og grunnlendt kalkmark komplett) varierer i detaljnivå og på hvilken skala variablene blir estimert. To av metodene påviste signifikante resultater i lokalitetstilstand; høyere forekomst av fremmede arter i de uskjøttede lokalitetene. Ytterligere signifikante resultater ble funnet i biologisk mangfold; en metode oppdaget høyere artsrikdom av habitatspesifikke arter i de skjøttede lokalitetene og en annen metode fant det samme for rødlistede arter.

4. Resultater fra denne oppgaven peker på viktigheten av å tilpasse prøvetakingsskalaen til type effekt som ønskes undersøkt. Både antall og størrelse på prøvefelt påvirker resultatet. Å begrense overvåking av effekter til variabler forvaltningstiltak har fokusert på og å gjøre det i en praktisk romlig skala, vil ikke bare gi mer brukbare data for forvaltningen, men også redusere de økonomiske kostnadene og bidra til bærekraftig overvåking av effekter av tiltak. Å tette gapet mellom vitenskapelig forskning og praktiske forvaltningstiltak, kan være et viktig utgangspunkt for å øke dokumentasjon av forvaltningstiltak og effekter av slike handlinger.

1 Introduction

The ongoing global decline of biodiversity poses a major threat to human health and well-being (IPBES, 2019). Although there are several factors causing decline of biodiversity, the biggest threat is anthropogenic driven degradation and fragmentation of species habitats (Bellard et al., 2022). Therefore, conservation of species in their native environment presents a key component in preventing further loss. In 2020, the United Nations designated the ongoing decade as the “decade of ecosystem restoration”, to improve the ecological status of habitats across the earth (UNDP, 2020).

In 2004, the Society for Ecological Restoration International Science & Policy Group (SER) published a primer on ecological restoration and defined it as “the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed” (Balensiefer et al., 2004). Ecological restoration is used as a management method where success is measured in terms of the how resilient and self-sustaining ecosystem functions are post restoration action. Ecosystem-based management, such as ecological restoration, may be a more suitable approach to increase biodiversity than previous common methods focusing on single species (Boudouresque et al., 2020; Panitsa et al. 2011). Even though ecosystem-based approaches shift the scope of focus from single species to diversity and ecosystem functioning, the approach still benefit rare and endangered species through increased habitat quality (Giam et al., 2010). Ecosystem-based management also include benefits for humans through ecosystem services, and thus provide management authorities with “more bang for buck” when negotiating for funding to policymakers (Langhans et al., 2019). It may therefore come as no surprise that conservation on an ecosystem level, in terrestrial as well as aquatic systems, has increased in popularity through the recent decades (Delacámara et al., 2020).

The increased popularity of ecosystem-based management approaches calls for a growing need of identifying appropriate management actions, as well as evaluation and optimalization of these actions. Within the field of ecological restoration, a key element is the use of set goals for the wanted outcome of restoration, and to use these goals when evaluating the successfulness of the project (Clewell et al., 2013). Both defined goals and postimplementation documentation are key aspects of successful restoration (Rieger et al., 2014; Palmer et al., 2016).

Buxton et al. (2021) examine the gap between available scientific data and practical management in the light of the failure to halt biodiversity loss. They conclude that one of the main reasons for this gap could be that management authorities have difficulties translating data from science into usable management actions, and thus end up with less effective goals and methods. Other studies have shown that even with scientific knowledge available, management authorities and practitioners are more willing to rely on their own experience and anecdotal facts rather than scientific data (Sutherland & Wordley, 2017). This may lay way for a trial-and-error way of performing management actions, without knowing which method that ultimately provides the best result. Thus, it is clear that management will benefit from following scientific methods when implementing conservation actions, to create a better understanding of how conducted actions contribute to a desired result.

The lack of documentation of methods used in ecological restoration and conservation management presents a barrier to understand how actions affect the outcome of the project. Evaluating the success of restoration projects would benefit from using more standardized variables (Evju et al., 2020a; Groom et al., 2017; Wallace et al., 2020). However, there seems to be a significant gap between the wish for comparable and standardized evaluation methods and the fact that the majority of restoration projects are not documented at all (Nilsson et al., 2016; see also Brooks & Lake, 2007). The lack of documentation throws shade on the outcome of both restoration projects and management actions, and leaves practitioners as well as policymakers in the dark of how their involvement in form of work and funding, contribute to a desired effect. More studies that focus on effects of management actions (effect studies) will help to shine light on how restoration projects and management actions enhance habitat quality within and across ecosystems.

Dry calcareous grassland (hereafter calcareous grassland) is an ecosystem type that has been given increased conservation focus in Norway the past recent years. Calcareous grasslands are defined by natural lack of trees due to shallow calcareous soil, and are typically associated with calciphilous vascular plant communities (Wollan et al., 2011). Many of the herbs and graminoids forming these communities have limited distribution and low abundance outside of this nature type (Diacon-Bolli et al., 2012). Calcareous grasslands host a multiple of red-listed plant species and contributes with a magnitude of ecosystem functions and services, such as pollination and recreational experiences (Bakkestuen et al., 2014; Grêt-Regamey et al., 2014). Calcareous grassland habitats are found dispersed through small patches on calcareous bedrock across several vegetation zones in Norway. On the national red list of nature types, calcareous grasslands are listed as vulnerable (VU) in the southern boreal- and endangered (EN) in the boreonemoral vegetation zone (Høitomt et al., 2018 (southern boreal) and Evju et al., 2018 (boreonemoral)). In addition, the Norwegian Environment Agency listed in 2020 calcareous grassland in the boreonemoral vegetation zone as a selected nature type, which indicates that there is a strong political will to conserve this habitat (Regjeringen, 2020). Lastly, calcareous grassland habitats are frequently situated in protected areas and so benefits through a third protection.

The most important factors that contribute to the decline of calcareous grasslands include habitat loss, invasive plant species, disturbance from recreational activities, and nitrogen deposition. The current distribution of calcareous grasslands is only a fragment of its historical prevalence (Wollan et al., 2011), and to prevent a further decline of this nature type, several management actions have been implemented. Such actions include removal of invasive species, shrubs, and trees, but also fencing and information signs to reduce soil erosion caused by people (Evju et al., 2021). However, there is still little certainty of to which extent these actions provide the wanted outcome (Aalberg Haugen, 2019).

Dry calcareous grasslands in Norway represents a suitable case study to implement effect studies on. First, as a selected nature type, it is a habitat that benefits from recently increased political attention. Secondly, there are already several ongoing management actions funded by the government to conserve this specific habitat. Thirdly, a monitoring project of habitat condition has already been implemented (Evju, et al., 2020b) and thus makes it more feasible to conduct effect studies.

In this thesis I will through four monitoring methods analyze ecological differences between managed and unmanaged localities of calcareous grassland, and investigate how the monitoring methods detect effects of management actions. The four monitoring methods vary in level of detail, from least to most: 1) NatStat: percentage cover data of red listed- and invasive plants in a restricted number of plots, 2) Calcareous grassland reduced monitoring: frequency and occurrence of red listed- and invasive plants of the locality, 3) NiN mapping by the Norwegian Environment Agency's instruction: locality-based assessment of condition and biodiversity scores, and 4) Calcareous grassland complete monitoring: full species composition analyses in permanent vegetation plots and vegetation layer estimations. I will compare data from ten localities that have undergone management actions to ten localities that have not undergone management actions. In addition, I have visited four localities that underwent management actions for the first-time summer 2022 and collected data from these localities both prior to and after management actions were conducted.

The aim of my thesis is to test the suitability of different monitoring methods for measuring the effects of management actions on locality condition and biodiversity in dry calcareous grasslands 1) in managed and unmanaged localities and 2) before and after the implementation of management actions.

I will examine how the different monitoring methods detect effects on locality condition, represented by:

- Shrub cover
- Soil erosion
- Invasive species

I will examine how the different monitoring methods detect effects on biodiversity, by examining:

- Habitat-specific species
- Red listed species
- Species composition

In addition, I will through the calcareous grassland complete method, investigate immediate effects of management actions on calcareous grassland in the four localities that underwent first-time management actions in 2022.

I hypothesize that the calcareous grassland complete monitoring method detects a more diverse variety of effects from management actions, due to being the method that provide the most detailed data.

2 Methods

2.1 Study area

The study was conducted in the inner Oslofjord, Southeast Norway (Figure1), between June and October 2022. The climate in the study area is described as temperate oceanic with an average temperature of 16.4 ℃ in July and -4.3 ℃ in January (Yr.no, 2022). The weather for the year of data collection was within the precipitation normality with a slightly warmer summer compared to the 1991-2020 normal period (MET, 2022). Calcareous grassland habitats in the Oslofjord region are situated close to some of the most densely populated areas in Norway, and thus are threatened by a high degree of anthropogenic stressors. The prevalence of calcareous grassland in the Oslofjord area is estimated to be approximately 2km^2 (Evju et al., 2018). All of the calcareous grassland habitats in the Oslofjord area are situated in the boreonemoral vegetation zone, and through this are listed as endangered (EN) on the national red list of habitats (Evju et al., 2018). Approximately half of the calcareous grassland habitats in the Oslofjord region are situated in a conservation area (Regjeringen, 2020).

2.2 Study localities

The data collection took place on 20 unique localities (Figure 1). The main criterium for selecting the localities were 1) existing information on whether management had been implemented, and 2) that the localities were part of the ongoing "Monitoring of dry calcareous grasslands"-project (Evju et al., 2020b). The localities in my project were each mapped once by the project either in 2020, 2021, or 2022 (Evju et al., 2020b; Evju et al., 2021; Evju et al., 2022c). I made efforts to pair localities with and without management actions, so that they were comparable through three criteria: geographical proximity, easily accessible with public transport and locality size. These criteria resulted in 20 localities, ten with management actions and ten without management actions. The average size of the localities is 1556 m^2, with the smallest being 326 m^2 and the largest 6800 m^2. A total of 9 localities were situated in conservation areas. For more information regarding the localities see appendix 1.

Information concerning localities with management actions was collected through the County Governor, and the City of Oslo, Agency for City Environment. The information consisted in most part of annual management reports. The reports included information on how long the localities had undergone management actions, which methods were used, the extent of the challenge the locality had (e.g., abundance of invasive species), and suggestions for the next years' management action method. The "Monitoring of dry calcareous grasslands"-project provided data for localities and included shapefiles delineating the localities. The shapefiles were uploaded in Q-GIS (Q-GIS Development Team, 2022).

In addition to the previously mentioned 20 localities, a set of four localities (Bleikøya, Loffen, Padda and Torvøya) was selected to analyze short-term effects of management actions that was to be implemented for the first time in 2022. Information on planned actions was collected through the County Governor. The average size of these localities was 825m^2 and were all situated in conservation areas. None of the four localities had previously been mapped by the "Monitoring of dry calcareous grasslands"-project. See appendix 1 for more details.

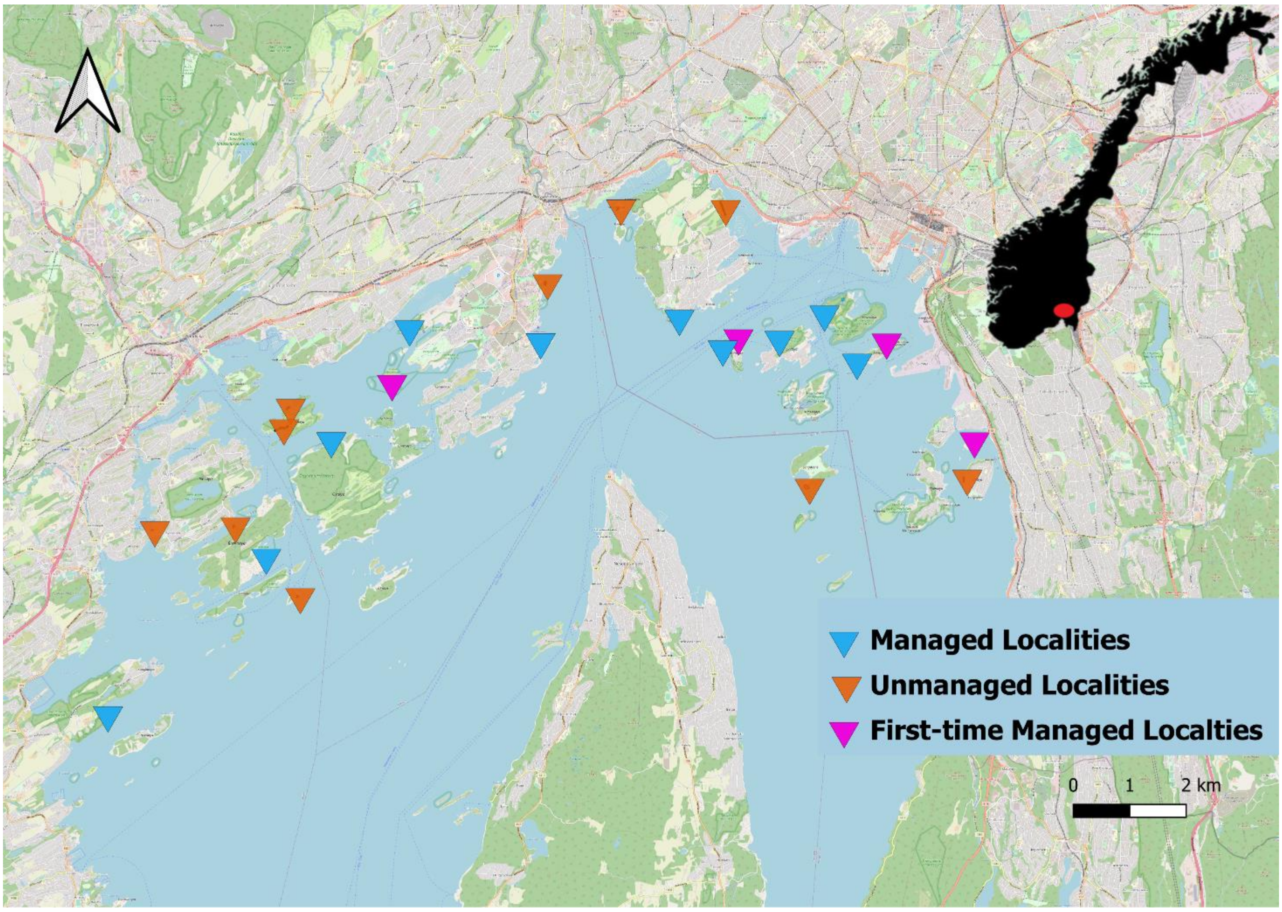

FIGURE 1. MAP SHOWING LOCALITIES OF DATA SAMPLING IN THE OSLOFJORD AREA, NORWAY. EACH TRIANGLE REPRESENT A LOCALITY OF DRY CALCAREOUS GRASSLAND WITH EITHER HISTORY OF MANAGEMENT ACTIONS (BLUE), NO HISTORY OF MANAGEMENT ACTIONS (ORANGE) OR WHERE MANAGEMENT ACTIONS STARTED UP THE SUMMER OF 2022 (PINK).

2.3 Monitoring methods

The following sections present the four monitoring methods that was used for data collection. The order of the method-descriptions is presented from least- to most comprehensive, in terms of 1) number of variables estimated, 2) scale of data collection, and 3) time use. The four monitoring methods were conducted in all the localities, either by myself (NatStat, calcareous grassland reduced, NiN) or by personnel from Norwegian Institute for Nature Research (NINA) (calcareous grassland complete).

2.3.1 NatStat monitoring

NatStat is a monitoring method developed by the Norwegian Environment Agency to provide a tool for regional management authorities when monitoring habitat quality in conservation areas (Miljødirektoratet, 2020). The NatStat system first asks the management authorities to define quantifiable ecological goals for habitat quality for a locality, and then to choose indicators and monitoring methods to evaluate the progress towards these goals. According to the NatStat instructions, sampling of data can be conducted through transects or observation points (Miljødirektoratet, 2020). I adapted the NatStat method by establishing a 20 meter transect line with three observation points at each locality. The observation points were placed ten meter apart and marked the beginning, the middle, and the end of the transect line. At each observation point I recorded the percentage cover of invasive- and red listed plant species within a 5m radius circle (see Figure 2). Invasive species were limited to include the categories: Severe Impact (SE), High Impact (HI), and Potential High Impact (PH) according to the Norwegian List of Invasive species (Artsdatabanken, 2018). Red listed species included species in the categories: Critical (CR), Endangered (EN), Vulnerable (VU), and Near Threatened (NT) according to the Norwegian Red List of species (Artsdatabanken, 2021). To make the method comparable between localities, I did not identify ecological goals for each locality.

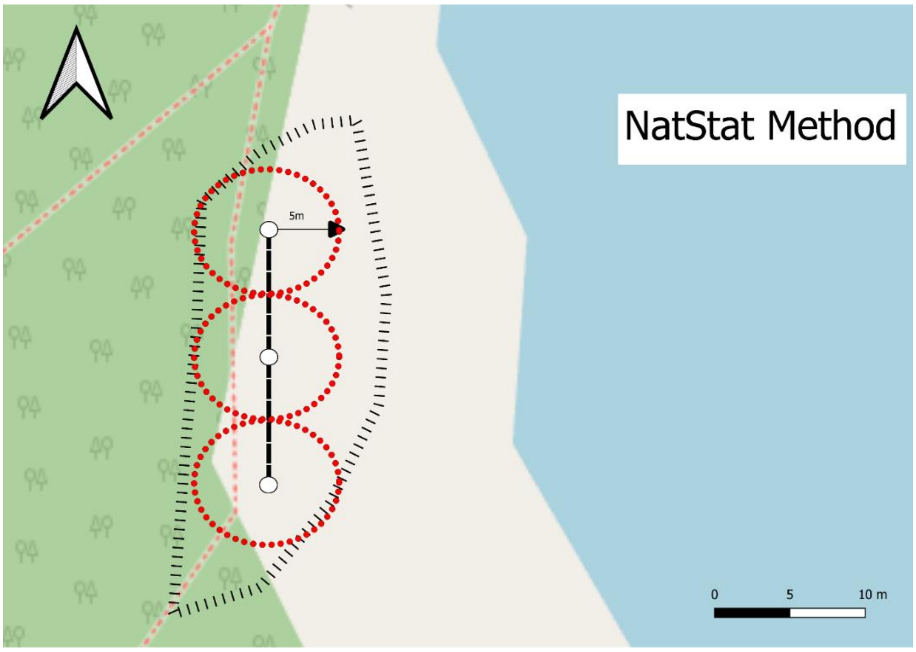

FIGURE 2. NATSTAT METHOD: TRANSECT LINE (STAPLED), WHERE PERCENTAGE COVER OF INVASIVE- AND RED LISTED VASCULAR PLANT SPECIES ARE REGISTERED FOR EVERY TEN METERS (WHITE DOTS) WITHIN A FIVE METER RADIUS CIRCLE (RED RING). THE METHOD PROVIDES DATA IN THREE CIRCLES FOR EACH LOCALITY.

2.3.2 Calcareous grassland reduced monitoring method

The calcareous grassland reduced monitoring method is a simplified version of the calcareous grassland complete monitoring method developed by the Norwegian Institute of Nature Research (NINA) for the "Monitoring of dry calcareous grasslands"-project. The method is conducted through walking transects established systematically with 10m distances, covering the locality (Evju et al., 2021). For every ten meter along the transect, the occurrence of all invasive- and red listed vascular species (as defined above, ch. 2.3.1) within a 5m radius circle is recorded (see Figure 3). The calcareous grassland reduced monitoring method provides occurrence and frequency data for invasive-, red listed species for the complete locality.

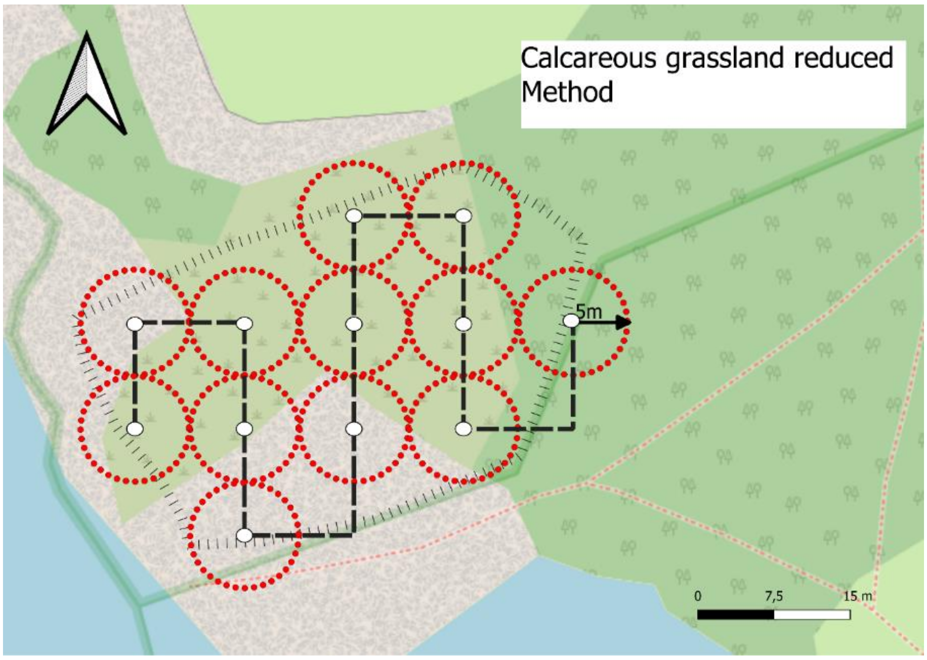

FIGURE 3. CALCAREOUS GRASSLAND REDUCED METHOD: TRANSECT LINE (STAPLED), WHERE PRESENCE OF INVASIVE- AND RED LISTED VASCULAR PLANT SPECIES ARE REGISTERED FOR EVERY TEN METERS (WHITE DOTS) WITHIN A FIVE METER RADIUS CIRCLE (RED RING) FOR THE COMPLETE LOCALITY.

2.3.3 NiN mapping by the Norwegian Environment Agency's instructions

The NiN mapping method by the Norwegian Environment Agency's instructions is based on the Natur I Norge (NiN) mapping method developed by Artsdatabanken (Bryn, 2020). I have conducted the NiN mapping method as described in the mapping instructions provided by the Norwegian Environment Agency (Miljødirektoratet, 2022). In addition to delineating the habitat itself, the NiN method by the Norwegian Environment Agency's instruction aims to define a quality score to each locality (Miljødirektoratet, 2022). After delineation of the locality in field, one estimates the score of a set of variables representing 1) locality condition and 2) biodiversity. For calcareous grasslands, the locality condition is represented by 1) invasive species abundance, 2) soil erosion, 3) signs of vehicle tracks, 4) man-made objects, and 5) shrub cover, with each of the variables assessed at the locality level. The biodiversity score for calcareous grassland represented by 1) the number of habitat-specific species (a list of 30 vascular plants that are defining for the habitat, see: Miljødirektoratet, 2022), 2) the number of red listed species, and 3) size of the locality. The condition- and biodiversity score are together combined into a locality quality score. See table 1 for how variables are registered, and Miljødirektoratet (2022) for complete method instructions.

Table 1. Complete overview of how variables by the NiN method are registered (Miljødirektoratet, 2022).

Variable	Score:	Method:
Invasive species abundance	1-6	The score is estimated in an eight-scale ordinal variable, where level 1 represents a locality without invasive species, level 2 has one or two invasive species, and level 6 has only invasive species.
Soil erosion	0-3, X	The score is estimated in a four-scale ordinal variable of how many 2x2m plots in the locality that show signs of erosion: 0=0, 1=0–-$\frac{1}{16}$, 2=$\frac{1}{16}$-$\frac{1}{2}$, 3= >$\frac{1}{2}$, and X= not assessed.
Signs of vehicle tracks	0-3, X	The score is estimated in a four-scale ordinal variable of how many 2x2m plots in the locality that show signs of vehicle tracks: 0=0, 1=0–-$\frac{1}{16}$, 2=$\frac{1}{16}$-$\frac{1}{2}$, 3= >$\frac{1}{2}$, and X= not assessed.
Man-made objects	Yes/No	Registration of type of object in addition to presence/not presence of man-made objects.
Shrub cover	0-8	Shrub cover, i.e., the cover of woody plants between 0.8 and 2m height, is estimated in a nine-scale ordinal variable: 0=0%, 1=0-2.5%, 2=2.5-5%, 3=5-10%, 4=10-25%, 5=25-50%, 6=50-75%, 7=75-90%, and 8=>90%.
Habitat-specific species richness	High, moderate, low	Score is given based on how many unique habitat-specific species found in locality. High = >11, moderate = 6-11, low = <6.
Red listed species richness	High, moderate, low	Score is given based on how many unique red listed species based on the red list category found in locality. High = ≥4NT or ≥1 VU/EN/CR, moderate = 2-3 NT, low = ≤NT or ≥ 1 DD or none, red listed species observed.
Size of locality	High, moderate, low	Score is based on the size of locality, which is given when the locality is delineated in field. High = >1000m^2, moderate = 500-1000m^2, low = <500m^2.

2.3.4 Calcareous grassland complete monitoring method

The calcareous grassland complete monitoring method is developed by the Norwegian Institute of Nature Research to monitor and estimate the occurrence, distribution, and qualitative status of dry calcareous grassland in the Oslofjord area (Evju et al., 2020b; Evju et al., 2021). The calcareous grassland complete method collect data from permanent vegetation plots and from circles surrounding the plots, with number of plots corresponding to the size of the locality; <1000m^2: 5 plots, 1000-2000m^2: 10 plots, and >2000m^2: 15 plots. The vegetation plots are 0,5×0,5m and the circles surrounding the plots have a 5m radius from the center of the plot. The coordinates of the vegetation plots are saved with a high-precision GPS marker, and the plots are then photographed from above and from south, east, north, west to make future revisiting of the plots easier. Within each vegetation plot percentage cover of each vascular plant occurring, field layer, moss, lichen, dead organic matter, and bare rock is estimated. In the circle surrounding the plots, percentage cover of the following variables are estimated: tree layer (>2m), shrub layer (0,8-2m), wooden species in field layer (<0,8m), invasive species (SE, HI, PH), bare rock, soil erosion, vehicle tracks, and identification and presence of man-made objects.

2.4 Data collection

Upon visiting the localities, I cross-checked the delineation of each locality to the provided shapefile using Touch GIS (Touch GIS, 2022), on an iPad (Apple, 2022) in field. For the four localities that were to undergo management actions the for the first time in 2022, delineation of the localities was conducted in cooperation with NINA in field.

I conducted the NatStat method according to the method description. When conducting the method, the center point of the locality was chosen in field and marked with a pin. In the majority of the localities the transect stretched from north to south through the center point. However, in those localities where this was not feasible due to size limitations or due to obvious deviant in species composition than the rest of the locality, the transect direction was altered east- or westward to detect a better representation of the locality. At each observation point a circle with a radius of 5 meter was established. Within the circle, identification, and percentage cover of red listed (CR, EN, VU, NT) and invasive species (SE, HI, PH) was estimated. If the circles stretched beyond the confined habitat, percentage estimations were descaled to match the habitat covered by the circle. The method was altered in one of the localities due to the locality's figuration. In this locality, the distance between observation points was reduced to 8 meters, and the circles surrounding the observation points had a radius of 4 meters.

To conduct the calcareous grassland reduced monitoring method, red listed- (CR, EN, VU, NT), invasive- (SE, HI, PH) vascular plant species were systematically registered along transects according to the instructions in Evju et al. (2020b). Data for this method was registered on an IPAD in the Touch GIS software. Due to inconsistency of accurate GPS-coordinates of the observations, I had difficulties with differentiating registrations of species between the observation points. Therefore, I standardized the frequency of the species by dividing the number of times each species was observed by the area of the locality.

The NIN-method was conducted according to method descriptions (chapter 2.3.3). In addition to the registration of variables, I made lists of all habitat-specific-, red listed- and invasive species that was observed in the locality. The condition and biodiversity score by the method, was combined to set a locality quality score.

Data collected through the calcareous grassland complete monitoring method in 2020, 2021 and 2022 were made available by NINA for my thesis. However, data were only available for 19 localities, thus, one locality was excluded from analyses of data from the complete method (136-1, appendix 1). In the four localities that were to undergo management actions for the first-time summer of 2022, I collected data according to the method in collaborations with NINA (Evju et al., 2022a).

For the four localities that underwent management actions the first-time summer of 2022, localities were visited prior-, during-, and post implementation of actions. All four monitoring methods were conducted by NINA personnel and me in the four localities prior to implementation of actions. For investigations of short-term effects of management actions, it was decided to only conduct and include the calcareous grassland complete method post management actions. This decision was based on that management actions were completed in October, and any differences in species analyses would likely be a result from seasonal effects rather than from effects of management. During implementation of actions, the localities were visited multiple times to gather first-hand information of how instructions were passed down from management authorities to practitioners, what and how management methods were conducted, and the extent of resource use in each locality. See appendix 2 for more details.

2.5 Statistical analyses

In order to investigate if the different monitoring methods detected difference in condition and biodiversity of unmanaged vs. managed localities, I analyzed the datasets with the desktop version of R and R.Studio (version 4.1.2; R. Core Team, 2021) with packages dplyr (Wickham, et al., 2023a), tidyr (Wickham, et el., 2023b), and Kendall (McLeod, 2022). The mixed model tests, either Glmm-TMB (Brooks, et al., 2017) or lmer (Bates, et al., 2015), were residual checked through the dHARMa package (Hartig, 2022). The presentation of untransformed data in boxplots was designed in ggplot2 (Wickham, 2016) and organized in cowplot (Wilke, 2020).

To investigate if there was systematic difference in size between unmanaged and managed localities, I performed a t-test with management actions as independent variable and locality size as predictor variable. There was no such difference and locality size was not used in further analyses.

All tests were run with management action (yes/no) as independent variable. For the calcareous grassland reduced- and the NiN-method, one sample per locality was available (n=20). One sample per locality was also used in all the four methods for analyses of difference in species richness between managed vs. unmanaged localities. Welsch's t-test (paired) was used in analyses where one sample per locality was used.

The datasets from the NatStat- and calcareous grassland complete-method included several samples per locality, and general linear mixed-effects models was used with locality included as a random variable to account for spatial dependency of samples within each locality. Before the tests were run, I accounted for zero-inflated data by adding zi-fomula~1 in the mixed-effects models, in the tests were predictor variables contained many zero values.

For several tests, transformations of predictor variables were necessary to meet the assumptions of linearity, normality, and homogeneity of variance. Log transformations, both natural and common, were done to variables where values were left skewed, to make distribution more normal. Transformations of /0.1 were done to transform variables into integer values, in order to complete the mixed-effect model tests. In the few models where the residual check provided a significant result for Levene's test, variance of the data was investigated to validate the model. See appendix 3 for information of how variables were tested by which method, including data transformations.

2.5.1 Shrub cover and soil erosion

Investigation of difference in shrub cover and soil erosion between unmanaged and managed localities was done for the NiN- and the calcareous grassland complete method. For the NiN method, the shrub cover variable was tested through Welsch's t-test, without any transformations. For the calcareous grassland complete method, data for erosion was zero-inflated, both variables were log10 transformed and analyzed in a mixed-effect model with Gaussian distribution.

2.5.2 Invasive species

All four methods were used for investigating difference in abundance and richness of invasive species between unmanaged and managed localities. For the NatStat method (zero-inflated data), percentage cover of invasive species (/0.1 transformed) and richness of invasive species were analyzed through mixed-effects model with a Poisson distribution error. For the calcareous grassland reduced method, frequency of invasive species (log transformed) and number of invasive species (untransformed) recorded by the "reduced" method were analyzed with Welsch's t-test. For the NiN method, the difference in score (untransformed) and richness (log transformed) was tested by Welsch's t-test. For the calcareous grassland complete method, abundance data was zero-inflated. The difference in cover of invasive species in plots was log10 transformed and analyzed as Gaussian distribution in a mixed-effects model. Difference in cover of invasive species in circles was /0.1 transformed and tested as a negative binomial distribution in a mixed-effect model. The difference in richness of invasive species in plots was analyzed by Welsch's t-test without any transformations made.

2.5.3 Habitat-specific species

Investigations of the difference in abundance and richness of habitat-specific species between managed- and unmanaged localities, was done with the NiN- and the calcareous grassland complete method. Two response variables were tested for each method. Richness of habitat-specific species was analyzed by Welsch's t-test, without any transformations made, in both methods. For the NiN method, score of habitat-specific species (log10 transformed) was tested with Welsch's t-test. By the calcareous grassland complete method, cover of habitat-specific species (zero-inflated and log10 transformed) in plots was analyzed as mixed-effects model with a Poisson distribution.

2.5.4 Red listed species

Investigations of difference in abundance and richness of red listed species was done in all four methods. For the NatStat method (zero-inflated data), the difference in percentage cover of red listed species was log10 transformed and analyzed with mixed-effects model. The difference in number of red listed species was analyzed by Welsch's t-test without any transformations made. For the calcareous grassland reduced- and the NiN method, the difference in frequency-/score- and number of red listed species in the localities was analyzed by Welsch's t-test. The number of red listed species in the NiN method was log transformed before the test was performed. For the calcareous grassland complete method, the difference in percentage cover of red listed species (zero-inflated and /0.1 transformed) was analyzed with a negative-binominal distribution in a mixed-effects model. The difference in number of red listed species was analyzed by Welsch's t-test without any transformations.

2.5.5 Species composition

In order to investigate the difference of species composition between managed and unmanaged localities, I used data collected through the calcareous grassland complete method and made subset lists of species detected in the vegetation plots. Subsets were divided into invasive-, red listed-, habitat-specific- and total species lists, but due few observations within the respective species subsets which resulted in incomplete datasets, it was decided to only analyze the habitat-specific- and the total species subset. For the habitat specific species 17 rows were emitted, which provided a sample size of 158, and one row was emitted for the total species, which resulted in a sample size of 174. The analyses were done through a global non-metric multidimensional scaling (GNMDS) plot with two ordination axes. A linear mixed-effects model (lmer) was used to analyze the first axis in the GNMDS plot. I used the plot ordination score along the first ordination axis as response variable and management actions (yes/no) as independent variable. Locality was included as a random factor to account for spatial dependency of samples within each locality.

2.5.6 First-time managed localities

For the four localities that underwent management actions first-time summer 2022, data from the calcareous grassland complete method was used to analyze short-term effects of management actions on shrub-, erosion- and invasive species percentage cover within 5m radius circles with a generalized mixed-effect model. Time, in terms of before and after management actions, was used as response variable and locality was added as a random variable to account for spatial dependency of samples within each locality (n=90, groups=4). The response variables were transformed (/0.1) and run with a negative binomial distribution.

3 Results

3.1 Locality condition

3.1.1Shrub cover

Shrub cover was generally low across localities; with the NiN method median shrub cover score was 2.0 and 1.0 in managed and unmanaged localities, respectively, whereas with the calcareous grassland complete method, median shrub cover was 5% (managed) and 3% (unmanaged) (Figure 4A+B). None of the monitoring methods showed significant differences in shrub cover between unmanaged and managed localities (Table 2, Table 3).

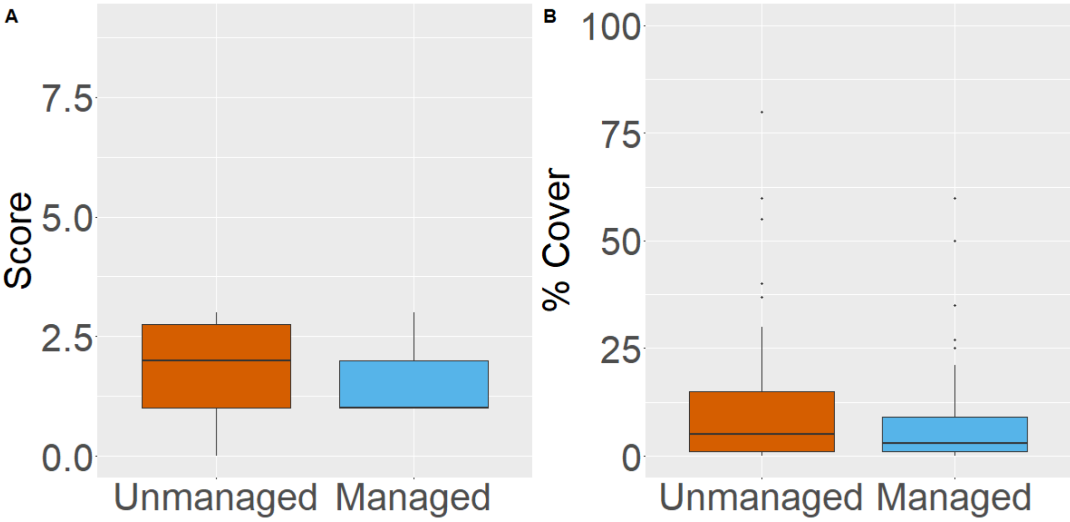

FIGURE 4. SHRUB COVER OF DRY CALCAREOUS GRASSLANDS IN INNER OSLOFJORD DIFFERENTIATED BY UNMANAGED- (ORANGE) AND MANAGED (BLUE) LOCALITIES. 4A SHOW SHRUB COVER SCORE (ORDINAL VARIABLE, AT THE LOCALITY SCALE) AS RECORDED BY THE NIN-METHOD AND 4B SHOW SHRUB COVER (NOMINAL VARIABLE, PERCENTAGE COVER IN CIRCLES) AS RECORDED BY THE CALCAREOUS GRASSLAND COMPLETE-METHOD. THE BOLD LINE IN THE BOXES REPRESENTS THE MEDIAN AND THE VERTICAL LINES REPRESENT LOWER AND UPPER QUARTILE.

TABLE 2. EFFECTS OF MANAGEMENT ACTIONS (YES/NO) ON SHRUB COVER SCORE (ORDINAL VARIABLE, LOCALITY SCALE) RECORDED BY THE NIN METHOD ON 20 LOCALITIES OF DRY CALCAREOUS GRASSLAND IN THE INNER OSLOFJORD AREA, TESTED WITH WELCH'S PAIRED-TEST. SEE APPENDIX 3 FOR VARIABLE TRANSFORMATIONS.

Shrub cover		t(df)	t-value	p-value
NiN	Managed vs. unmanaged	14.88	0.48	0.650

TABLE 3. EFFECTS OF MANAGEMENT ACTIONS (YES/NO) ON SHRUB COVER (% COVER, 5M-RADIUS CIRCLES) RECORDED BY THE CALCAREOUS GRASSLAND COMPLETE (COMPLETE) METHOD ON LOCALITIES OF DRY CALCAREOUS GRASSLAND IN THE INNER OSLOFJORD AREA, TESTED WITH MIXED-EFFECTS MODEL (GLMM-TMB). INTERCEPT REPRESENTS AVERAGE SHRUB COVER IN UNMANAGED LOCALITIES. SEE APPENDIX 3 FOR VARIABLE TRANSFORMATIONS.

Shrub cover		Estimate	SE	z-value	p-value
Complete	Intercept	1.58	0.21	7.46	<0.001
	Managed vs. unmanaged	0.17	0.31	0.57	0.570

3.1.2 Soil erosion

Median score for soil erosion recorded with the NiN method was 2 in unmanaged localities and 1 in managed localities (Figure 5A), and median cover of erosion recorded with the calcareous grassland complete method, was 6% for unmanaged- and 15% for managed localities (Figure 5B). Neither of the methods showed significant difference in cover of erosion between unmanaged and managed localities (Table 4, Table 5).

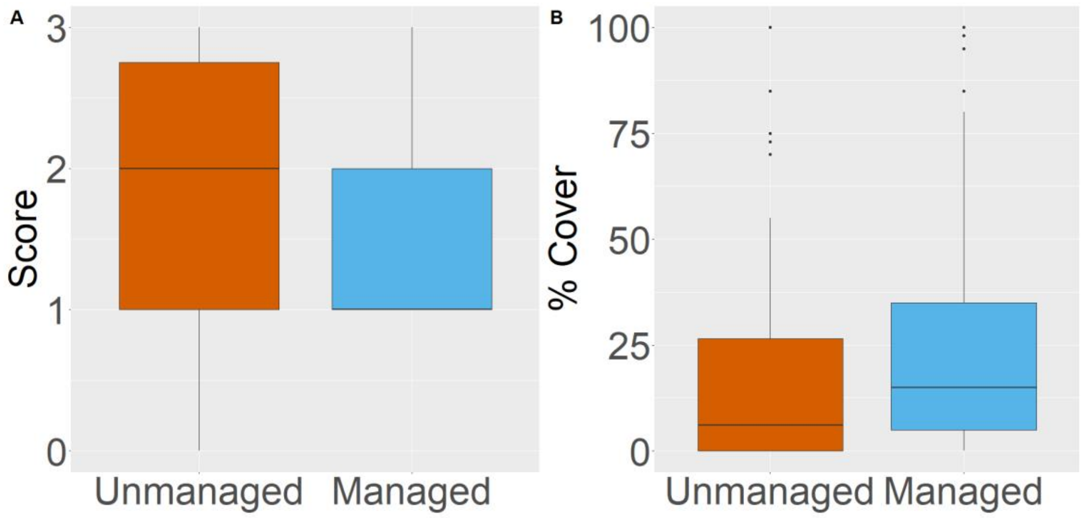

FIGURE 5. SOIL EROSION OF DRY CALCAREOUS GRASSLANDS IN INNER OSLOFJORD DIFFERENTIATED BY UNMANAGED- (ORANGE) AND MANAGED (BLUE) LOCALITIES. 5A SHOW SOIL EROSION SCORE (ORDINAL VARIABLE, AT THE LOCALITY SCALE) AS RECORDED BY THE NIN-METHOD AND 5B SHOW SOIL EROSION COVER (NOMINAL VARIABLE, PERCENTAGE COVER IN CIRCLES) AS RECORDED BY THE CALCAREOUS GRASSLAND COMPLETE-METHOD. THE BOLD LINE IN THE BOXES REPRESENTS THE MEDIAN AND THE VERTICAL LINES REPRESENT LOWER AND UPPER QUARTILE.

TABLE 4. EFFECTS OF MANAGEMENT ACTIONS (YES/NO) ON SOIL EROSION SCORE (ORDINAL VARIABLE, LOCALITY SCALE) RECORDED BY THE NIN METHOD ON LOCALITIES OF DRY CALCAREOUS GRASSLAND IN THE INNER OSLOFJORD AREA, TESTED WITH WELCH'S PAIRED-TEST. SEE APPENDIX 3 FOR VARIABLE TRANSFORMATIONS.

Erosion		**t(df)**	**t-value**	**p-value**
NiN	Managed vs. unmanaged	14.881	0.47	0.648

TABLE 5. EFFECTS OF MANAGEMENT ACTIONS (YES/NO) ON SOIL EROSION (% COVER, 5M RADIUS CIRCLES) RECORDED BY THE CALCAREOUS GRASSLAND COMPLETE (COMPLETE) METHOD ON LOCALITIES OF DRY CALCAREOUS GRASSLAND IN THE INNER OSLOFJORD AREA, TESTED WITH MIXED-EFFECTS MODEL (GLMM-TMB). INTERCEPT REPRESENTS AVERAGE SOIL EROSION COVER IN UNMANAGED LOCALITIES. SEE APPENDIX 3 FOR VARIABLE TRANSFORMATIONS.

Erosion		**Estimate**	**SE**	**z-value**	**p-value**
Complete	Intercept	1.75	0.43	4.08	<0.001
	Managed vs. unmanaged	0.67	0.62	1.08	0.281

3.1.3 Invasive species

Cover of invasive species was significantly higher, as detected by NatStat and calcareous grassland complete method (by circles) (p=0.025 and p=0.048 respectively, Table 6), in unmanaged- (median cover 14.0% and 4.0%, respectively. Figure 6C) than in managed localities (median cover 2.5% and 0.1%, respectively. Figure 6C). Cover of invasive species in vegetation plots (complete method) was low and similar for both unmanaged and managed localities, (median cover 0%, Figure 6C) with no significant difference between them (p=0.603, Table 6).

Frequency of invasive species, as measured by the calcareous grassland reduced method, (median frequency 0.006 and 0.011, in managed vs. unmanaged localities respectively, Figure 6A) showed close to a significant difference between unmanaged and managed localities (p=0.070, Table 7). Score of invasive species, by the NiN method (ordinal variable) showed the same median (3, Figure 6B) in both unmanaged and managed localities, with no significant difference between unmanaged- and managed localities (p=0.344, Table 7).

Richness of invasive species as measured by the NatStat method was low and showed the same median (3 species) for both managed- and unmanaged localities (p= 0.830. Figure 8D). The same median of invasive species richness (5.5, Figure 6D) in unmanaged- and managed localities, and showed no significant difference between the groups (p=0.889, Table 7). Richness of invasive species by the NiN method was 5.5 and 6 species, in unmanaged and managed localities respectively (Figure 6D), with no significant difference between the two groups (p=0.562, Table 7).

Richness of invasive species as measured by the calcareous grassland complete method within the vegetation plots was low (median 1.5 and 1, for unmanaged and managed localities respectively, Figure 6D), and showed no significant difference for managed vs. unmanaged localities (p=0.810, Table 7).

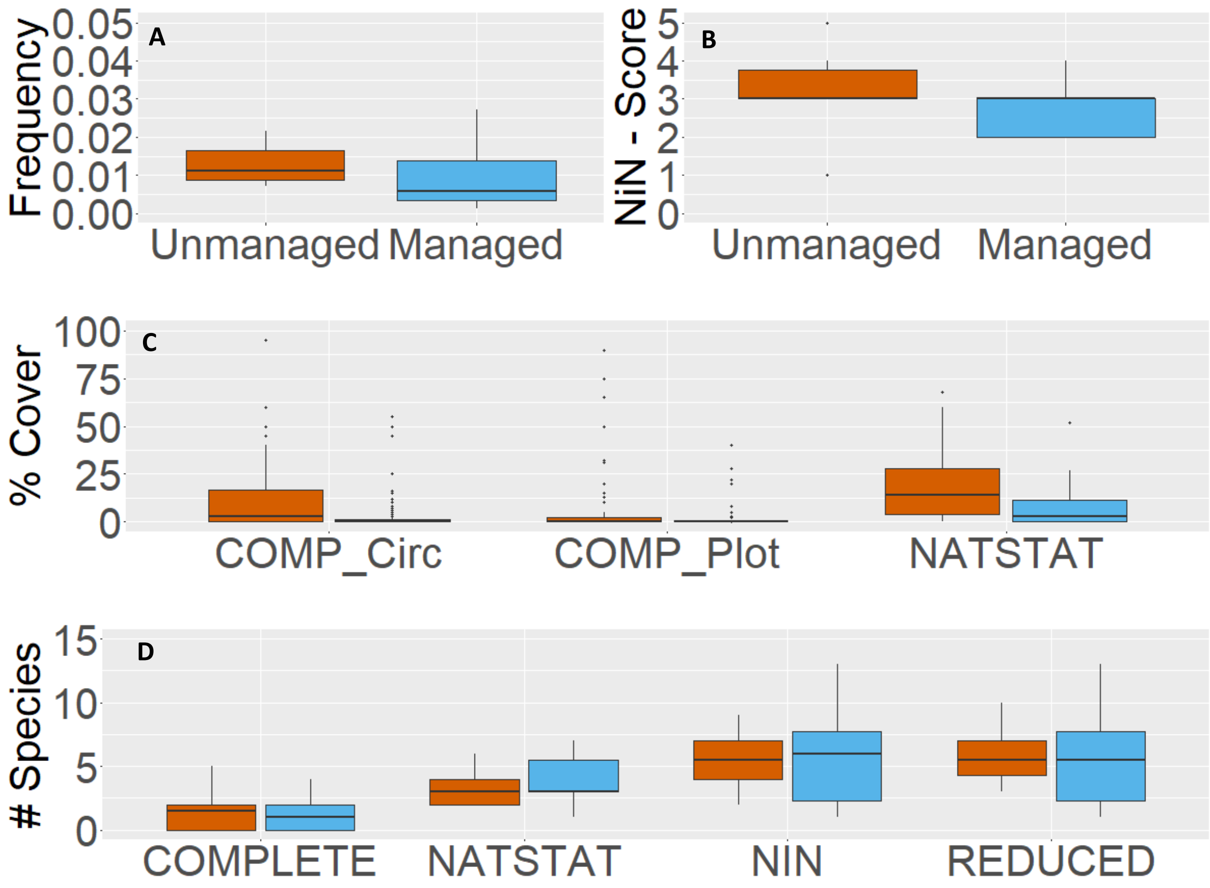

Figure 6. Untransformed presentation of invasive species abundance and richness in unmanaged (orange)- and managed (blue) localities of dry calcareous grassland in the Inner Oslofjord area. 6A show invasive species frequency (nominal variable, at the locality scale) as recorded by the calcareous grassland reduced-method, 6B show invasive species score (ordinal variable, locality scale) as recorded by the NiN-method, 6C show cover (%) of invasive species by the NatStat (within 5 meter circles)- and the calcareous grassland complete (both within 5m radius circles (Comp_Circ) and 0.25m^2 vegetation plots (Comp_Plot)) method, and 6D show richness (#) of invasive species by the NatStat-, calcareous grassland reduced-, NiN- and calcareous grassland complete method at the locality scale. The bold line in the boxes represents the median and the vertical lines represent lower and upper quartile.

Table 6. Effects of management actions (yes/no) on abundance (% cover), and richness (#) of invasive species recorded by the NatStat- and calcareous grassland complete (Complete) method on localities of dry calcareous grassland in the Inner Oslofjord area, tested with mixed effects-models (Glmm-TMB). Intercept represents average invasive species cover/richness in unmanaged localities. See appendix 3 for variable transformations.

Invasive species			**Estimate**	**SE**	**z-value**	**p-value**
NatStat	Cover	Intercept	5.09	0.46	11.00	<0.001
		Managed vs. unmanaged	-1.50	0.67	-2.24	0.025
NatStat	Richness	Intercept	0.59	0.17	3.38	<0.001
		Managed vs. unmanaged	-0.05	0.25	-0.21	0.830
Complete	Cover plot	Intercept	1.97	0.44	4.50	<0.001
		Managed vs. unmanaged	-0.35	-0.52	-0.52	0.603
Complete	Cover circle	Intercept	4.31	0.52	8.33	<0.001
		Managed vs. unmanaged	-1.52	0.76	-1.98	0.048

TABLE 7. EFFECTS OF MANAGEMENT ACTIONS (YES/NO) ON ABUNDANCE (FREQUENCY/SCORE), AND RICHNESS (#) OF INVASIVE SPECIES RECORDED BY THE CALCAREOUS GRASSLAND REDUCED- (REDUCED) AND THE NIN METHOD ON LOCALITIES OF DRY CALCAREOUS GRASSLAND IN THE INNER OSLOFJORD AREA, TESTED WITH WELSCH'S PAIRED T-TEST. SEE APPENDIX 3 FOR VARIABLE TRANSFORMATIONS.

Invasive species			**t(df)**	**t-value**	**p-value**
Reduced	Frequency	Managed vs. unmanaged	11.45	1.99	0.070
	Richness	Managed vs. unmanaged	13.50	0.14	0.889
NiN	Score	Managed vs. unmanaged	16.83	0.97	0.344
	Richness	Managed vs. unmanaged	12.69	0.60	0.562
Complete	Richness	Managed vs. unmanaged	16.80	0.24	0.810

3.2 Biodiversity

3.2.1 Habitat-specific species

The calcareous grassland complete method detected a higher richness of habitat-specific species in managed- compared to unmanaged localities (p=0.016, Table 8), with a median of 9.5 and 7.5 species, respectively (Figure 7C). The median richness of habitat-specific species by the NiN method was 10 in the managed- and 8 species in the managed localities (Figure 7C), and the method showed no significant difference (p=0.130) between unmanaged and managed localities. Median score of habitat-specific species by the NiN method was 0 in the managed- and 1 in the unmanaged localities (Figure 7B), with close to a significant difference between them (p=0.064. Table 8). Measured by the calcareous grassland complete method, the median cover of habitat-specific species in vegetation plots showed tendency, though not significantly (p=0.702, Table 9) to be higher in the managed- compared to the unmanaged localities (median cover was 10% vs. 3% respectively, Figure 7A).

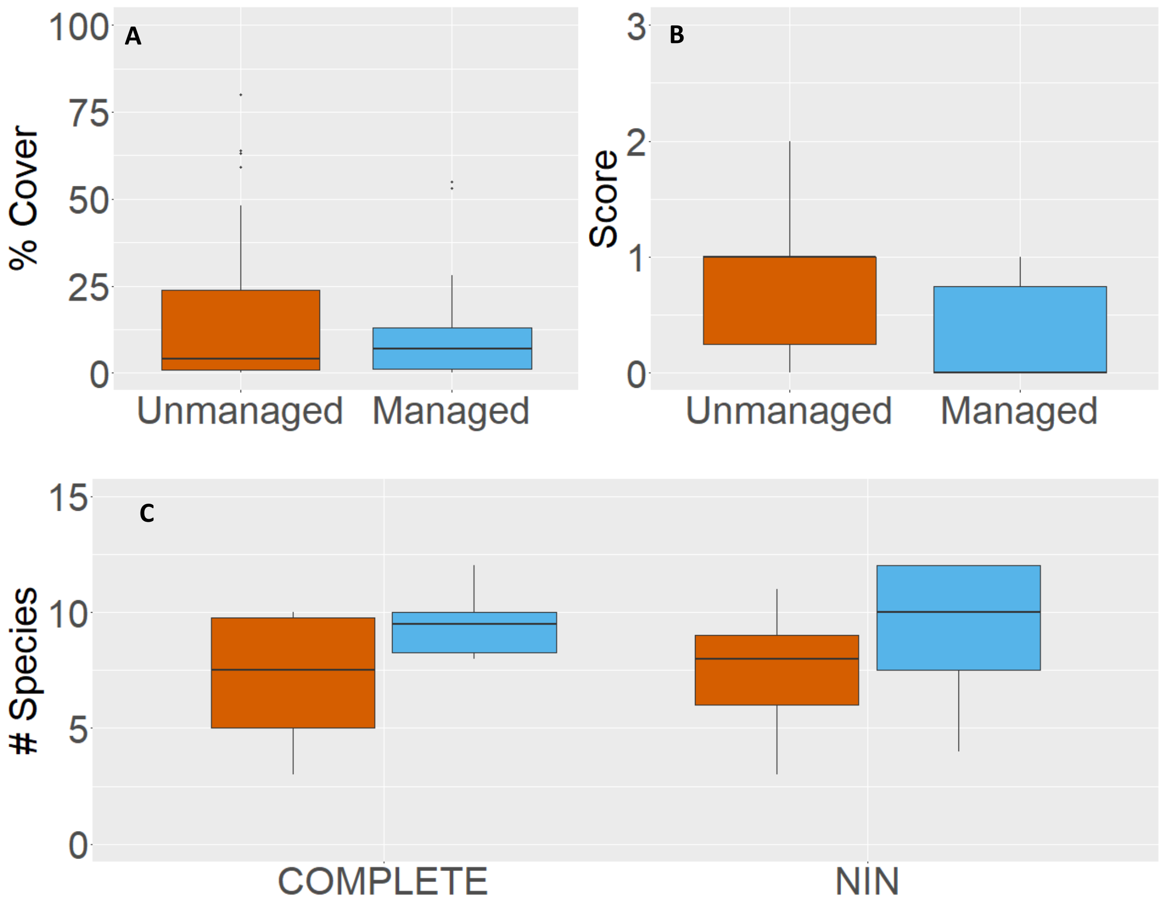

FIGURE 7. UNTRANSFORMED PRESENTATION OF HABITAT-SPECIFIC SPECIES ABUNDANCE AND RICHNESS IN UNMANAGED- (ORANGE) AND MANAGED (BLUE) LOCALITIES OF DRY CALCAREOUS GRASSLAND IN THE INNER OSLOFJORD AREA. 7A SHOW COVER (%) OF INVASIVE SPECIES BY THE CALCAREOUS GRASSLAND COMPLETE (WITHIN 0.25M^2 VEGETATION PLOTS) METHOD, 7B SHOW HABITAT-SPECIFIC SPECIES SCORE (ORDINAL VARIABLE, LOCALITY SCALE) AS RECORDED BY THE NIN-METHOD, , AND 7C SHOW RICHNESS (#) OF INVASIVE SPECIES BY THE NIN- AND CALCAREOUS GRASSLAND COMPLETE METHOD AT THE LOCALITY SCALE. THE BOLD LINE IN THE BOXES REPRESENTS THE MEDIAN AND THE VERTICAL LINES REPRESENT LOWER AND UPPER QUARTILE.

TABLE 8. EFFECTS OF MANAGEMENT ACTIONS (YES/NO) ON SCORE (ORDINAL VARIABLE, LOCALITY SCALE)-, AND RICHNESS (#) OF HABITAT-SPECIFIC SPECIES RECORDED BY THE NIN- AND THE CALCAREOUS GRASSLAND COMPLETE (COMPLETE) METHOD ON LOCALITIES OF DRY CALCAREOUS GRASSLAND IN THE INNER OSLOFJORD AREA, TESTED WITH WELSCH'S PAIRED-TEST. SEE APPENDIX 3 FOR VARIABLE TRANSFORMATIONS.

Habitat-specific species			t(df)	t-statistic	p-value
NiN	Score	Managed vs. unmanaged	17.67	1.97	0.064
NiN	Richness	Managed vs. unmanaged	17.58	-1.59	0.130
Complete	Richness	Managed vs. unmanaged	12.30	-2.78	0.016

TABLE 9. EFFECTS OF MANAGEMENT ACTIONS (YES/NO) ON COVER (% COVER IN 0.25M^2 VEGETATION PLOTS) OF HABITAT-SPECIFIC SPECIES RECORDED BY THE CALCAREOUS GRASSLAND COMPLETE (COMPLETE) METHOD ON LOCALITIES OF DRY CALCAREOUS GRASSLAND IN THE INNER OSLOFJORD AREA, TESTED WITH MIXED-EFFECTS MODELS (GLMM-TMB). INTERCEPT REPRESENTS AVERAGE HABITAT-SPECIFIC SPECIES COVER IN UNMANAGED LOCALITIES. SEE APPENDIX 3 FOR VARIABLE TRANSFORMATIONS.

Habitat-specific species			Estimate	SE	z-value	p-value
Complete	Cover	Intercept	1.78	0.22	8.27	<0.001
		Managed vs. unmanaged	0.12	0.31	0.38	0.702

3.2.2 Red listed species

Results by NatStat method showed a significant higher richness of red listed in managed- compared to unmanaged localities, as detected by the NatStat method (median richness 10 and 6 species, respectively, Figure 8C, p=0.036. Table 11). In addition, there was a trend towards higher richness of red listed species in managed localities, as measured by the calcareous grassland reduced- and NiN methods, (calcareous grassland reduced p=0.064 and NiN p=0.084. Table 11). Median richness of red listed species in managed- and unmanaged localities were 10.5 and 8 species for the calcareous grassland reduced and the NiN method respectively (Figure 8C).

Median cover of red listed species by the NatStat method was 7.5% and 10.15% in unmanaged and managed localities respectively (Figure 8B), with no significance shown (p=0.162, Table 10). Further, frequency of red listed species, as measured by the calcareous grassland reduced method was 0.0231 and 0.0252 unmanaged and managed localities, respectively (Figure 10A), with no significance difference found (p=0.747, Table 11).

Analyses of cover- and richness by the calcareous grassland complete method (in plots), provided results with no significant difference between managed and unmanaged localities (cover p=0.186, richness p= 0.158. Table 10 and 11). Median cover- and richness of red listed species by the calcareous grassland complete method, was 1% and 4.5 species respectively in unmanaged-, and 4% and 6 species in managed localities (Figure 8A+B). Abundance (score) of red listed species by the NiN method was left out analyses, because all localities (both managed and unmanaged) showed the same score.

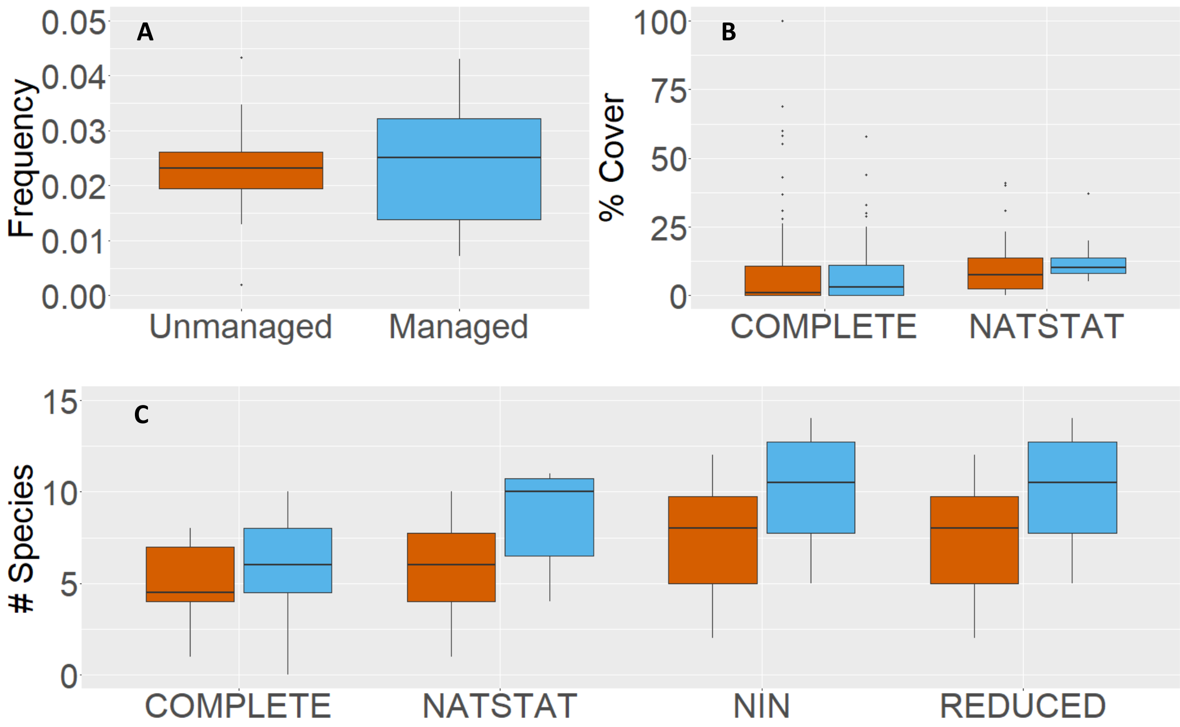

Figure 8. Untransformed data of red listed species abundance and richness in unmanaged- (orange) and managed (blue) localities of dry calcareous grassland in the Inner Oslofjord area. 8A show red listed species frequency (nominal variable, at the locality scale) as recorded by the calcareous grassland reduced-method, 8B show cover (%) of red listed species by the NatStat (within 5m radius circles)- and the calcareous grassland complete (within 0.25m^2 vegetation plots) method, and 8C show richness (#) of red listed species by the NatStat-, calcareous grassland reduced-, NiN- and calcareous grassland complete method at the locality scale. The bold line in the boxes represents the median and the vertical lines represent lower and upper quartiles.

Table 1. Effects of management actions (yes/no) on abundance (% cover) of red listed species recorded by the NatStat- and calcareous grassland complete (Complete) method on localities of dry calcareous grassland in the Inner Oslofjord area, tested with mixed-effects models (Glmm-TMB). Intercept represents average red listed species cover in unmanaged localities. See appendix 3 for variable transformations.

Red listed species			Estimate	SE	z-value	p-value
NatStat	Cover	Intercept	2.07	0.19	11.15	<0.001
		Managed vs. unmanaged	0.36	0.26	1.39	0.162
Complete	Cover	Intercept	4.85	0.20	24.19	<0.001
		Managed vs. unmanaged	-0.36	0.27	-1.32	0.186

Table 11. Effects of management actions (yes/no) on frequency, and richness (#) of red listed species recorded by the NatStat-, calcareous grassland reduced (Reduced)-, NiN, and the calcareous grassland complete (Complete) method on localities of dry calcareous grassland in the Inner Oslofjord area, tested with Welsch's paired-test. See appendix 3 for variable transformations.

Red listed species			t(df)	t-value	p-value
NatStat	Richness	Managed vs. unmanaged	17.92	-2.78	0.036
Reduced	Frequency	Managed vs. unmanaged	17.77	-0.33	0.747
Reduced	Richness	Managed vs. unmanaged	17.99	-1.97	0.064
NiN	Richness	Managed vs. unmanaged	17.99	-1.73	0.084
Complete	Richness	Managed vs. unmanaged	16.85	-1.48	0.158

3.2.3 Species composition.

Analyses with the calcareous grassland complete dataset, showed no significant difference in habitat-specific- or total species composition between unmanaged- and managed localities. The species subsets of habitat-specific- and total species composition was measured by the plot score, against the ordination axes (first axis: p=0.990 and p=0.477, respectively. Table 12).

TABLE 12. EFFECTS OF MANAGEMENT ACTIONS (YES/NO) ON SPECIES COMPOSITION AGAINST FIRST AXIS (GNMDS1) IN ORDINATION PLOTS BY THE CALCAREOUS GRASSLAND COMPLETE (COMPLETE) METHOD ON LOCALITIES OF DRY CALCAREOUS GRASSLAND IN THE INNER OSLOFJORD AREA, TESTED WITH MIXED-EFFECTS MODELS (LMER). ANALYSES WERE DONE SEPARATELY FOR SUBSET LISTS OF HABITAT-SPECIFIC- AND TOTAL SPECIES COMPOSITION. INTERCEPT REPRESENTS AVERAGE SPECIES COMPOSITION SCORE AGAINST AXIS GNMDS1 FOR UNMANAGED LOCALITIES.

Species composition			Estimate	SE	z-value	p-value
Habitat-specific	gnmds1	Intercept	0.01	0.11	0.11	0.910
		Managed vs. unmanaged	-0.002	0.17	-0.01	0.990
Total	gnmds1	Intercept	0.035	0.08	0.4	0.665
		Managed vs. unmanaged	-0.08	0.12	-0.73	0.477

3.3 Short-term effect analyses

Analyses of short-term effects within the 5m radius circles, of management actions for the four localities that underwent management actions for the first-time summer 2022, detected a significant (p<0.001, Table 13) lower cover of invasive species post actions (median cover = 28% and 5%, prior- and post actions respectively, Figure 9C). Analyses of management actions on percentage shrub cover, showed close to a significant effect (p=0.073, Table 13) with higher cover prior than post actions (median = 5% and 4% respectively, Figure 9A). There was a low cover of soil erosion both prior and post management actions (median=0%, Figure 9B) in the four localities and no significant effect (p= 1, Table 13) of management actions on erosion was found.

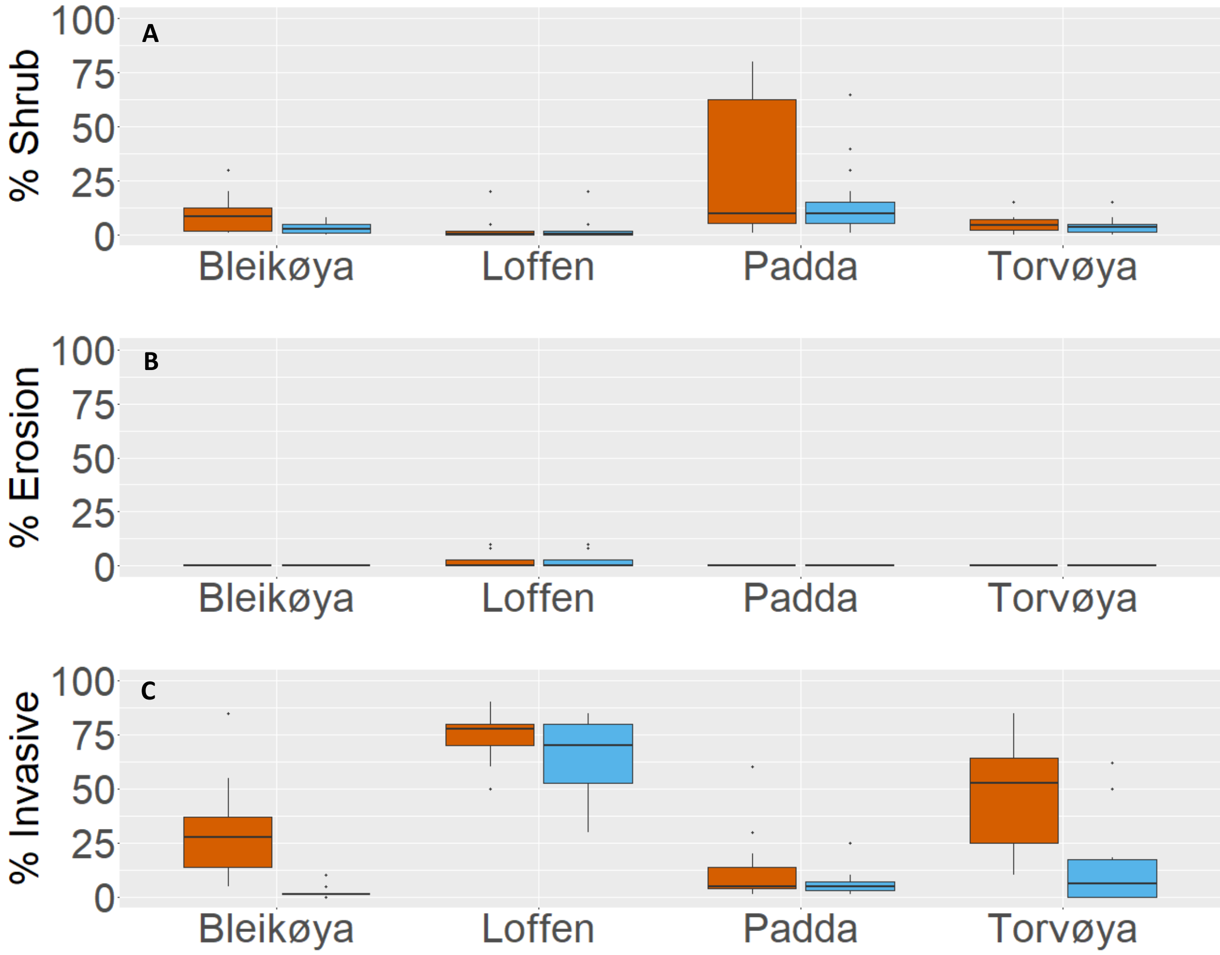

FIGURE 9. UNTRANSFORMED DATA OF SHRUB- (A), EROSION-(B) AND INVASIVE SPECIES (C) PERCENTAGE COVER SAMPLED BY THE CALCAREOUS GRASSLAND COMPLETE METHOD WITHIN 5M RADIUS CIRCLES, PRIOR- (ORANGE) AND POST (BLUE) MANAGEMENT ACTIONS IN FOUR LOCALITIES OF DRY CALCAREOUS GRASSLAND IN THE INNER OSLOFJORD AREA. X-AXIS PRESENTS DATA PER LOCALITY. THE BOLD LINE IN THE BOXES REPRESENTS THE MEDIAN AND THE VERTICAL LINES REPRESENT LOWER AND UPPER QUARTILES.

TABLE 13. EFFECTS OF MANAGEMENT ACTIONS (YES/NO) ON COVER (% COVER, IN 5M RADIUS CIRCLES) OF SHRUB, -EROSION AND -INVASIVE SPECIES SPECIES RECORDED BY THE CALCAREOUS GRASSLAND COMPLETE METHOD ON LOCALITIES OF DRY CALCAREOUS GRASSLAND IN THE INNER OSLOFJORD AREA, TESTED WITH MIXED-EFFECTS MODELS (GLMM-TMB). PREDICTOR VARIABLES WERE /0.1 TRANSFORMED AND ANALYZED WITH A NEGATIVE BINOMIAL DISTRIBUTION. INTERCEPT REPRESENTS AVERAGE INVASIVE COVER IN UNMANAGED LOCALITIES.

Cover		Estimate	SE	z-value	p-value
Shrub	Intercept	4.52	0.41	11.05	<0.001
	Managed vs. unmanaged	-0.56	0.31	-1.79	0.073
Erosion	Intercept	-0.01	5.06	-2.19	0.028
	Managed vs. unmanaged	-0.01	9.33	0.00	1.000
Invasive species	Intercept	5.88	0.44	13.33	<0.001
	Managed vs. unmanaged	-0.99	0.25	-3.97	<0.001

4 Discussion

4.1 Did the monitoring methods detect effects on locality condition and biodiversity?

4.1.1 Locality condition

The main finding in my thesis is that a higher cover of invasive species can be detected in unmanaged vs. managed localities by two of the monitoring methods: NatStat- and the calcareous grassland complete method by the circles. Common for these methods is the use of 5m-radius circles in which cover is estimated. Recording abundance at the locality level through frequency with the calcareous grassland reduced method detected near significant higher frequency of invasive species in unmanaged localities, while abundance differences were not detected by small-scale vegetation plots (calcareous grassland complete method). Further, recording abundance at the locality level with an ordinal scale (the NiN method) did not detect any significant difference.

Explanations for why the NiN method does not seem to provide the same results as the other methods may be because ordinal data will benefit from different analyses than quantitative data. Conversion of cover data from quantitative (e.g. 0-100%) to ordinal values, like with the NiN method, may be subjected to problems regarding analyses, such as multivariate analysis (Podani, 2006), and it is debated whether if and how ordinal data should be transformed prior to analyses (e.g., Ricotta & Feoli, 2013; McNellie et al., 2019), For the calcareous grassland complete method, explanations for the different result of invasive species abundance between vegetation plots and the circles is more likely to be caused by the sampling scale. In Otypková & Chytry (2006), the authors suggest that it is difficult to detect difference in species composition through small-scale vegetation plots, and further, that correlation between environment variables and vegetation, increase with the size vegetation plots (Reed et al., 1993). The difference in scale of sampling through $0.25m^2$ vegetation plots and 5m-radius circles is on a 1:314 ratio, therefore, it might not be surprising that the calcareous grassland complete method will provide different data based on the scale of sampling.

Distribution of invasive species in calcareous grasslands as well as in other native environments can often be described as patchy, with invasions spreading in from neighboring disturbed sites, such as gardens, roads, and tracks (Emry et al., 2011; Daugstad et al., 2018). Small, even if spread out, sampling plots may miss aggregated clutches of invasive species (Huebner, 2007). Data collected by small spatial scales, like from the calcareous grassland complete method by the vegetation plots, is the most common sample scale for monitoring of invasive species (Kettenring & Adams, 2011). Sampling by small-scale- compared to larger vegetation plots is often considered more reliant, as estimations of abundance- and identification of species in larger plots will easier lead to misidentification and overlooking of species with low abundance (Archaux et al., 2009). However, my thesis points to that larger sample plots are needed to detect species with clutched distribution pattern. In addition, Ogden & Rejmánek (2005) found that adapting results from small-scale sampling into answers for how to conduct restoration actions on a locality-level may be challenging for management due to post-restoration processes, such as secondary invasions or disturbance of native species. Conclusively, my thesis points to that optimizing relevance for management would include estimations of invasive species through bigger spatial plots.

Further, the difference in median cover of invasive species in the 5m-radius circles between the NatStat- and the calcareous grassland complete method (chapter 3.1.3) could be explained by placement of sample plots. In the calcareous grassland complete method, the sampling plots are randomly placed within the locality, whilst in the NatStat method the plots are situated next to each other. Sampling in adjacent plots may be seen as increasing the spatial sample scale, and because of the invasive species clutched distribution pattern, hence more likely to detect higher cover.

The lack of detecting effects for shrub cover and erosion is most likely connected to management practice than suitability of the monitoring methods. Only half of the managed localities (n=5) had management actions that targeted shrub cover, and none where erosion was targeted (see appendix 2). In contrary, invasive species were targeted in all managed localities and may contribute to explain why I detected significant results between managed- and unmanaged localities.

4.1.2 Biodiversity

There seemed to be higher richness of red listed species in managed- vs. unmanaged localities, significantly when using the NatStat method, whilst the calcareous grassland reduced- and the NiN method pointed towards the same with near significance. The calcareous grassland complete method did not detect any significant difference in red listed species richness but given the result from the analyses of invasive species, it is not unlikely that the method would have provided a different answer if red listed species were measured by 5m-radius circles, instead of by the 0.25m^2 vegetation plots. Nygaard et al. (2011), investigated difference in detection of species richness between 0.25m^2 plots and 5m-radius circles, and found a noticeable gap in higher richness for the 5m-radius circles. The results from Nygaard et al. (2011) are in line with the species-area curve, where species richness increases with locality size at a decreasing rate (e.g., Cain (1938)). Similarly, in my study the number of species detected seemed to be correlated with the size of sampling area and that the 0.25m^2 vegetation plots fail to portray true richness for the localities.

Although the difference in richness within the methods (between unmanaged- and managed localities) seems to vary little, one could argue that data collection on a locality scale will contribute to more complete species lists than when sampling in smaller spatial scales. Least number of species (per locality) was detected by the vegetation plots in the calcareous grassland complete method, and the most by the calcareous grassland reduced- and the NiN-method (Figure 6D, 7C & 8C). Again, this pattern was clearer for invasive species than red listed- and habitat-specific species and so further contributes to the theory that invasive species have a more clutched distribution pattern compared to native species, which are more evenly distributed throughout the habitat. Therefore, methods where small-scale sampling plots are used, are more likely to underestimate invasive- than native species richness in the locality.

Powell et al. (2011) argues that invasive species have a stronger negative effect on general plant species diversity compared to rare plants. Can this provide answers to why the calcareous grassland complete method detected significant result of difference in richness of habitat-specific- but not red listed species, between managed and unmanaged localities? Even if only ten out of the thirty species on the habitat-specific species list are not red listed, it is likely that they have a relative higher abundance compared to the red listed species in the localities (personal observation; e.g. *Polygonatum odoratum)*. Another explanation could be that analyzing more species provide more datapoints, which will lead to increased clarity and certainty in the tests. In line with the results from red listed species, the calcareous grassland complete method detected difference in richness- and not abundance of habitat-specific species. Conclusively, it could be beneficial to include habitat-specific species richness in monitoring of effects from management actions on calcareous grassland habitats, either instead of, or as a supplement to the red listed species richness variable. Here, one should weigh time-consumption of analyzing more species against robustness of data, since habitat-specific species richness provided a more distinct result than richness of red listed species.

Ordination of species-by-plot data from the calcareous grassland complete method showed no difference in species composition between managed and unmanaged localities. It could be the case that cover of invasive species in unmanaged localities is too low to alter species composition, or that there is too little data provided by the small-scale vegetation plots to detect composition differences. In Chytrý & Otýpková (2003), the authors argue that for composition analyses, sample plots in grasslands should be at least $16m^2$ to reduce the chance of stochastic results. Still, another study argues against a minimum sample plot size, giving evidence that difference could be detected also through $0.25m^2$ plots (Auestad et al., 2008). Interestingly, Olsen et al., (2018) detected a significant difference in species composition, and habitat-specific species richness, between various levels of habitat fragmentation using $0.25m^2$ sampling plots in the same study area as my thesis. Viewing these contradictory findings in the light of my thesis raises questions of how both number- and spatial scale of sample plots affect species composition analyses in calcareous grasslands and should be further investigated in future studies.

In summary, my results from locality condition and biodiversity analyses shows that different spatial scales of sampling can lead to different results. Focusing on spatial sample scales, may contribute to direct monitoring of effects from management actions on calcareous grassland projects to sample from a spatial "golden mean". The spatial golden mean would include several sample plots small enough for detecting accurate effects from management, but big enough so that management will not get lost in the details. In addition, the results from invasive- and red listed species may point to that 1) management actions have a hard time eradicating the invasive species, though actions limit their abundance and 2) management facilitate for red listed species richness, though not abundance, indirectly by reducing abundance of invasive species.

4.2 Short-term effects of management actions

Results for the localities that underwent first-time management actions are in line with the results for the other localities. Invasive species were targeted in all four-, shrubs in two-, and erosion in none of the localities, providing significant-, near significant- and no significant difference respectively, before vs. after management actions. Even though I did not analyze data on species level, I observed patterns that could be linked to species results in the other localities. In all four localities invasive species were abundant and the main aim was investigating how different management methods would affect invasive species abundance, though it was less clear if management aimed at complete eradication (personal observation in field). Wooden invasive species (high coverage per plant), largely invasive species of *Cotoneaster sp*, were targeted and removed, while shoots of the same species remained in the locality. Other methods that aimed at controlling the invasive species *Phedimus spurius*, consisted of placing dark tarpaulin mats to prevent photosynthesis and for later to "restart" the vegetation process. The effect of using tarpaulin mats is little investigated in the study area, and upon the timing of placing the mats it was not decided by management exactly how long the mats would stay or whether or not to revegetate with native species after removal. In another one of the localities, herbicide was used to limit *Phedimus spurius*, with little knowledge of how this would affect native species. However, multiple studies have investigated effects from these management methods in similar habitats and could have served as background knowledge prior to the actions being conducted (e.g. Holl et al., 2014; Huguenin-Elie et al., 2011) Unfortunately, both methods of using tarpaulin and herbicide suggests that trial-and-error practices are still commonly in use.

Additionally, no management method was systematically documented by management personnel throughout the process, and it can be clear to see how this makes it hard to estimate effects from the actions. Further, because of little physical documentation, new practitioners involved in the restoration projects have to rely more on oral handed-down information, which may create issues regarding method consistency for the projects (trial-and-error approaches). I have also experienced how restoration projects can benefit from a close follow-up from management personnel with a background in biology/ecology. Restoration work in one of the four first-time localities was contracted by a company that do not specialize in ecological restoration, hence, likely do not understand intuitively details of the project in terms of aims and methods. Inexperience did not seem to provide any problems when supervised- or performed by management personnel with a background in biology, whilst in one event, inexperienced personnel from the contractor targeted native species instead of invasive species when clearing shrubs. In line with Rieger et al. (2014), I want to emphasize that restoration projects highly benefit from being conducted by- or at least in the presence of qualified personnel with a thorough ecological understanding. If this is difficult to achieve, a clear and detailed instruction of method should be made available to all practitioners.

4.3 How can we adapt the monitoring methods to detect effects from management actions?

Contrary to my hypothesis, the calcareous grassland complete monitoring method does not seem to detect a *more diverse* variety of effects from management actions. On the other hand, analyses by the 5m-radius circle scale provide matching results to the NatStat method for both locality condition and biodiversity variables. The different results between plot sizes, indicates that big spatial sample plots ($80m^2$) provide clearer results than smaller plots ($0.25m^2$). Further, both the calcareous grassland reduced- and the NiN method fail to provide any significance but show tendency to many of the same results as the NatStat and the calcareous grassland complete method. One could argue that the lack of clear results is because estimating one value for each variable is a too simple method for detecting effects of management actions. In summary, monitoring of effects from management methods should include several values for the same variable in each locality, and not be summarized into a single value adapted to the locality scale.

The main weakness of my thesis is that the managed localities only serve as a general representation of what the condition and biodiversity of managed localities are, with no data prior to the implementations of management actions at each specific site. Decisions of where to implement management actions could be influenced by both locality condition and biodiversity factors, such as the condition is in better/worse state than the localities not chosen for management, or that the locality is inhabited by umbrella species, increasing the likelihood of implementing management actions. In addition, more practical factors such as accessibility and whether the land is privately- or publicly owned, may also affect decisions of where to conduct management actions. The key point for my thesis, however, is that I do not know what influenced decisions on where to conduct management actions nor the status of the locality before actions were conducted, and therefore could not take any possible dependent factors relating to this into account.

The unknown factor of what the locality status was like prior to management actions, can be solved with documentation (Evju et al., 2022b). Before and after documentation is essential in order to understand what the effects from management actions are (Underwood, 1991), and to take into account environmental conditions related to the year management projects were initiated (Vaughn & Young, 2010). Therefore, it is strongly urged for future management projects to thoroughly document the locality both prior- and post management to ensure that actions contribute to the wanted outcome for the project. For examples of how documentation can be done, look into the four first-time management localities documented by NINA and through my thesis (Evju et al., 2022a).

This thesis seems to detect little effects from management actions through the $0.25m^2$ plots but provides no argument for discontinuing with analyses through this spatial scale in general monitoring projects, such as the "Monitoring of calcareous grassland project" by NINA. It is essential to understand that monitoring of effects is not a substitution to monitoring of habitats, but rather a supplement. Compared to monitoring of effects, in monitoring habitats, one can shift the scope of focus from a single predictor variable (management actions) to use any of the estimated variables in the locality as a predictor. Detailed habitat monitoring opens up for more in-depth analyses of habitat status on a wider scale and may for instance contribute to new policies (Evju et al., 2020b), conservation of biodiversity (de Bello et al., 2010) and understanding of connectivity patterns (Kimberley et al., 2021). In addition, with habitat-monitoring analyzing a range of predictor variables, it may be also easier to detect extent of threats and guide management to where and how actions should be conducted. In summary, since restoration projects should be based on scientific knowledge, habitat-monitoring in calcareous grasslands can be used as valuable background information that management should use when deciding on restoration projects sites, -aims, and -methods (Noss, et al., 2009; Wilson, et al., 2011).

4.4 How can we ensure effective management actions?

The road to success of management actions, whether the target is erosion, invasive species or increasing native biodiversity, is laid before the monitoring efforts takes place. It starts with the planning, and making sure that the planning is in line, ecologically as well as economically, with the aim of the management project. Scientific publications are typically awarded for being broad specter and rarely focus on recommendations for specific management challenges (Matzek et al., 2015). However, there are indications that contribution from academia directed at management should aim to provide readily useful data that focus on methods management should use, and if possible, involve management in research (Young et al., 2005; Kettenring & Adams, 2011). The provided scientific information should be used by management to tie together information and goals for the management project. Doing this may prevent practitioners from using a trial-and-error method, which in invasive plant removal actions is linked to further spread of invasive species (Wolde & Lal, 2018), and facilitation for secondary invasions (Hess et al., 2019). Adapting management methods to knowledge and tying them to goals, is proven effectful through adaptive management (Moore et al., 2011). To separate and focus on management methods that work, from methods that do not work is also relevant for this thesis, as in some cases, I have observed that even when annual management reports state that the condition of the locality is of a lower quality than the year before, there are no sign of reviewing or changing the methods used. Further, since an occurring issue is that management have problems with access to relevant scientific data (Bayliss et al., 2012), a dynamic two-way communication between management and scientists (data providers) will minimize this problem and contribute to more successful management action solutions. In my study, I experienced how interdisciplinary meetings and face-to-face communication, untangled misunderstandings and increased understandings of how different management actions would contribute to a wanted outcome for projects.

Implementing reliant monitoring methods of management actions that consider costs will likely benefit ecosystems in the long term. Restoration projects are commonly limited by funding (Larson et al., 2011); therefore, it is important to consider cost-efficiency also when monitoring the effects of management actions. Successful restoration projects and management actions require long-term financial support as any positive outcome may quickly be lost without follow-up actions (Norton, 2009). Monitoring effects of restoration actions may be "competing" for the same resources as the practical restoration, but while the practical work will be rewarding in terms of tangible changes, monitoring will not provide direct visual effects. Could this be part of the explanation of why so few restoration projects are linked to effect studies? In any case, choosing monitoring method for effect studies based on financial cost can be seen as controversial, because the quality of scientific knowledge is typically linked to extent of sampling. On the other hand, Braun and Reynolds (2012), argue that collecting more variables is not necessarily better. Longer lasting and more sustainable monitoring programs can be achieved with cost-effectiveness, by excluding collinear variables and limiting estimation of variables to what provides useful information with little cost. The importance of knowing "why" a variable is included in a monitoring method is important and will reduce the chance of the “data rich but information poor syndrome” (Likens & Lindenmayer, 2018; Ward et al., 1986). Implementing effect-monitoring methods that limit scale of detail (hence time spent), and limit variables to what is relevant in terms of what management have focused their actions towards, may pose as a restricted, yet logical way to try to sew together management actions and effect-documentation. In my study, this would exclude all registration of variables done in the calcareous grassland complete method by vegetation plots. Excluding this detailed and time-consuming part of the method, will reduce costs and so be easier to implement in management. On the other hand, as with the NiN method in my thesis, a *too* simplified method for monitoring effects will fail to detect effects and prove to be purposeless.

5 Conclusion

In line with the results in my thesis, method for monitoring effects of management actions in dry calcareous grassland should include locality condition variables that are relevant to what type of management method that has been executed in the respective locality, whilst biodiversity variables should include habitat-specific species/red listed species richness for the complete locality. Abundance, in terms of percentage cover, should be sampled from multiple larger plots, such as 3x5m-radius circles, because this provides clearer results than when using small scale plots. For selection of whether to include habitat-specific species richness as a supplement to red listed species richness, one should consider resources spent on sampling time vs. data robustness. It is further important for management to include detailed documentation of what, where, when and how management actions were performed and tie this up to set goals that are wanted outcome for the locality. Finally, management should eagerly look-up existing scientific literature within relevant fields of knowledge prior to planning and conducting of management actions. Following these guidelines will provide a monitoring of effects program that serve management with reliant easy-to-use and relevant data, in addition to being more cost-efficient.

Simplified proposal for monitoring of effects from management actions in localities of dry calcareous grassland:

- Create a project plan and connect variables one wants to investigate to aim and focus of management action. The plan should be based on previous documentation of what, where, how, and when actions have been conducted.
- Choose multiple plots with bigger spatial sampling scale (e.g. 5m radius circles) in the locality for estimations of relevant abundance variables. Placement of the plots should be in areas directly affected by management actions. Always consider including invasive species percentage cover with identification of which species.
- Systematically search the complete locality for red listed and/or habitat-specific species presence.
- Data of management methods and variables collected from effect-monitoring in each individual locality should be well documented and evaluated against the aim for the project. Learnings from evaluation of methods and variables should be easily accessible to management and serve as a management guide to which methods that contribute to desired effects.

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Appendices

Appendix 1

TABLE WITH INFORMATION FOR EACH LOCALITY. PRESENTATION OF LOCALITY'S UNIQUE NAME AND ID-NUMBER, MANAGEMENT ACTIONS YES/NO, WHICH MONITORING METHOD THAT HAS BEEN CONDUCTED, DATE OF DATA COLLECTION IN FIELD, SITUATED IN A PROTECTED AREA (YES/NO), AND SIZE OF LOCALITY (M^2). YES AND NO IS PROVIDED WITH 1 AND 0, RESPECTIVELY.

Locality	Locality ID	Management actions	Calcareous grassland reduced	Calcareous grassland complete	NiN	NatStat	Date of data collection 2022	Protected area	Locality size (m^2)
Ulvøya	75-1	0	1	1	1	1	22/6	0	1032
Bygdøy	72-1	0	1	1	1	1	28/6	0	326
Nesøya	65-2	0	1	1	1	1	21/6	0	402
Holme SV for Saraholmen	46-7	0	1	1	1	1	29/6	1	1080
Borøya N	46-2	0	1	1	1	1	29/6	1	4397
Vesle Killingen	31-1	0	1	1	1	1	28/6	0	1200
Langøyene S	302-2	0	1	1	1	1	5/8	0	1300
Høyerholmen	17-3	0	1	1	1	1	2/7	0	633
Lagmannsholmen	131-1c	0	1	1	1	1	27/6	0	2162
Brønnøya N	110-1	0	1	1	1	1	1/7	0	462
Rolfstangen	95-6a	1	1	1	1	1	25/6	0	3000
Lindøya N	41-1	1	1	1	1	1	23/6	0	627
Huk	204-5	1	1	1	1	1	8/6	1	380
Hovedøya	174-3	1	1	1	1	1	30/6	1	1000
Lilleøya	188-3	1	1	1	1	1	27/6	1	500
Spireodden	167-1	1	1	1	1	1	24/6	1	6800
Nakholmen	136-1	1	1	0	1	1	30/6	1	1400
Viernbukta	122-2	1	1	1	1	1	29/6	1	3050
Bleikøya SV	112-1	1	1	1	1	1	23/6	0	1482
Oustøya	106-3	1	1	1	1	1	2/7	1	786
Bleikøykalven	1.1	1	1	1	1	1	9/6, 18/8, 2/9	1	850
Padda	2.1	1	1	1	1	1	10/6, 15/8, 18/8, 1/9	1	900
Loffen	3.1	1	1	1	1	1	1/8, 15/8, 2/9	1	1200
Torvøya	4.1	1	1	1	1	1	17/8	1	800

Appendix 2

TABLE SHOWING INFORMATION FOR MANAGEMENT ACTIONS CONNECTED TO LOCALITY. PRESENTATION OF LOCALITY'S UNIQUE NAME AND ID-NUMBER, AUTHORITY IN CHARGE OF MANAGEMENT, MANAGEMENT METHOD (WEEDING, SHRUB CLEARING, HERBICIDE, TARPAULIN), WHAT MANAGEMENT FOCUSED THEIR ACTIONS ON (TARGETED), FREQUENCY OF MANAGEMENT, AND RESOURCE USE FOR THE FOUR FIRST-TIME LOCALITIES (HOURS SPENT). YES AND NO IS PROVIDED WITH 1 AND 0, RESPECTIVELY.

Locality	Locality ID	Management authority*	Weeding invasive species	Shrub clearing	Herbicide	Tarpaulin mats	Invasive species targeted	Soil erosion targeted	Shrub layer targeted	Frequency of managment**	Approximately hours spent on restoration
Rolfstangen	95-6a	Bærum kommune	1	1	1	0	1	0	1	2	?
Lindøya N	41-1	BYM	1	0	0	0	1	0	0	3	?
Huk	204-5	BYM	1	0	0	0	1	0	0	3	?
Hovedøya	174-3	BYM	1	0	0	0	1	0	0	3	?
Lilleøya	188-3	SFOV	1	0	0	0	1	0	0	2	?
Spireodden	167-1	SFOV	1	1	1	0	1	0	1	2	?
Nakholmen	136-1	BYM	1	0	0	0	1	0	0	2	?
Viernbukta	122-2	SFOV	1	1	0	0	1	0	1	2	?
Bleikøya SV	112-1	BYM	1	0	0	0	1	0	0	2	?
Oustøya	106-3	SFOV	1	0	0	0	1	0	0	2	?
Bleikøya	1.1	BYM	1	1	0	1	1	0	1	?	400
Padda	2.1	BYM	1	1	0	0	1	0	1	?	1100
Loffen	3.1	BYM	1	0	0	1	1	0	0	?	30
Torvøya	4.1	SFOV	1	0	1	1	1	0	0	?	150

* BYM = Oslo kommune Bymiljøetaten, SFOV = Statsforvalteren i Oslo og Viken
** 1= <1 per year, 2= 1-2 per year, 3= >2 per year

Appendix 3

PRESENTATION OF HOW VARIABLES BY METHOD WERE TESTED IN ANALYSES. MANAGEMENT ACTIONS REPRESENTS THE PREDICTOR VARIABLE. LOG TRANSFORMATIONS OF THE RESPONSE VARIABLES WERE DONE TO VARIABLES WHERE VALUES WERE LEFT SKEWED, TO MAKE DISTRIBUTION MORE NORMAL, AND /0.1-TRANSFORMATION TO TRANSFORM VARIABLES INTO INTEGER VALUES. RESPONSE VARIABLES IN THE MIXED MODELS WERE EITHER TESTED WITH A GAUSSIAN, POISSON DISTRIBUTION OR NEGATIVE BINOMINAL DEPENDING ON DATA DISTRIBUTION. LAST COLUMN SHOW NUMBER OF OBSERVATIONS (N)- AND NUMBER OF GROUPS AFTER ADDING LOCALITY AS A RANDOM VARIABLE.

Response Variable	Method	Variable type	Transformation	Test	Distribution	n (groups)
Shrub cover	NiN	Ordinal	-	Welsch's t-test (paired)	-	20
Shrub cover	Complete	Continuous	log10 (x+1)	Glmm-TMB	Gaussian	175 (19)
Soil erosion score	NiN	Ordinal	-	Welsch's t-test (paired)	-	20
Soil erosion	Complete	Continuous	log10 (x+1)	Glmm-TMB	Gaussian	175 (19)
Invasive species cover	NatStat	Continuous	/0.1	Glmm-TMB	Poisson	60 (20)
Invasive species number	NatStat	Count	-	Glmm-TMB	Poisson	60(20)
Invasive species frequency	Reduced	Continuous	log	Welsch's t-test (paired)	-	20
Invasive species number	Reduced	Count	-	Welsch's t-test (paired)	-	20
Invasive species score	NiN	Ordinal	-	Welsch's t-test (paired)	-	20
Invasive species number	NiN	Count	log	Welsch's t-test (paired)	-	20
Invasive species cover plot	Complete	Continuous	log10 (x+1)	Glmm-TMB	Gaussian	175(19)
Invasive species cover circle	Complete	Continuous	/0.1	Glmm-TMB	Negative binominal	175(19)
Invasive species number	Complete	Count	-	glmer	Poisson	18
Habitat-specific species score	NiN	Ordinal	log10 (x+1)	Welsch's t-test (paired)	-	20
Habitat-specific species number	NiN	Count	-	Welsch's t-test (paired)	-	20

Habitat specific species cover	Complete	Continuous	log10 (x+1)	Glmm-TMB	Gaussian	175(19)
Habitat-specific species number	Complete	Count	-	Welsch's t-test (paired)	-	19
GNMDS axis score from habitat-specific	Complete	Continuous	-	lmer	Normal	158(19)
GNMDS axis score from total species	Complete	Continuous	-	lmer	Normal	174(19)
Red listed species cover	NatStat	Continuous	log10 (x+1)	Glmm-TMB	Gaussian	60(20)
Red listed species number	NatStat	Count	-	Welsch's t-test (paired)	-	20
Red listed species frequency	Reduced	Continuous	-	Welsch's t-test (paired)	-	20
Red listed species number	Reduced	Count	-	Welsch's t-test (paired)	-	20
Red listed species score	NiN	Ordinal	-	Welsch's t-test (paired)	-	20
Red listed species number	NiN	Count	log	Welsch's t-test (paired)	-	20
Red listed species cover	Complete	Continuous	/0.1	Glmm-TMB	Negative binominal	175(19)
Red listed species number	Complete	Count	-	Welsch's t-test (paired)	-	19

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