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The condition of forest and mountain ecosystems in Norway

Assessment by the IBECA method

Erik Framstad, Anders L. Kolstad, Signe Nybø, Joachim Töpper and Vigdis Vandvik

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Abstract

Framstad, E., Kolstad, A. L., Nybø, S., Töpper, J. & Vandvik, V. 2022. The condition of forest and mountain ecosystems in Norway. Assessment by the IBECA method. NINA Report 2100. Norwegian Institute for Nature Research.

In 2016, the Ministry of Climate and Environment appointed an expert group to develop a system for assessing the ecological condition of terrestrial and marine ecosystems in Norway. Following the expert group's report, further projects were conducted to make the proposed system operational. This report covers the first national assessments of the ecological condition of forest and mountain ecosystems. The assessments are performed according to the Index-Based Ecological Condition Assessment (IBECA) approach. Empirical indicators have been developed for each of seven ecosystem characteristics that describe the structure, functions and productivity of ecosystems. To facilitate integration across indicators, the value of each indicator is rescaled to a common scale between 0 and 1, and with a limit for good ecological condition set to a scaled value of 0.6. The indicators may then be aggregated into indices for each of the seven ecosystem characteristics, as well as an overall index for the condition of the ecosystem. Indicators have a scaled value of 1 for the reference condition, an intact ecosystem with little impact from direct drivers, and a scaled value 0 in a severely degraded ecosystem. We also compile data for various direct drivers of ecosystem change and other data to assess the causes of reduced ecosystem condition and the robustness of our conclusions.

The assessment of ecosystem condition for forests is based on 13 indicators, resulting in an overall value of 0.42, clearly below the limit for good ecological condition (0.6). Six indicators contribute especially to this low value (scaled values in parentheses): *large carnivores* (0.05), *coarse woody debris* (0.04), *dead wood total* (0.13), *rowan-aspen-goat willow* (0.15), *area without technical infrastructure* (0.18) and *biologically old forest* (0.24). The indicator values for the *nature index for forests* (0.41) and *bilberry cover* (0.47) are also well below the limit for good ecosystem condition. Other indicators have scaled values near or above this limit. The ecosystem characteristics *distribution of biomass between trophic levels, functionally important species and biophysical structures, landscape ecological patterns* and *biological diversity* all have condition values below the limit for good condition, whereas the condition values for *primary production* and *abiotic factors* are above this limit. Condition indicators have been assigned to one or more direct drivers of ecosystem change (mean values in parentheses): Land use (forestry, infrastructure development) affects 10 indicators (0.39), climate change (increasing temperatures, longer growing season) affects 7 indicators (0.67), pollution (nitrogen deposition) affects 3 indicators (0.62), direct population management (hunting, culling) affects 2 indicators (0.38) and alien species affects 1 indicator (1). There are only minor differences in condition values between different regions. We lack data for developing indicators for the characteristic *functional composition within trophic levels* and have no or very short time series for all indicators. Despite inadequate indicator coverage, we have a high confidence in the conclusion that the condition of forest ecosystems are degraded, due to very low values for several indicators and negative current trends for key drivers like forestry and infrastructure development.

The assessment of ecosystem condition for mountains is based on 19 indicators, resulting in an overall value of 0.68, just above the limit for good ecological condition (0.6). Three indicators have particularly low scaled values (in parentheses): *Arctic fox* (0.04), *small rodents* (0.11) and *wolverine* (0.14). Values for *vegetation heat requirement* (0.44) and *willow grouse* (0.52) are also well below the limit value for good ecosystem condition. Other condition indicators have scaled values at or above the limit value. The ecosystem characteristics *distribution of biomass between trophic levels, functional composition within trophic levels* and *functionally important species and biophysical structures* have values below the limit value for good condition. Condition values are above, but near, the limit value for *biological diversity* and *landscape ecological patterns*, whereas *primary production* and *abiotic conditions* have values well above the limit value. Condition indicators have been assigned to one or more categories of direct drivers of ecosystem change (mean values in parentheses): Land use (grazing, infrastructure development) affects 10 indicators (0.71), climate change (increasing temperatures, longer growing season) affects 15 indicators (0.70), pollution (nitrogen deposition) affects 2 indicators (0.86), direct population management (hunting, culling, population reinforcement) affects 6 indicators (0.46) and alien species affects 1 indicator (1). There are only minor differences in the condition values between different regions. Based on the overall value for ecosystem condition, mountain ecosystems in Norway can be considered as being in good ecological condition. This conclusion is somewhat uncertain, however, due to inadequate indicator coverage, low values for some key indicators and negative trends for key drivers like infrastructure development and climate change.

We further discuss the underpinning of scientific credibility and transparency of the IBECA approach and summarise how the IBECA approach may be used to set management targets and develop empirical approaches for ecosystem accounting. Finally, we describe how the IBECA approach aligns with international frameworks and can help fulfil international reporting on ecosystem condition for Norway.

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Sammendrag

Framstad, E., Kolstad, A. L., Nybø, S., Töpper, J. & Vandvik, V. 2022. Økologisk tilstand for skog og fjell i Norge. Vurdering ved indeksmetoden. NINA Rapport 2100. Norsk institutt for naturforskning.

Klima- og miljødepartementet nedsatte i 2016 en ekspertgruppe for å utvikle et system for vurdering av den økologiske tilstanden til norske terrestriske og marine økosystemer. Etter levering av ekspertgruppens rapport ble det gjennomført ytterligere prosjekter for å gjøre det foreslåtte systemet operativt. Denne rapporten dekker de første nasjonale vurderingene av den økologiske tilstanden for hovedøkosystemene skog og fjell. Vurderingene er utført etter indeksmetoden. Det er utviklet empiriske indikatorer for hver av syv økosystemegenskaper som beskriver strukturen, funksjonene og produktiviteten til økosystemene. For bedre integrasjon på tvers av indikatorer, skaleres verdien av hver indikator til en felles skala mellom 0 og 1, med en skalert grenseverdi for god økologisk tilstand satt til 0,6. Indikatorene kan da sammenstilles til indekser for hver av de syv egenskapene, samt til en samlet indeks for tilstanden til økosystemet. Indikatorer har en skalert verdi 1 i referansetilstanden, et intakt økosystem med liten menneskelig påvirkning, og en skalert verdi 0 i et sterkt forringet økosystem. Vi har også sammenstilt data for ulike påvirkningsfaktorer og andre data for å vurdere årsaker til redusert økosystemtilstand og hvor robuste konklusjonene er.

Vurderingen av økosystemtilstanden for skog er basert på 13 indikatorer, som gir en samlet verdi på 0,42, klart under grensen for god økologisk tilstand (0,6). Seks indikatorer bidrar i særlig grad til denne lave verdien (skalerte verdier i parentes): *store rovdyr* (0,05), *grov død ved* (0,04), *død ved totalt* (0,13), *rogn-osp-selje* (0,15), *arealandel uten teknisk infrastruktur* (0,18) og *biologisk gammel skog* (0,24). Indikatorverdiene for *naturindeksen for skog* (0,41) og *blåbærdekke* (0,47) ligger også godt under grensen for god økologisk tilstand. Andre tilstandsindikatorer har skalerte verdier nær eller over denne grensen. Økosystemegenskapene *fordeling av biomasse mellom trofiske nivåer, funksjonelt viktige arter og biofysiske strukturer, landskapsøkologiske mønstre* og *biologisk mangfold* har alle tilstandsverdier under grensen for god tilstand, mens tilstandsverdiene for *primærproduksjon* og *abiotiske faktorer* ligger over denne grensen. Tilstandsindikatorene er tilordnet en eller flere påvirkningsfaktorer (middelverdier i parentes): Arealbruk (skogbruk, infrastrukturutvikling) påvirker 10 indikatorer (0,39), klimaendringer (økende temperaturer, lengre vekstsesong) påvirker 7 indikatorer (0,67), forurensning (nitrogentilførsel) påvirker 3 indikatorer (0,62), direkte bestandsforvaltning (jakt, uttak) påvirker 2 indikatorer (0,38) og fremmede arter påvirker 1 indikator (1). Det er kun mindre forskjeller i tilstandsverdier for ulike regioner. Vi mangler data for å utvikle indikatorer for egenskapen *funksjonell sammensetningen innen trofiske nivåer* og har ingen eller svært korte tidsserier for alle indikatorer. Til tross for utilstrekkelig indikatordekning, har vi stor tillit til konklusjonen om at tilstanden for skogøkosystemer er forringet, på grunn av svært lave verdier for flere indikatorer og negative trender for viktige påvirkningsfaktorer som skogbruk og infrastrukturutvikling.

Vurderingen av økosystemtilstand for fjell er basert på 19 indikatorer som gir en samlet verdi på 0,68, rett over grensen for god økologisk tilstand (0,6). Tre indikatorer har spesielt lave skalerte verdier (i parentes): *fjellrev* (0,04), *smågnagere* (0,11) og *jerv* (0,14). Verdier for *vegetasjonens varmekrav* (0,44) og *lirype* (0,52) ligger også godt under grenseverdien for god økologisk tilstand. Andre tilstandsindikatorer har skalerte verdier på eller over grenseverdien. Økosystemegenskapene *fordeling av biomasse mellom trofiske nivåer, funksjonell sammensetning innen trofiske nivåer* og *funksjonelt viktige arter og biofysiske strukturer* har verdier under grenseverdien for god tilstand. Tilstandsverdier er over, men nær, grenseverdien for *biologisk mangfold* og *landskapsøkologiske mønstre*, mens *primærproduksjon* og *abiotiske forhold* har verdier godt over grenseverdien. Tilstandsindikatorene er tilordnet en eller flere kategorier av påvirkningsfaktorer (middelverdier i parentes): Arealbruk (beite, infrastrukturutvikling) påvirker 10 indikatorer (0,71), klimaendringer (økende temperaturer, lengre vekstsesong) påvirker 15 indikatorer (0,70), forurensning (nitrogentilførsel) påvirker 2 indikatorer (0,86), direkte bestandsforvaltning (jakt, uttak,

bestandsforsterking) påvirker 6 indikatorer (0,46) og fremmede arter påvirker 1 indikator (1). Det er kun små forskjeller i tilstandsverdiene for ulike regioner. Ut fra den samlete verdien for økosystemtilstand kan fjelløkosystemer anses å være i god økologisk tilstand. Denne konklusjonen er imidlertid noe usikker på grunn av utilstrekkelig indikatordekning, lave verdier for noen nøkkelindikatorer og negative trender for viktige påvirkningsfaktorer som infrastrukturutbygging og klimaendringer.

I rapporten diskuteres også grunnlaget for indeksmetodens vitenskapelige troverdighet og åpenhet og hvordan indeksmetoden kan brukes til å sette forvaltningsmål og i empiriske tilnærminger for økosystemregnskap. Til slutt sammenliknes indeksmetoden med noen andre internasjonale rammeverk og hvordan metoden kan bidra til internasjonal rapportering om økosystemtilstand for Norge.

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Contents

Foreword

The Ministry of Climate and Environment has on behalf of the government, and as a follow-up to Norway's action plan for biodiversity ('*Nature for life'*, Meld. St. 14 (2015-2016)), commissioned the development of a system for assessing the ecological condition of Norwegian terrestrial and marine ecosystems. The work started in 2016 with the appointment of an expert group to develop a framework for such a system. The expert group delivered its recommendations in June 2017. Subsequently, methodologies to implement the proposed framework were developed through projects for operationalisation and testing of the system in 2018 and 2019. NINA has been central in this work. In spring 2020, NINA was asked by the Norwegian Environment Agency to lead the work of assessing the condition of forest and mountain ecosystems for the whole country according to the Index-based ecological condition assessment framework (the IBECA approach). These assessments are published in Norwegian NINA reports (Framstad et al. 2021, 2022).

The assessment of the ecological condition of forest ecosystems was carried out by a working group under the leadership of NINA, with Erik Framstad as project manager. Other participants in the working group have been Anne Sverdrup-Thygeson and Mikael Ohlson from the Norwegian University of Life Sciences (NMBU), Håkan Berglund from the Swedish University of Agricultural Sciences (SLU), and Rannveig Jacobsen, Simon Jakobsson and Joachim Töpper from NINA. This working group started in January 2021 and delivered the assessment for forests to the Norwegian Environment Agency in May 2021.

The assessment of the ecological condition of mountain ecosystems was carried out by a working group under the leadership of NINA, with Erik Framstad as project manager. Other participants in the working group have been Kari Klanderud from NMBU, Vigdis Vandvik from University of Bergen, Wenche Eide from SLU, and Nina E. Eide, Anders Kolstad and Joachim Töpper from NINA. This working group started in May 2021 and delivered the assessment for mountains to the Norwegian Environment Agency in December 2021.

For each assessment, a workshop with external participation was conducted, respectively, in March and November 2021. In addition to contributions from working group members and workshop participants, valuable inputs and comments have been received from several colleagues in NINA and other research institutions.

The current report provides a somewhat condensed English version of the Norwegian reports on the assessments of the condition for forest and mountain ecosystems. In addition, this report contains a chapter discussing management implications of the IBECA approach. This discussion is based on a separate report (Nybø et al. 2020). The work has been conducted by the authors during December 2021 and January 2022. Most of the content relies on the reports for the assessment of the condition for forest and mountain ecosystems. We are especially grateful for the contributions of the working group members responsible for these reports. In addition, we thank Tessa Bargmann, NINA, for help with translating the appendices.

Contact person at the Norwegian Environment Agency has been Eirin Bjørkvoll.

Oslo/Trondheim, January 2022

Erik Framstad/Signe Nybø
(project managers)

Extended summary

In 2016, the Ministry of Climate and Environment appointed a group of experts to develop a framework for assessing the condition of Norwegian terrestrial and marine ecosystems. Based on the expert group's recommendations, the system has since been further developed for national implementation. The assessment of ecosystem condition is based on a comparison of the current condition with a reference condition in an intact ecosystem with minimal human impact. The comparison is made using a set of condition indicators assigned to seven ecosystem characteristics that cover the structure, functions and productivity of ecosystems. The observed values for the indicators are scaled to a common scale between 0 and 1, with scaled value 1 in the reference condition, an intact ecosystem, and 0 for a very degraded ecosystem. For each indicator, a limit value is also specified which indicates whether the indicator shows that the ecosystem is in good condition or not. For scaled indicator values, this limit value is set at 0.6. The scaled values of the indicators are combined to an overall condition value for the ecosystem characteristics and for the entire ecosystem. Condition values above 0.6 are classified as good condition.

This report presents the first national assessments of the condition of forest and mountain ecosystems, based on the IBECA approach (Jakobsson et al. 2020, 2021, Töpper & Jakobsson 2021; cf. chapter 2). The assessment for forest ecosystems is based on 13 indicators and the assessment for mountain ecosystems on 19 indicators. To assess the robustness of the calculated condition values, we have also assessed trends for indicators where time series exist, as well as for relevant anthropogenic drivers and for some supplementary variables.

Condition of forest ecosystems
The results of the assessment of the ecological condition of forest ecosystems are summarized in **Figure A**. The overall condition of forest ecosystems in Norway is estimated at 0.42 (with 95% confidence interval 0.41–0.43). This is clearly lower than 0.6, which is the limit value for good ecological condition. There are only minor differences in the calculated condition values for different regions. Particularly, six indicators contribute to the low overall condition value (scaled values in parentheses): *large carnivores* (0.05), *coarse woody debris* (0.04), *dead wood total* (0.13), *rowan-aspen-goat willow* (0,15), *area without technical infrastructure* (0.18) and *biologically old forest* (0.24). The *nature index for forests* (0.41) and *bilberry cover* (0.47) are also well below the limit value for good ecological condition. Other condition indicators have scaled values near or above this limit value (two-sided indicators with values for lower/upper limit value): *NDVI* (0.88/0.77), *Ellenberg N* (0.55/0.69), *Ellenberg F* (0,76/0.68), *large cervids* (0.71), and *absence of alien species* (1.00). We have no time series for three of the selected indicators and only short time series for the other ten. Except for *area without technical infrastructure*, most indicators with time series show a slight increase. The short time series for supplementary variables vary between slight increases and slight decreases. Two of the supplementary variables, indices for top predators and decomposers, have such low levels that it indicates a substantial deviation from the reference condition.

The aggregated condition values for the ecosystem characteristics are below the limit value for good condition for the following characteristics: *distribution of biomass between trophic levels* (0.38), *functionally important species and biophysical structures* (0.34), *landscape ecological patterns* (0.21) and *biological diversity* (0.41). The condition values for *primary production* (0.70) and *abiotic factors* (0.64) are above this limit value. We have no indicators for the characteristic *functional composition within trophic levels*.

The condition indicators are assigned to one or more main categories of anthropogenic drivers that are assumed to be of great or medium importance for the individual indicators. Ten of the indicators are associated with land use, with a mean condition value of 0.39 (**Figure B**). Various effects of forestry activities, as well as impacts from buildings and technical infrastructure, are considered as the main reasons for the low condition level in forests. This is in line with the significant extent of forestry activities and land affected by technical infrastructure. Seven of the

indicators are associated with climate change, with a mean condition value of 0.67. Increases in temperature and length of the growing season since about 1990 are considered as most important, but the effects of such changes are currently shown to a limited extent for our indicators. Three indicators are associated with impacts from pollution in the form of nitrogen deposition, with a mean condition value of 0.62. However, the relationship between the ecological condition values and the geographical distribution of nitrogen deposition over time is weak. Two indicators are associated with direct population management, with a mean condition value of 0.38. Especially population control of large carnivores contributes to a low value. For elk and red deer, numbers of felled animals show great coincidence with population abundances. There is only one indicator associated with the impact of alien species, absence of alien species, with a value of 1. This does not capture the occurrence of alien tree species in forestry, possibly due to few data points in regions with such species.

The reliability of the results is assessed against the indicators' coverage of the ecosystem characteristics, the underlying data, and the certainty of the assessments. This is summarized in **Table A**. The indicators cover relevant aspects of all characteristics except *functional composition within trophic levels*, but the coverage is still deficient for other characteristics. There is a particular lack of coverage of food chains that include invertebrates, bryophytes, lichens, and fungi, as well as mycorrhizal fungi and communities of decomposers in dead wood and soil. Indicators of soil chemical condition and fragmentation of forest area and old forest are also lacking. The underlying data for existing indicators are representative of forests in the whole country and the regions used, but the possibility of finer spatial resolution is limited for several of the indicators. All indicators have relatively short (< 30 years) or no time series, making it difficult

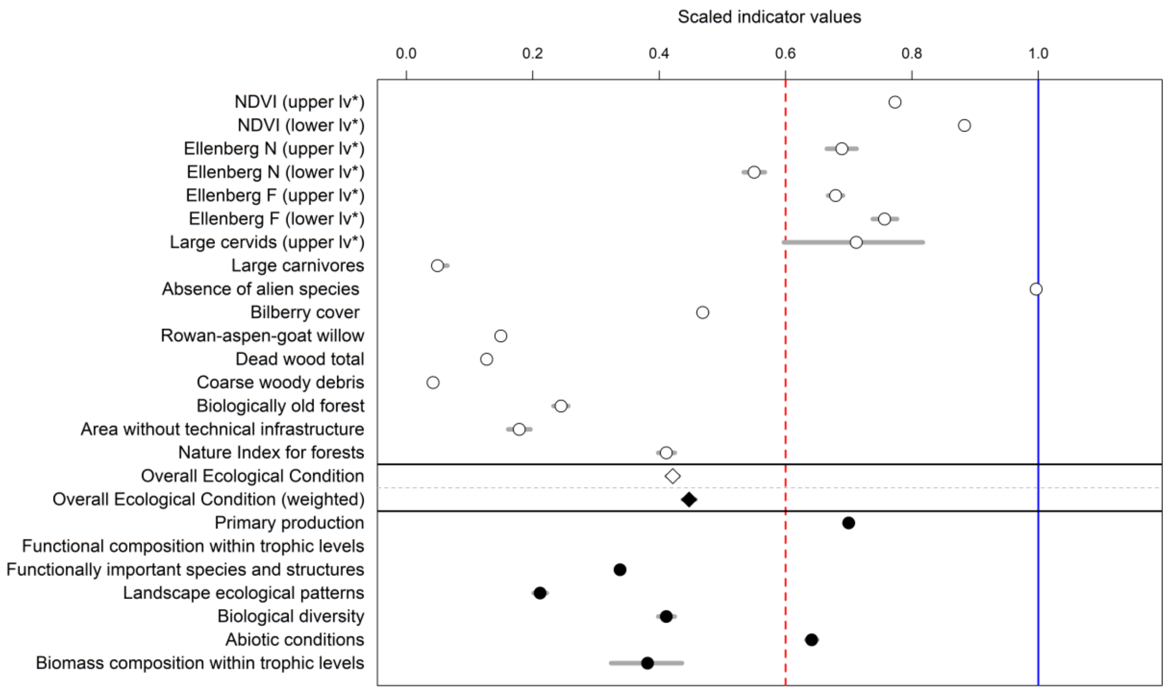

Figure A *Calculated condition for forest ecosystems in Norway. White circles indicate the scaled values for indicators included in the calculation. The white diamond shows the overall condition value of the ecosystem based on these indicators directly, whereas the black diamond shows the total condition value based on the condition values of the various characteristics of the ecosystem (black circles). The symbols show median values for indicators or average condition values, and grey and black bars show the 95% confidence intervals (some are hidden by the symbols). The blue vertical line marks the reference value, and the red dotted line marks the limit value for good ecosystem condition. This figure is also presented as Figure 3.2 in chapter 3.3.1.*

to assess interannual variability or trends. Despite some uncertainty in the determination of reference values and limit values for good ecosystem condition for the indicators, the values for several of the indicators associated with old natural forest, absence of technical infrastructure or populations of large carnivores, indicate that the condition of forest ecosystems is considerably lower than the condition expected in intact natural forest. This is also supported by data on forestry activities and the area affected by buildings and other infrastructure. The trends for such drivers indicate that a continuation of current policies for forestry, climate, transport, and land use will lead to a degradation of the condition of forest ecosystems in the coming decades.

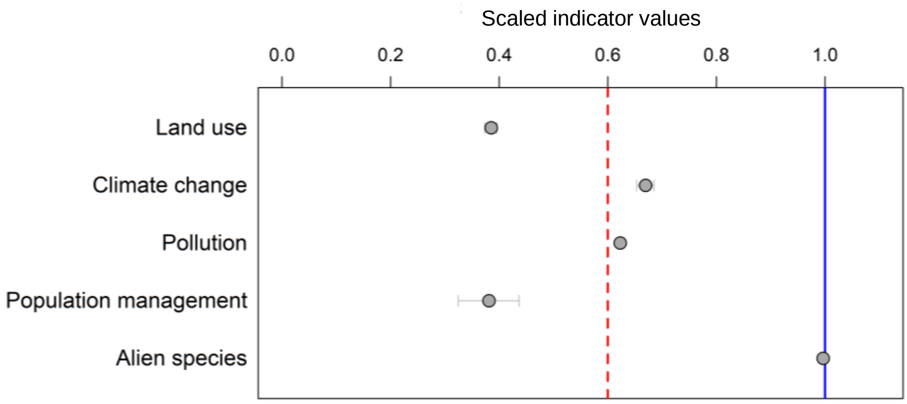

Figure B *Aggregated scaled values for forest indicators associated with main categories of anthropogenic drivers. Some confidence intervals are hidden by the symbols. The blue vertical line represents the reference value, whereas the red dotted line represents the limit value for good ecosystem condition. This figure is also presented as Figure 3.6 in chapter 3.3.2.*

Table A *Overall assessment of the reliability of the results for the condition of forest ecosystems, based on the indicators' coverage of the ecosystem characteristics, level (compared to the reference condition) and trends for the indicators' unscaled values, as well as the effects of main drivers on the scaled values of indicators assigned to each characteristic. The right column indicates whether the condition is certainly good, probably deviates from good (Degraded), or certainly deviates from good condition (Very Degraded), considering all aspects. This table is also presented as Table 3.9 in chapter 3.3.4.*

Ecosystem characteristics	**Condition value**	**Indicators**	**Indicator values**		**Effect of drivers**	**Condition**
			Levels	**Trends**		
Primary production	0.70	Insufficient	Small deviation	Stable, increasing	Positive?	Good
Distribution of biomass between different trophic levels	0.38	Insufficient	Large deviation	Increasing	Negative	Degraded
Functional composition within trophic levels	–	None				
Functionally important species and biophysical structures	0.34	Insufficient	Large deviation	Increasing	Negative	Very degraded
Landscape ecological patterns	0.21	Insufficient	Large deviation	Varying	Negative	Very degraded
Biological diversity	0.41	Insufficient	Large deviation	Increasing	Negative	Degraded
Abiotic factors	0.64	Insufficient	Some deviation	Uncertain	Positive?	Good
Overall assessment	**0.42**	**Insufficient**	**Large deviation**	**Varying**	**Negative**	**Degraded**

There is a need to further develop the system to assess the condition of forest ecosystems, partly by supplementing the set of indicators to obtain a better coverage of major organismal groups and functions, to provide more balanced coverage of the ecosystem characteristics, to improve and quality assure the setting of reference and limit values, and to improve the understanding of dose-response relationships between drivers and indicators. New indicators based on existing data can be developed for the biomass of trees, functional groups of plant species and birds, very decayed coarse dead wood, area of natural forest, as well as fragmentation of the forest area and old forest. New data are needed to develop new indicators for insects, soil chemistry, mycorrhizal fungi and other soil organisms.

Condition of mountain ecosystems

The results of the assessment of the condition of mountain ecosystems are summarized in **Figure C**. The condition of mountain ecosystems in Norway is estimated at 0.68 (with 95% confidence interval 0.63–0.71). This is above the limit value for good condition (0.6). There are only minor differences in the calculated condition values for various regions. Particularly the indicators *Arctic fox* (scaled value 0.04), *small rodents* (0.11) and *wolverines* (0.14) contribute to a reduced overall condition value. *Vegetation heat requirement* (0.44) and *willow grouse* (0.52) also have scaled values below the limit value for good condition. The indicators *reindeer*, *area of glaciers*, *connectivity of mountain area* and *nature index for mountains (modified)* have values at or just above the limit value. The other indicators have scaled values closer to the reference value. For some indicators, the uncertainty is very high.

The aggregated condition values for ecosystem characteristics are below the limit value for good condition for the characteristics *distribution of biomass between trophic levels* (0.49), *functional composition within trophic levels* (0.44) and *functionally important species and biophysical structures* (0.57). The other characteristics *biological diversity* (0.65), *landscape ecological patterns* (0.70), *primary production* (0.77) and *abiotic factors* (0.84) have values above this limit.

The condition indicators are assigned to one or more main categories of human drivers that are assumed to be of great or medium importance for the individual indicators. Ten of the indicators are associated with land use (mainly infrastructure development), with a mean condition value of 0.71, whereas as 15 indicators, with a mean condition value of 0.70, are particularly affected by climate change (increasing temperatures, longer growing season) (**Figure D**). Six indicators are particularly affected by direct population management (hunting, population regulation or population reinforcement), with a mean condition value of 0.46. Only two indicators, with a mean condition value of 0.87, are considered as sensitive to pollution in the form of nitrogen deposition, and only one indicator, with a value of 1, is considered as potentially much affected by alien species. Hence, indicators that are strongly affected by direct population management exhibit the greatest deviation from the reference condition. Most of these indicators are also considerably affected by other factors such as land use and climate change.

The reliability of the results is assessed against the indicators' coverage of the ecosystem characteristics, the underlying data, and the certainty of the assessments. This is summarized in **Table B**. The indicators cover relevant aspects of all properties, but the coverage is still deficient. In particular, several indicators based on plants and vegetation structure are missing, as well as invertebrates, fungi and decomposers in soil. Most indicators have no or only short time series, making it difficult to assess interannual variability or trends. Nevertheless, the report's overall results and conclusions on ecosystem condition and causes for deviation from the reference condition correspond with other knowledge such as the red lists for species and habitat types, as well as international knowledge on the condition of mountain ecosystems.

There is a great need to further develop the system to assess the condition of mountain ecosystems. This includes supplementing the set of indicators to get a more balanced coverage of the ecosystem characteristics, by improving the underlying data, and to improve and quality assure reference and limit values for the indicators. New indicators based on existing data from ongoing monitoring may be developed for different functional groups of plants, coverage of different vegetation layers and indices for mountain birds. New data collection is needed to develop indicators for invertebrates or biological and chemical conditions in soil.

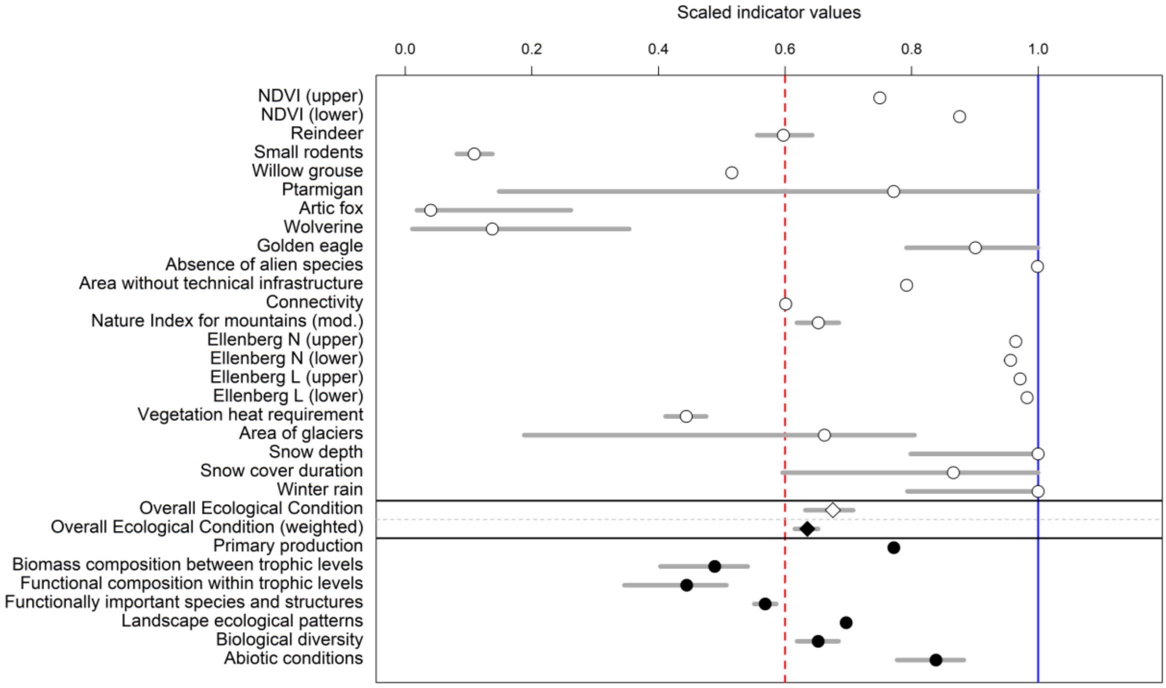

***Figure C** Calculated condition of mountain ecosystems in Norway. White circles indicate the scaled values for indicators included in the calculation. The white diamond shows the overall condition value of the ecosystem based on these indicators directly, whereas the black diamond shows the total condition value based on the condition values of the various characteristics of the ecosystem (black circles). The symbols show median values for indicators or average condition values, and grey and black bars show the 95% confidence intervals (some are hidden by the symbols). The blue vertical line marks the reference value, and the red dotted line marks the limit value for good ecosystem condition. This figure is also presented as Figure 4.2 in chapter 4.3.1.*

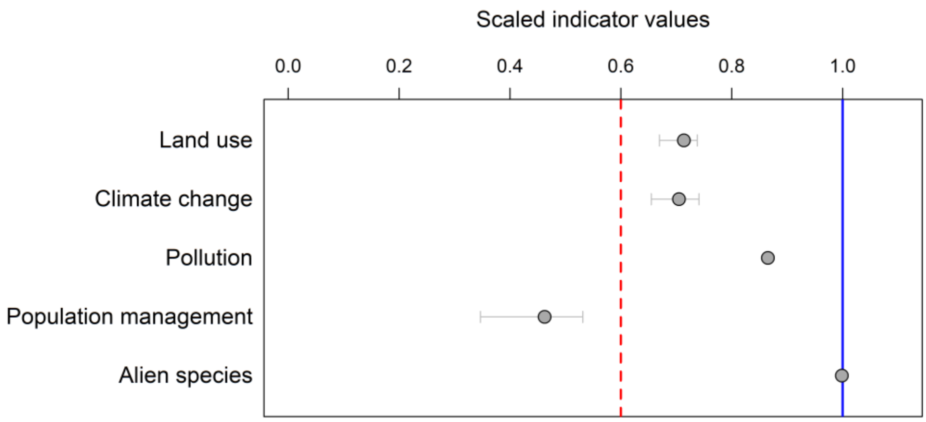

Figure D *Aggregated values for indicators associated with main categories of anthropogenic direct drivers for mountains. Horizontal lines indicate 95% confidence intervals (some are hidden by the symbols). The blue vertical line represents the reference value, whereas the red dotted line represents the limit value for good ecosystem condition. This figure is also presented as Figure 4.6 in chapter 4.3.2.*

Based on the wide range in the indicators' deviations from their respective reference values, the great uncertainty for some indicator estimates, the inability to assess trends for most indicators, and inadequate indicator coverage for the ecosystem characteristics, it is considered uncertain whether the current overall condition for mountain ecosystems is good or degraded. However, with expected climate change and current development trends for land use and infrastructure development, it is very likely that the condition of mountain ecosystems will be considered as degraded within a few decades.

Table B *Overall assessment of the reliability of the results for the condition of mountain ecosystems, based on the indicators' coverage of the ecosystem characteristics, level (compared to the reference condition) and trends for the indicators' unscaled values, as well as effects of the main drivers on the scaled values of indicators assigned to each characteristic. The right column indicates whether the condition is certainly good, probably deviates from good (Degraded) or is uncertain, considering all aspects. This table is also presented as Table 4.9 in chapter 4.3.4.*

Ecosystem characteristics	Condition value	Indicators	Indicator values		Effect of drivers	Condition
			levels	**trends**		
Primary production	0.77	Insufficient	Some deviation	Increasing	Negative	Good
Distribution of biomass between different trophic levels	0.49	Somewhat insufficient	Partly large deviation	Variable	Negative	Degraded
Functional composition within trophic levels	0.44	Somewhat insufficient	Partly large deviation	Variable	Negative	Degraded
Functionally important species and biophysical structures	0.57	Insufficient	Partly deviation	Variable	Negative	Uncertain
Landscape ecological patterns	0.70	Insufficient	Some deviation	Decreasing	Negative	Uncertain
Biological diversity	0.65	Insufficient	Some deviation	Decreasing	Negative	Uncertain
Abiotic factors	0.84	Somewhat insufficient	Small deviation	Variable	Positive, Negative	Good
Overall assessment	**0.68**	**Insufficient**	**Some deviation**	**Variable**	**Negative**	**Uncertain**

1 Introduction

Records on loss of biodiversity and ecosystem functioning, leading to subsequent losses in ecosystem services and benefits to people, have become increasingly abundant in both the scientific literature and media over the last decades. Despite the increase in focus on and awareness of the importance of functionally intact ecosystems for sustaining human societies, we still witness unprecedented degradation of natural systems and increases in human appropriation of natural resources (Mace et al. 2018, Krausmann et al. 2013). The 2020 Aichi targets were set to turn the tides of nature loss and initiate a shift towards sustainable management of the planet, but it has been clear for a while that we failed to reach these targets (CBD 2011, 2020, Sabima 2020, Tittensor et al. 2014). One important aspect of this failure is that we largely still do not know what we are losing on scales and in terms that actually matter to nature and land management (cf. Pe'er et al. 2014; Tittensor et al. 2014, Reed 2008). To counter this, the development of frameworks like the Essential Biodiversity Variables (EBV; Scholes et al. 2008, Pereira et al. 2013), the EU Water Framework Directive (EC 2019), and the Ecosystem Condition Typology (ECT) as part of the SEEA EA framework for ecosystem accounting has been pushed forward over the last two decades (UN et al. 2021, Hein et al. 2020). The pressure on nature is a global concern, but nature loss happens locally, and within national management settings. As countries subscribe to goals and strategies defined by, e.g., the UN or EU, they thus need to develop or adopt schemes for measuring the state of nature that are compatible with these international frameworks.

For Norway, the country's dedication to the SEEA EA framework, as well as national targets for nature and biodiversity are communicated through the government's action plan for biodiversity (Meld. St. 14 (2015–2016)), stating that ecosystems shall achieve good ecological status and deliver important ecosystem services. As a consequence of the action plan, a national framework for assessing the condition of ecosystems was developed by an expert group appointed by the Norwegian Ministry of Climate and the Environment in 2016. The mandate for the expert group specified that the system should be simpler than the system employed under the EU Water Framework Directive, and it should only characterise good ecological condition as distinct from degraded condition, without specifying criteria for other condition classes. It should be based on a limited set of indicators which reflect the structure and functions of ecosystems, with due consideration of the natural dynamics of ecosystems. It should build on existing and accessible scientific knowledge on condition and trends of Norwegian ecosystems, and it should build on and supplement existing relevant systems for classifying nature. The expert group should also propose a suitable geographical resolution relevant for environmental management, as well as a relevant schedule for updating the assessments.

The expert group delivered its report in June 2017 (Nybø & Evju 2017). To develop the expert group's proposed framework into a more operational system, several projects were initiated to specify indicators and test approaches for selected areas and ecosystems (cf. Nybø et al. 2018, 2019, Jepsen et al. 2018, 2019, 2020). One of the approaches developed for assessment of ecosystem condition is the Index-Based Ecosystem Condition Assessment (IBECA). The IBECA approach is briefly described in chapter 2. After receiving the reports from the pilot projects (Nybø et al. 2019, Jepsen et al. 2019), the Ministry of Climate and Environment decided that national ecosystem condition assessments should be conducted for forest and mountain ecosystems according to the IBECA approach, reported in Framstad et al. (2021, 2022). The Ministry also decided that a national assessment should be conducted for Arctic terrestrial ecosystems according to the Panel-based Assessment of Ecosystem Condition (PAEC) approach, reported in Pedersen et al. (2021).

The purpose of this report is to present the results from the ecosystem condition assessments for forest and mountain ecosystems to English-speaking readers. The method of assessment according to the IBECA approach is briefly described (chapt. 2); more details are available in scientific publications presenting the approach (Jakobsson et al. 2020, 2021) and in a methodological report (Töpper & Jakobsson 2021). The main emphasis in this report is on the respective assessments for forest (chapt. 3) and mountain ecosystems (chapt. 4), with presentations of their specific indicators and underlying data, the national results, and an overall assessment of the reliability of these results. Based on current trends in condition indicators and variables for direct drivers, we also discuss the likely future development for the ecological condition of forest and mountain ecosystems. We emphasise the need to improve the assessment system; with particularly pressing needs and opportunities for improved performance though (i) developing additional indicators, (ii) collecting and making available improved data across a wider range of indicators, (iii) research to provide better scientific support for various elements in the method and (iv) methodological development to support spatial downscaling to allow use at regional and local scales. Finally, we highlight the relevance of the IBECA approach for environmental management (chapt. 5). A full technical description of the currently available indicators is given in appendices.

2 The IBECA framework

In this chapter we present the main elements of the IBECA framework and method. For more detailed descriptions, see Jakobsson et al. (2020, 2021) and Töpper & Jakobsson (2021).

Ecological condition
In its clause 3 (item s), the Norwegian Nature Diversity Act[1] provides the following definition of the ecological condition of ecosystems (called 'ecological status' in the English translation): "*status of and trends for functions, structure and productivity in areas of a habitat type, viewed in the light of relevant environmental pressures.*" This implies that the ecological condition of ecosystems should be linked to their structures, functions and productivity, as well as their natural dynamics, where these characteristics and hence the condition may be affected by various direct drivers of ecosystem change.

Ecosystem structures are interpreted as the biophysical structure of the ecosystems, usually its composition of genotypes, species, habitats and other units included in the ecosystem, and the amount of each of these units (Noss 1990). Functions cover the various processes occurring within and between the various organisational levels of the ecosystem, from genes, via populations, to communities, habitats and whole landscapes. Productivity is an important ecosystem function and covers the primary production of plants and micro-organisms by photosynthesis and the secondary production of various consumers. Other functions of the ecosystem are decomposition of dead organic material, cycles of water and various nutrients, carbon storage, soil formation and various interactions among species.

Structures and functions of intact ecosystems are shaped by the natural dynamics in the form of various disturbances and subsequent successions in the ecosystem properties, until a new disturbance occurs. Such disturbances may be physical, such as fires, windthrows, avalanches and floods, or biological, such as population outbreaks of insects, small rodents and epidemics of disease organisms. Ecosystems with similarities of climate, terrain, quaternary deposits and species composition may have similar dynamics, although random events may also play a considerable role.

In our context, we refer to direct drivers, i.e., results of human activities that have a direct influence on structures, functions and dynamics of ecosystems. Anthropogenic direct drivers are often grouped to the main categories of land use (including infrastructure development etc), climate change, pollution, direct management or exploitation of populations, and introductions of species (MEA 2005, IPBES 2019). Natural disturbances or other external influences on ecosystems may also be considered as direct drivers but here we will limit this term to anthropogenic drivers. Indirect drivers do not influence ecosystems directly but work via the direct drivers (MEA 2005, IPBES 2019). These may be socio-cultural factors, human population change and migration, economic factors, science and technology, as well as politics and governance. These are not considered here, and we simply refer to anthropogenic direct drivers as *drivers*.

Changes in ecosystems due to natural or human impacts may manifest themselves as changes in both extent and condition of ecosystems. It should be noted that in our assessment of ecosystem condition, changes in the extent of ecosystems are not considered. Assessment of changes in extent is considered as a separate process, outside the framework for assessment of ecosystem condition as described in the report from the expert group (Nybø & Evju 2017). Such a distinction between assessments of the extent and condition of ecosystems is consistent with the UN recommendations for ecosystem accounts (UN et al. 2021).

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[1] https://lovdata.no/dokument/NL/lov/2009-06-19-100

Reference condition
The expert group specified the reference condition as the condition of an intact ecosystem and described it as follows (Nybø & Evju 2017):
"An intact ecosystem is characterised by the integrity of its structure, functions, and productivity. An intact ecosystem has complete food webs and nutrient cycles. Native species dominate all parts of the food web, within all trophic levels and functional groups. Species composition, population structure and genetic diversity of native species are the results of natural processes through the ecosystem's ecological and evolutionary history. The characteristics of an intact ecosystem do not change systematically over time but vary within the boundaries of the ecosystem's natural dynamics.
Effects of human activities may occur but shall not be comprehensive or dominant, or change the ecosystem's structure, functions, or productivity. This means that the effects of human activities shall be on a scale and of a magnitude which does not exceed the effect of natural disturbances or dominating species. Further, human activities shall not lead to changes which are quicker or more comprehensive than natural changes in the ecosystem."

We follow the expert group in defining *intact ecosystems* as ecosystems where structures and functions are shaped overwhelmingly by natural climatic and ecological processes, and where human impacts have limited impact.

One should be aware that the condition of natural ecosystems may vary considerably between years or over longer time spans (Landres et al. 1999). This must be incorporated in the understanding of the reference condition, e.g., when it comes to consider what is a substantial deviation from the reference condition (cf. good ecological condition, below). Natural changes in natural environments or ecosystems over longer time spans may in principle lead to a change in the reference condition over time. In practical terms, we need to consider changes over time scales that are relevant for management, i.e., a few decades. Hence, we will not consider natural variation in the ecosystem's structure, functions or dynamics over timespans exceeding 100 years, and will in most cases for practical reasons of data availability etc. have to limit our discussion to shorter time scales.

The expert group also proposed that the climate for the reference condition should be based on the climate of the last meteorological normal period 1961–1990. In the Nordic countries, the climate of this period was less affected by human-induced climate change than the decades following 1990.

Finally, the expert group proposed that the species community of the reference condition should be based on the current native species of the ecosystem. This excludes species which arrived in Norway after 1800, cf. the definition of alien species applied by the Norwegian Biodiversity Information Centre (Artsdatabanken 2018).

Good ecosystem condition
For an ecosystem in good condition, the ecosystem's structure, functions and productivity do not deviate substantially from those of the reference condition of an intact ecosystem. This represents a well-functioning ecosystem where natural functions are maintained and most native species are present. Human impacts may occur but shall not have a dominating influence or be of a magnitude resulting in structure and functions showing substantial deviation from the reference condition.

In an ecosystem where the condition deviates substantially from the reference condition, some species may have considerably lower or higher populations than in the reference condition and the distribution of biomass and diversity, both within and between trophic levels, may be changed. Rates for processes like primary production or decomposition may be considerably slower or faster than in the reference condition. A substantial deviation from the reference condition may imply that a changed value for a given variable has substantial effects on other parts of the ecosystem or that the value is far from the value one would observe in the reference condition. Such deviations may often be linked to one or more anthropogenic drivers, thus supporting the understanding that this represents a true substantial deviation from intact nature.

Characteristics of ecosystems
The expert group specified the description of good ecosystem condition and linked this to seven characteristics of ecosystems:

- Primary production
- Distribution of biomass between different trophic levels
- Functional composition within trophic levels
- Functionally important species and biophysical structures
- Landscape ecological patterns
- Biological diversity
- Abiotic factors

According to the expert group, for an ecosystem in good condition these characteristics should not deviate substantially from those in the reference condition.

These seven characteristics are linked to the ecosystem's structures and functions. Some may be relevant for several characteristics, whereas others may be specific for one characteristic. Changes in the ecosystem may thus affect the various characteristics in different ways, depending on how the underlying structures and functions for the characteristics are affected.

For *primary production* both high and low values may indicate a deviation from good ecosystem condition, e.g., due to eutrophication or over-harvesting, respectively. The primary production represents the production of biomass per unit time by photosynthesis in plants or microorganisms. This production may be considered as gross or net production, where net production does not include the production used in the plants' respiration.

The *distribution of biomass between different trophic levels* in an ecosystem in good condition implies a balance between primary producers, decomposers and various levels of consumers throughout the food web. The biomass at each trophic level must also be maintained. Deviation from the reference condition implies that the biomass of one or more species or species groups deviates substantially from their levels in the reference condition.

For the *functional composition within trophic levels*, both the relative proportion and the absolute amount of various functional groups should be maintained in an ecosystem in good condition.

F*unctionally important species and biophysical structures* are important for the ecological opportunities of other species and for various ecosystem processes, by influencing the dynamics or structuring of ecosystems, by being 'ecological engineers', or by providing key resources at critical stages in the life history of species.

The *landscape ecological patterns* of various habitats or key resources in the ecosystem should be consistent with the long-term survival of native species in ecosystems in good condition. In intact ecosystems, such patterns are shaped by the natural disturbances and dynamics of the ecosystem, with a variation in extent, frequency and intensity that is determined by the local climate, terrain and other environmental properties. Such disturbances are followed by successions of varying duration until a new disturbance occurs. In intact ecosystems, such disturbances and successions have created characteristic patterns in habitat properties and resources. Native species have become adapted to such patterns over a long time. External human impacts represent disturbances which often deviate substantially from natural patterns in intensity, frequency, or spatial distribution. This may change ecosystem functions and reduce the opportunities for native species. Changes following human impacts may also open new opportunities for other species with different habitat requirements, e.g., opportunistic species with general habitat requirements and good dispersal ability.

Biological diversity in this context includes the diversity of species and genotypes, as well as the turnover rates of species and genotypes by migration, extinction or evolution. The diversity of species encompasses species richness, species composition and the abundance of species. Changes in biological diversity may change ecosystem functions and make ecosystems less robust against external impacts. This is obviously the case with loss or strong reduction in the abundance of key species like trees, but also applies for a more general reduction in the diversity of species or genotypes. Other rates of species turnover than what is characteristic for intact ecosystems, e.g., by quicker loss of native species or immigration of alien species, indicate degraded ecosystem conditions.

Abiotic factors, i.e., physical or chemical properties of ecosystems, such as geology, terrain, local climate, or cycles of water and nutrients, have great importance for ecosystem dynamics and various functions, and consequently for the ecosystem's species diversity. Several human impacts, such as land use, climate change, or pollution, may change the abiotic factors, resulting in degraded ecosystem conditions.

Indicators and reference values

To quantitatively assess the condition of ecosystems we need relevant empirical indicators that cover the seven characteristics of ecosystems as well as possible. Such indicators should also be responsive to important drivers that affect ecosystems to make it possible to link changes in indicator values to changes in one or more drivers. An established relationship between an indicator and a driver will facilitate the interpretation of possible causes behind observed changes in indicator values and to assess which management responses may be most appropriate.

Abiotic condition indicators should be rather closely linked to important ecosystem functions and should not directly represent drivers (cf. Nybø & Evju 2017, IPBES 2019). For example, an indicator for nitrogen content of the soil may be considered as part of the chemical condition of the ecosystem, whereas deposits of nitrogen compounds through pollution or fertilisation should be considered as external drivers. Similarly, changes in air temperatures over large areas may be considered as external climate drivers, whereas variation in local snow cover may be seen as a physical property of the ecosystem and, hence, as a possible condition indicator.

In the reference condition indicators will have values, or variation around a mean, comparable to what we may expect to observe in intact ecosystems. Such a reference value for an indicator may be determined in several ways (cf. Jakobsson et al. 2020, Töpper & Jakobsson 2021):

- *Absolute physical limits*, e.g., as given by effects of drivers which should not exist in the reference condition, such as alien species or technical infrastructure.
- *Reference areas,* e.g., areas assessed to have ecosystem conditions quite close to the reference condition or where the observed values for relevant indicators are assumed to be closed to the indicators' reference values.
- *Reference communities,* i.e., species communities which are assessed to be quite close to comparable communities in the reference condition, often based on knowledge of species communities in sites similar to reference areas.
- *Models of ecosystem dynamics* where reference values are based on models for those parts of the ecosystem which are important to the indicator, knowledge of the ecosystem and data for key parts of the model from sites close to reference conditions.
- *Models for habitat availability* where reference values are based on knowledge of the ecological requirements of the species and models for how these demands are satisfied in the reference condition. This approach is similar to habitat availability modelling for species.

The reference values applied to our indicators for assessment of the condition for forest and mountain ecosystems are presented in the respective chapters 3 and 4.

Limit values for good ecosystem condition
The expert group specified that good ecosystem condition implies that the characteristics of ecosystems do not deviate substantially from what they would have been in the reference condition of intact nature. For indicators which represent the various characteristics, this implies that indicator values in an ecosystem in good condition do not deviate substantially from the reference values of the indicators.

It is, however, not always easy to decide what should be considered a substantial deviation from the reference value for the individual indicators. If one has knowledge of a functional relationship between the indicator and certain drivers, with this relationship established as a specific dose response function, it may be possible to specify a quantitative and empirical limit value for the indicator when the ecosystem passes from good to degraded condition. Today, this is only possible for a few indicators, mainly linked to pollution effects in aquatic ecosystems. Lacking knowledge of dose response relationships, or when the indicator most likely is affected by several drivers, the limit value for good ecosystem condition must be based on the best ecological knowledge about indicator values in ecosystems at the transition from good to degraded condition. Various types of data from experiments, ecological gradient studies, or time series may form a basis for setting limit values (Jakobsson et al. 2020, Töpper & Jakobsson 2021). A lower value than the limit value implies a substantial negative change in the characteristics of the ecosystem. With limited knowledge, a linear relationship between driver and condition may be assumed as a first approximation. Such a linear response function may be changed when improved knowledge or data become available.

A few general approaches for setting limit values for good ecosystem condition are presented in Jakobsson et al. (2020) and Töpper & Jakobsson (2021), and briefly described here:

- *Empirical limit values* may be set based on empirical studies of the critical loads for the indicators in sites varying in condition from good to degraded.
- *Statistical distributions* for the indicator values in sites varying in condition. Specific parts of the distribution may be defined as expressions of deviation from the reference condition.
- *Assumed linear relationship* between the indicator value and the condition of the ecosystem. This implies that the relationship between the unscaled limit value and the unscaled reference value is the same as the relationship between the scaled limit and reference values. This approach may be applied when the underlying relationship is assumed to be linear, or as a first approximation when we lack knowledge about the relationship.

The limit values applied to our indicators for the assessments of the condition for forest and mountain ecosystems are presented in the respective chapters 3 and 4.

Scaling, weighting, and aggregation of indicator values
A key element of the IBECA approach is the scaling of indicator values to a common scale with values between 0 and 1. This will let us compare the deviations of the individual indicators from their reference values, as well as to combine the scaled indicator values into an overall index of ecosystem condition. The scaling is based on each indicator's unscaled reference value, limit value for good ecological condition and a minimum or maximum value for the most degraded possible condition of the ecosystem. After scaling, the indicator's scaled reference value for an intact ecosystem is 1, whereas the scaled indicator value for the most degraded ecosystem is 0.

We have chosen to set the scaled limit value to 60% of the scaled reference value, i.e., 0.6. This is equivalent to the limit value between good and moderate condition for the normalised EQR values used in ecological assessments of water bodies and streams in the Norwegian implementation of the EU Water Framework Directive (Direktoratsgruppen vanndirektivet 2018). We note that because of flexibility in scaling (see below), this limit between good and degraded condition in the scaled indicator makes no assumption about the unscaled indicator value at the limit between good and degraded state. **Figure 2.1** illustrates the scaling for three hypothetical indicators where the unscaled limit value is, respectively, 25%, 60% and 87% of the unscaled reference value.

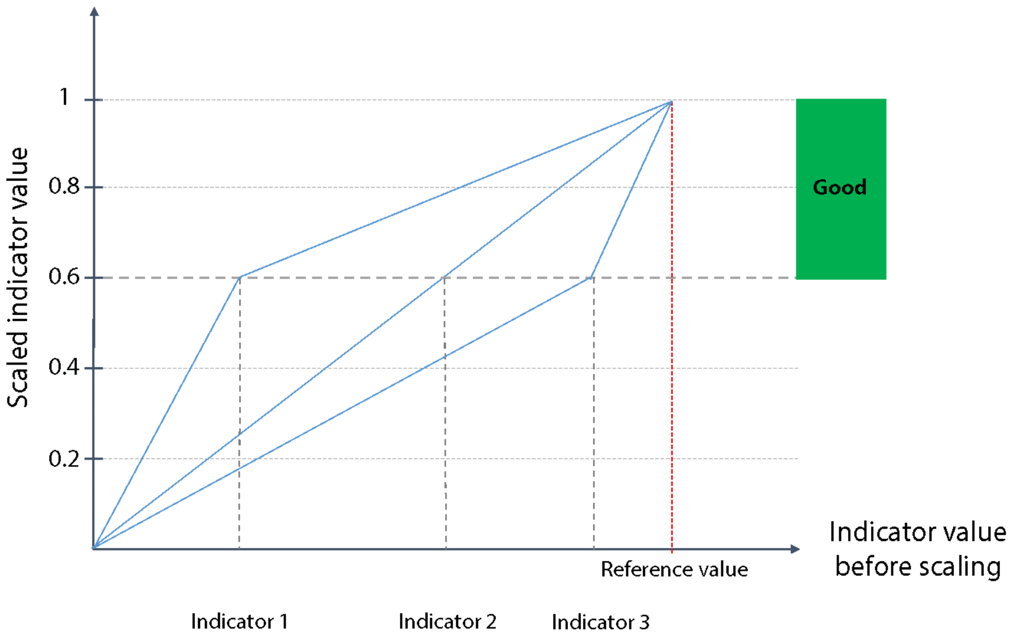

Figure 2.1 *Example of scaling of three indicators with unscaled limit values (vertical dashed lines) of, respectively, 25%, 60%, and 87% of the unscaled reference value (red dotted line). The scaling functions (blue lines) are determined by the requirements that the scaled reference value shall be 1, the scaled limit value 0.6 (horizontal dashed line), and the scaled lowest/highest value for a degraded ecosystem 0.*

Some indicators (called two-sided indicators) may have values both lower and higher than the reference value. That is, both lower and higher values may represent a deviation from the reference condition. For such two-sided indicators both a lower and an upper limit value for good ecological condition will be set. Technically, two-sided indicators are treated as two separate indicators, but together they are given the same weight in calculations as a single one-sided indicator.

Minimum or maximum values represent the lowest or highest value an indicator may have under degraded conditions. For some indicators the minimum value is intuitively 0, e.g., the population level of a species or the area without alien species. Maximum values, however, must be defined for two-sided indicators. There may be theoretical limits for minimum or maximum values, e.g., set by the range of possible values in remote sensing data or for model-based indicators (cf. Töpper & Jakobsson 2021).

In the overall assessment of ecosystem condition the individual indicators may be assigned the same or different weights (cf. Töpper & Jakobsson 2021). Reasons for allocating different weights may be that two or more indicators cover similar aspects of the ecosystem condition, or that some indicators are assumed to reflect more important aspects of ecosystem condition than other indicators. Another reason for different weights may be that some indicators may not have values for the whole area of the ecosystem to be assessed. Finally, some indicators may have particularly uncertain values and their weight in the overall assessment should therefore be lower than indicators with more certain values. In the assessment of condition for forest and mountain ecosystems, we have chosen to give all indicators the same weight. All indicators have specified values for the entire area to be assessed (i.e., respectively, for all defined forest and mountain area in Norway). Although there is some correlation between values for some indicators, we consider that the indicators mainly cover distinct aspects of the condition for forest and mountain ecosystems.

Aggregation of indicator values to an overall value for ecosystem condition is based on the scaled indicator values in two different ways. (1) The overall ecosystem condition value is calculated directly as the mean of the scaled indicator values (where all indicators have the same weight). (2) A condition value is calculated for each ecosystem characteristic as the mean of scaled values for those indicators that are assigned to the characteristic in question. Then the overall ecosystem condition value is calculated as the mean of the values for each ecosystem characteristic. In this version, each characteristic is given the same weight, irrespective of which and how many indicators may be assigned to each characteristic. This implies that indicators which are assigned to more than one characteristic, will receive a higher weight in the calculation than indicators assigned to only one characteristic. Both these overall values for the ecosystem condition are presented in the results.

Estimating uncertainty

Where possible, we have tried to quantify the uncertainty of indicator value estimates. The most common approach is by resampling of observation data (with replacement), for a given time and region or all of Norway. The resampling is typically repeated about 10,000 times. The median and lower and higher confidence limits (2.5 and 97.5 percentiles) are determined from this distribution of indicator estimates. For some indicators the value estimates come from a statistical model, and in these cases the uncertainty of the model is transferred to the uncertainty of the indicator. Some indicators are based on map data with unspecified precision, and for these indicators no uncertainty is calculated. Description of the method applied for each indicator is given in appendix 1 and 2.

In a similar manner, uncertainty is estimated for aggregated index values, where the distribution for each indicator is used as described above. In each resampling, a value is drawn from each indicator distribution which is included in the relevant aggregated index. The mean of this sampling is included as one value in a distribution of index estimates. The process is repeated 10,000 times, and the median and the 95% confidence interval is extracted from the final distribution of index values. The process is the same for aggregated values per ecosystem characteristic as for the overall ecosystem condition value.

Overall assessment

The overall assessment of ecosystem condition is based on the index method as described above and the condition indicators included for the respective ecosystems. Where we have time series of observations for these indicators, we may also be able to assess whether the indicator values approach or depart from the reference value over time. However, we have only quite short time series for most indicators, or no time series at all. In addition, we have assessed a few supplementary variables which may represent some other nuances of the ecosystem condition, but which we, for various reasons, have not included as proper condition indicators. Some of the supplementary variables overlap to a considerable degree with included indicators, or we have not been able to set appropriate reference values for these variables.

To provide insight into possible causes for a deviation in overall ecosystem condition from the reference condition, we have assigned each indicator to one or more main categories of drivers. We have then calculated aggregated values for each of these main drivers. We have also assessed if variables for specific drivers, within each of the main categories, may provide additional insight on possible causes for observed levels or changes in indicator values. Similar trends over time for drivers as for condition indicators may support conclusions that the assessment of ecosystem condition reflects a real deviation from the reference condition and may point to a possible cause for this deviation. The relevance of the IBECA approach for informing environmental management is discussed in chapter 5.

3 The condition of forest ecosystems

3.1 Definition of forests

Several of the indicators used in the assessment of condition for forest ecosystems are based on data from the Norwegian National Forest Inventory (NFI)[2]. We have therefore applied the same definition for forests as the NFI (Tomter & Dalen 2018), which is the same definition as applied by the UN Food and Agriculture Organisation (FAO 2018): "*Land spanning more than 0.5 hectares with trees higher than 5 meters and a canopy cover of more than 10 percent, or trees able to reach these thresholds in situ. It does not include land that is predominantly under agricultural or urban land use."* This includes forest area temporarily without trees, e.g., clear-cut areas. Note that we, by following the FAO and NFI forest definition, include forests on both wetland and non-wetland, whereas the expert group originally included wetland forests in wetlands, not in forests (Nybø & Evju 2017).

The expert group suggested ecosystem condition could be assessed for subdivisions of the main ecosystems (Nybø & Evju 2017). We have not subdivided forests into, e.g., different forest types, as many of our indicators cannot be assigned consistently to such subtypes. Also, variation in the main anthropogenic direct drivers, forestry especially, only reflects ecological divisions of forest types to a limited extent.

The IBECA approach may in principle be applied at any geographical scale of interest to management authorities or scientists. However, the data for indicators will in most cases limit the extent of down-scaling, as most indicators do not have enough data points at sufficiently fine resolution to represent ecological condition at, e.g., the municipal level. In the assessment of the condition of forest ecosystems we have calculated condition values both for the national level and for broad regions, as illustrated in **Figure 3.1**. However, as the regional condition values are rather similar, we will only present national results in the following.

***Figure 3.1** Distribution of forest area (green) for various regions in Norway.*

[2] https://www.nibio.no/en/subjects/forest/national-forest-inventory

3.2 Forest condition indicators and other variables

To assess the condition of forest ecosystems we need indicators which represent the characteristics of the ecosystem and that we can use to calculate a condition value according to the IBECA approach. We have also included a few other variables that provide additional information on the ecosystem condition, although we have not included them in the calculation of condition values. We have also collated information on various drivers, to see if these factors may contribute to explain levels or trends for condition indicators. The various indicators and other variables are presented in the subchapters below.

3.2.1 Indicators used in the calculation of condition values

The individual indicators
The indicators used in the calculation of the condition of forest ecosystems are shown in **Table 3.1** and described below. A more technical description of the indicators is given in **Appendix 1**.

The data for the indicators come from various sources (cf. **Table 3.1** and the text below) and may vary in both the length of timeseries (from 1 to 30 years) and the temporal resolution. As current data we have used the available data for the 5-year period 2016–2020 (as aggregated or mean values if more than one year of data is available).

NDVI is an index closely associated with the amount of green vegetation involved in active photosynthesis and is often used as a measure of plant biomass or primary production (Pettorelli et al. 2005). The index is based on the ratio between red light (R) and near-infrared (NIR) radiation, given by the formula (NIR-R)/(NIR+R), most often based on satellite data. We have used country-wide data from the MODIS instrument of the Terra satellite made available by NASA through the MOD13Q1 V6 product. We have estimated an expected NDVI value (termed pNDVI) for all parts of the forest area, based on a model for forest in protected areas with climatic and edaphic predictor variables (cf. the concept of potential natural vegetation of Hengl et al. (2018)). This model for pNDVI is then extrapolated to all forest areas, with a pNDVI value for each observed NDVI value. To estimate the value of the indicator we calculate the difference between pNDVI and observed NDVI. The reference condition is based on the distribution of the differences between these variables in forest in protected areas in a specific region. The median of this distribution is used as the reference value in the scaling of the indicator, to take account of any regional deviations from the national model of pNDVI in protected areas. Since both positive and negative values for the NDVI indicator may indicate deviations from good ecological condition, we calculate both a lower and an upper limit value for good ecosystem condition based on the 95% prediction interval for the deviations in forest in protected areas. Negative values for NDVI may be due to deforestation, whereas positive values may be due to increased productivity from climate change or nitrogen deposition.

Ellenberg N is an index based on scores for the affiliation of vascular plants to the amount of available organic nitrogen in the soil (soil fertility). This nitrogen affiliation for plants has been scored by Ellenberg et al. (1991) on a scale from 1 (low affiliation) to 9 (high affiliation). It has later been adapted to British and Northern European conditions by Hill et al. (1999). Low values indicate that a species prefers nitrogen poor soil, whereas high values signify that a species prefers soils rich in nitrogen. By calculating a weighted mean Ellenberg N score based on the relative abundance of the various species, an Ellenberg N score for the vegetation at a specific site may be derived. This Ellenberg N score reflects the status for the relevant amount of organic nitrogen in the soil for the vegetation at the site. The reference value is based on the distributions of Ellenberg N values for generalised species lists for minor types of forest within the major types T4 (non-wetland forest) and T30 (riverine forest) in the EcoSyst hierarchy (Halvorsen et al. 2020), corresponding to the mapping units at scale 1:5,000 (Töpper et al. 2018). Since both low and high values for Ellenberg N may indicate deviations from good ecosystem condition, we calculate both lower and upper limit values based on the 95% prediction interval for the reference distributions (Töpper et al. 2018). Values above the upper limit value may indicate eutrophication by nitrogen deposition, whereas values below the lower limit value may be due to nitrogen deficiency. The vegetation data for the Ellenberg N indicator for forests come from the country-wide, representative monitoring programme ANO (Tingstad et al. 2019). Data for vascular plants and EcoSyst mapping units are recorded at 18 regularly placed 1 x 1 m sampling points within randomly placed 500 x 500 m sampling plots. The ANO-based data for the Ellenberg N indicator in forests come from 1742 forest points at 189 randomly placed plots from the whole country, covering the years 2019 and 2020.

Ellenberg F is an equivalent index to Ellenberg N but pertains to the affiliation of vascular plants to sites with varying soil moisture. Scores for Ellenberg F go from 1 (dry sites) to 9 (wet sites). The calculation of the reference value and the limit for good ecological condition is performed the same ways as for Ellenberg N. Both low and high values may indicate deviations from the reference condition for Ellenberg F. In forests, low values may be caused by ditching and a lowered water table, whereas high values may be due to increased precipitation under current climate change. The data come from the ANO programme (Tingstad et al. 2019) and are based on 1742 forest points at 189 randomly placed plots for the whole country (cf. Ellenberg N).

Large cervids includes the aggregated abundances of elk (*Alces alces*) and red deer (*Cervus elaphus*) per km^2, where the number of red deer has been converted to 'elk equivalents' based on the average metabolic weight for each species (i.e., with consideration of energy turnover related to body weight) (cf. Nybø et al. 2018). The population data come from the national cervid monitoring programme[3], the same data as used in the Norwegian Nature Index 2020 (Jakobsson & Pedersen 2020). The reference value is based on estimated population levels for elk and red deer in each county for the reference condition, as these are defined in the Nature Index[4]. The reference value includes considerations of potential habitat under natural conditions and natural populations of predators (cf. Nybø et al. 2018). Both low and high indicator values may indicate worse conditions than in the reference condition. Indicator values lower than the reference value can be a result of high hunting pressure, increased predation, or reduced access to food. Decimation of predator populations, reduced hunting, or climate change may give indicator values higher than the reference value, which can have a negative effect on the biodiversity by, e.g., overgrazing of vegetation. Hence, we use a two-sided indicator, scaled towards a lower and an upper limit value, corresponding to 60% and 140% of the reference value, respectively. Only the sub-indicator with the lowest scaled value is used in the assessment of ecosystem condition. For assessment of the current condition, this applies to the indicator's upper limit value, as the current cervid populations are clearly above their reference values. The use of only the upper limit is a pragmatic approach due to a lack of updated data from the Cervid Register[5]. It was necessary to use the same data as in the Nature Index 2020, thus limiting the possibility of including calculation of the condition against the lower limit value.

Large carnivores includes the aggregated abundances of the species wolf (*Canis lupus*), brown bear (*Ursus arctos*) and lynx (*Lynx lynx*) for the individual regions, where the numbers of wolves and brown bears are converted to 'lynx equivalents' based on the average metabolic weight for each species (cf. large cervids). As the diet of brown bears contains a substantial proportion of plants, the metabolic weight of brown bears has been reduced accordingly (Nybø et al. 2018). Population data for the individual species come from Rovdata[6], as reported in the Nature Index for Norway 2020 (Jakobsson & Pedersen 2020). The reference value is based on the estimated population levels for the individual species for potential habitat under natural conditions in the various carnivore regions, as used in the Nature Index (cf. Nybø et al. 2018). The limit value for good ecosystem condition is set to 60% of the reference value.

[3] https://www.hjortevilt.no/overvakingsprogrammet-for-hjortevilt/
[4] http://www.naturindeks.no
[5] Hjorteviltregisteret – nasjonal database fra jakt på elg, hjort, rådyr og villrein, og fallvilt av utvalgte arter - Hjorteviltregisteret
[6] www.rovdata.no, the national data centre for large carnivores

Absence of alien species is specified as the proportion of the area without alien vascular plant species with very high, high, or potentially high ecological risk, according to the list of alien species by the Norwegian Biodiversity Information Centre (Artsdatabanken 2018). In the reference condition, such alien species shall not occur, and the reference value is set to 100%. The limit value for good ecosystem condition is assessed by experts to 95% (Nybø et al. 2019). The data for this indicator come from ANO (Tingstad et al. 2019), where the cover of alien plant species is recorded within 250 m^2 circles at 18 regularly distributed points within each sampling plot (cf. Ellenberg N). The data have been recorded from 1742 forest points at 189 randomly placed plots for the whole country, covering the years 2019 and 2020 (cf. Ellenberg N).

Bilberry cover is specified as the proportion of the forest ground vegetation covered by bilberries (*Vaccinium myrtillus*). Bilberries are considered a key species in the forest, with great importance as forage for several mammal, bird, and insect species in both summer and winter. The data come from the National Forest Inventory (NFI). The reference value is the same as for the Norwegian Nature Index 2020 (Jakobsson & Pedersen 2020) and is based on NFI data from reference plots with natural forest characteristics (Nybø et al. 2018). The reference value varies between counties/part of counties, mainly linked to variations in regional productivity. The limit value for good ecosystem condition is set to 60% of the reference value.

Rowan-aspen-goat willow (*Sorbus aucuparia*, *Populus tremula* and *Salix caprea*, respectively) are boreal deciduous trees with great importance for many other species. The indicator is specified as total volume of the three species per hectare productive forest land, for trees of at least 10 cm in diameter. The data come from the NFI. The reference value is the same as for the Norwegian Nature Index 2020 and is specified as different values for various counties/part of counties, from 3 m^3/ha in Finnmark to 10 m^3/ha for lowland areas of eastern, southern, and western Norway. This is based on an assessment of volume of the three species in forest with natural disturbance regimes for NFI reference plots (Nybø et al. 2018). The limit value for good ecosystem condition is set to 60% of the reference value.

Tabell 3.1 *Indicators in the index for the condition of forest ecosystems, with data sources.*

Indicator	Explanation	Data source
NDVI	Deviation from the modelled reference NDVI score	MODIS satellite data
Ellenberg N	Ellenberg score for the affinity of plant species for nitrogen, weighted by the frequency of each species	ANO*
Ellenberg F	Ellenberg score for the affinity of plant species for soil moisture, weighted by the frequency of each species	ANO*
Large cervids	Aggregated abundance of elk (*Alces alces*) and red deer (*Cervus elaphus*) per km^2, weighted for size (metabolic weight), given as 'elk equivalents'	The Cervid Register/ Nature Index
Large carnivores	Aggregated abundance of wolf (*Canis lupus*), brown bear (*Ursus arctos*), lynx (Lynx lynx), weighted for size (metabolic weight), given as 'lynx equivalents'	Rovdata/Nature Index
Absence of alien species	Proportion (%) of area without alien vascular plant species	ANO*
Bilberry cover	Cover (%) of bilberry (*Vaccinium myrtillus*)	NFI*
Rowan-aspen-goat willow	Volume (m^3/ha) of trees of rowan (*Sorbus aucuparia*), aspen (*Populus tremula*), and goat willow (*Salix caprea*) >10 cm in diameter, for productive forest	NFI *
Dead wood total	Volume (m^3/ha) of dead wood >10 cm in diameter	NFI *
Coarse woody debris (CWD)	Volume (m^3/ha) of dead wood >30 cm in diameter	NFI *
Biologically old forest	Proportion (%) of area of forest older than specified limits for stand age for tree species and site productivity	NFI *
Area without technical infrastructure	Proportion (%) of forest area at least 1 km from major technical infrastructure	Norwegian Environment Agency
Nature index for forests	Aggregated scaled nature index value for forest	Nature Index

* ANO: Spatially representative nature monitoring programme; NFI: National Forest Inventory

Dead wood total and ***coarse woody debris*** are specified as volumes for dead wood per hectare, respectively, at least 10 cm and 30 cm in diameter. The data come from the NFI. The reference value for dead wood total is calculated for natural forest with varying site productivity, with a modelled age distribution and production of dead wood. The data for the volume of dead wood in old natural forests with varying productivity is based on various Nordic studies (see more detailed explanation and sources in Nybø et al. 2018). The volume of coarse woody debris is specified as 40% of the volume of dead wood total, based on various sources in the scientific literature (references in Nybø et al. 2018). The limit values for good ecosystem condition are set to 60% of the reference values for each indicator.

Biologically old forest is specified as the proportion of forest area with stand age older than limits set for each combination of spruce, pine or deciduous trees, and low, medium or high site productivity (cf. Nybø et al. 2018). The proportion of old forest is considered important for biodiversity in forests. The data come from the NFI. The reference value is estimated as 60% of the forest area based on adaptation of results from modelling studies for Finnish conditions (Nybø et al. 2018). The limit value for good ecosystem condition is set to 60% of the reference value. Note that since mountain birch forest makes up a large proportion of the area of deciduous forest, and mountain birch has a low maximum life expectancy, the age limits for deciduous forest for sites of different productivity are probably set somewhat too high. This means that the scaled indicator value should probably have been somewhat higher, especially for northern Norway where mountain birch forests make up a large proportion of the forest area.

Area without technical infrastructure is specified as the proportion of the forest area that is at least 1 km from major technical infrastructure such as roads, power lines, and other technical facilities (but not buildings). This is the same indicator for nature areas without technical infrastructure as compiled by the Norwegian Environment Agency[7]. Under the reference condition, there will be no such infrastructure, and the reference value is therefore set to 100%. The limit value for good ecosystem condition is set to 60% of the reference value.

Nature index for forests is an aggregated indicator of species diversity based on the value of the Nature Index for forests (Jakobsson & Pedersen 2020). The reason for including this index as an indicator of ecosystem condition is that it summarizes the condition of many species and some indirect indicators of species diversity. It thus provides a better opportunity to cover the characteristic biological diversity than a few species-based indicators for which we have available data. By integrating information on many species and indirect indicators, it also provides a more robust picture of the state of species diversity. Some of the data for the nature index for forests are also used in other indicators (bilberry cover, rowan-aspen-goat willow, biologically old forest, large cervids, large carnivores). However, these are assigned other ecosystem characteristics, and some of them are also designed differently here than in the Nature Index. Since the index is based on scaled indicators with their respective reference values (cf. Jakobsson & Pedersen 2020), the reference value here is 1. The limit value for good ecosystem condition is set as 60% of the reference value.

Indicators assigned to ecosystem characteristics

The assessment of ecosystem condition is based on the premise that an ecosystem in good condition has several characteristics that should not deviate significantly from the reference condition. To assess the condition of these characteristics, we need indicators that (to a greater or lesser degree) represent the individual characteristics. **Table 3.2** provides an overview of how the individual indicators presented above can be assigned to each of the seven characteristics that the expert group identified for ecosystems. The assignment is based on a qualitative assessment of how the individual indicators, or several indicators seen in context, can help to shed light on the condition of each characteristic (see also the description of each characteristic in

[7] Inngrepsfrie naturområder i Norge - Miljødirektoratet (miljodirektoratet.no)

chapt. 2). The assignment of the indicators to the individual characteristics is briefly justified as follows:

- *Primary production* includes indicators that represent different measures of the amount of green vegetation (NDVI) and vascular plants with different responses to access to nitrogen (Ellenberg N), respectively. Changes in the values of these indicators between different times may be seen as an expression of primary production.
- *Distribution of biomass between different trophic levels* includes the indicators *large cervids* and *large carnivores*, i.e., two important and closely linked ecosystem components among herbivores and predators, respectively. These indicators do not directly represent biomass, but abundance. We have not yet included indicators for primary producers, but indicators for the ecosystem characteristic primary production may be seen in connection with the indicators for cervids and carnivores. We have not constructed an indicator based on ratios between trophic levels but have chosen to assess the indicators for each trophic level individually. We can then assess whether deviations from the reference condition can be due to lower or higher abundance levels in one, more or all trophic levels.
- *Functional composition within trophic levels*: We have not yet succeeded in finding suitable indicators for this characteristic (but see proposals for further development in chapter 3.5).
- *Functionally important species and biophysical structures* include indicators of important structures such as dead wood and biologically old forests, the absence of alien species, as well as species such as bilberries and rowan, aspen, and goat willow. All are important for many other species in the ecosystem, in the form of habitat/substrate, food or the absence of negative ecological impacts (alien species).

Table 3.2 *Indicators assigned to the seven characteristics of ecosystems. The characteristic* functional groups within trophic levels *has no assigned indicators.*

Indicator	**Primary production**	**Distribution of biomass between trophic levels**	**Functional composition within trophic levels**	**Functionally important species and structures**	**Landscape ecological patterns**	**Biological diversity**	**Abiotic factors**
NDVI	x						
Ellenberg N	x						x
Ellenberg F							x
Large cervids		x					
Large carnivores		x					
Absence of alien species				x			
Bilberry cover				x			
Rowan-aspen-goat willow				x			
Dead wood total				x			
Coarse woody debris				x			
Biologically old forest				x	x		
Area without technical infrastructure					x		
Nature Index for forests						x	
Number of indicators	2	2	0	6	2	1	2

- *Landscape ecological patterns* include indicators for the proportion of biologically old forest area and area without technical infrastructure, respectively. Both represent areas of forest that are important for biodiversity. We currently lack indicators that explicitly represent the spatial pattern of such areas or resources of great importance for biodiversity.
- *Biological diversity* includes only one indicator, the nature index for forests. However, this includes over 80 species and other indicators compiled as a measure of the state of biological diversity in forests (Jakobsson & Pedersen 2020).
- *Abiotic factors* include two indicators, Ellenberg N and Ellenberg F. These represent the affiliation of vascular plant species to habitats with different access to nitrogen and moisture, respectively. They thus reflect some of the ecological effects of variation in chemical-physical conditions related to the availability of plant nutrients and moisture.

The number of indicators per characteristic varies a great deal, and some indicators represent several characteristics. The characteristic of *functionally important species and biophysical structures* has the most indicators (6), whereas the characteristic of *functional composition within trophic levels* has no suitable indicators. For the characteristic *biological diversity*, the choice of only one indicator is made deliberately, as this indicator represents a broad data set that has already been compiled in the work on the Nature Index, with the intention of assessing biological diversity in forests. Aggregated condition values for the individual characteristic are based on the values for the indicators included (cf. chapt. 3.3.1).

Indicators assigned to direct drivers
To make it easier to identify possible causes of observed changes in the ecosystem condition, and possibly follow up with management measures, it may be useful to assign the indicators to various main categories of drivers. **Table 3.3** shows the assignment of the indicators to main categories of drivers: different types of land use (including infrastructure development), climate change, pollution (here mainly eutrophication), direct management of wild populations (hunting or other management), and harmful alien species. We have tried to specify the most important drivers for each indicator, based on an expert assessment. Only direct impacts are used here, not indirect impacts via other parts of the ecosystem (e.g., the impact of forestry on predators via prey). The individual indicators can be influenced by several factors, in practice up to three factors.

Table 3.3 *Forest condition indicators assigned to main categories of anthropogenic direct drivers. Land use includes infrastructure development. Pollution mainly represents eutrophication.*

Indicator	Land use	Climate change	Pollution	Direct population management	Alien species
NDVI	x	x	x		
Ellenberg N		x	x		
Ellenberg F	x	x			
Large cervids	x	x		x	
Large carnivores				x	
Absence of alien species		x			x
Bilberry cover	x	x	x		
Rowan-aspen-goat willow	x				
Dead wood total	x				
Coarse woody debris	x				
Biologically old forest	x				
Area without technical infrastructure	x				
Nature index for forests	x	x			
Number of indicators	10	7	3	2	1

Ten indicators are mainly affected by land use or infrastructure development and seven by climate change. Five of these indicators are heavily affected by both factors. Few indicators are especially affected by the other factors. These indicators are most often also affected by climate change or land use. This assignment of the indicators to the drivers is the basis for calculating aggregate values for the indicators assigned to each driver (cf. chapt. 3.3.2).

3.2.2 Supplementary variables

We have data for some additional variables that may provide information on the condition of forest ecosystems. These cover aspects of some ecosystem characteristics that the regular condition indicators cover only partly or not at all. In addition, they may give different or more detailed impressions of the relevant characteristics. For some of these supplementary variables, we have not yet determined reference values or limit values. Hence, they cannot be used in the calculation of ecosystem condition according to the IBECA approach. Some variables also overlap too much with indicators already included. Nevertheless, such supplementary variables may provide additional information about the ecosystem condition by showing levels or trends that can be qualitatively assessed against what would be expected in an intact ecosystem. The purpose of assessing these supplementary variables is thus to see whether they strengthen, weaken or give details for the results based on the condition indicators and the IBECA approach.

Table 3.4 provides an overview of these supplementary variables and their data sources. They are briefly described below.

Biomass of trees represents the total standing biomass of forest trees calculated as volume per hectare. The data come from the National Forest Inventory. The biomass of trees constitutes a very large proportion of the biomass of primary producers in forests and thus covers a very important property of the ecosystem. We have not yet attempted to estimate what the volume of standing biomass of trees could have been in a reference state. This variable is assigned to the ecosystem characteristic *primary production* and is mainly influenced by the drivers land use, climate change, and pollution (eutrophication).

Tree species composition covers the native tree species in Norway and is specified as the share of standing volume (for cutting classes 3–5) or crown cover (for cutting classes 1–2) for the various tree species or groups of species (Viken 2020). This represents the species composition of the trees, the most dominating vegetation layer in forests. We have not yet attempted to derive an operational indicator with a reference value to represent tree species composition. Tree species composition is assigned to the ecosystem characteristics *functionally important species and biophysical structures* and *biological diversity*. It is mainly influenced by the drivers land use and climate change.

Birds in coniferous forest and ***birds in deciduous forest*** are aggregated population indices for birds associated with, respectively, coniferous and deciduous forests. They represent important and well-known parts of the species diversity in forests. The data come from the national breeding birds monitoring programme TOV-E (Kålås et al. 2021a); see Framstad et al. (2021) for the bird species included. The population data for each species have been normalised to its level in 2011. These normalised population scores for each species are then combined into aggregated indices for birds in coniferous and deciduous forests. We have not yet attempted to specify reference values for these indices. The indices are assigned to the ecosystem characteristic *biological diversity* and are mainly influenced by the drivers land use and climate change.

Trophic group indices have been constructed by assigning the individual indicators of the Nature Index for forests to relevant trophic groups (cf. Jakobsson & Pedersen 2020). The index values have been calculated from the scaled values for the underlying Nature Index indicators, where each indicator is scaled by its reference value and weighted by the geographical representation of the underlying data. Hence, the difference between the index value and 1 may be interpreted as the deviation from the reference condition, and the trophic indices could then be considered as possible condition indicators. However, as we have already included a condition indicator based on the full Nature Index for forest, there would be considerable overlap between this indicator and possible indicators based in the trophic indices. We have therefore just considered these trophic indices as supplementary variables. All these indices are assigned to the ecosystem characteristic *distribution of biomass between different trophic levels*. All the trophic indices are influenced by the driver land use. Primary producers, herbivores, medium predators, and decomposers are also influenced by climate change, primary producers also by pollution (eutrophication), and herbivores and top predators by direct population management.

Table 3.4 *Overview of supplementary forest variables and their data sources.*

Variable	Description	Data source	Ecological characteristics	Direct drivers
Biomass of trees	Volume of biomass with bark (m^3) per hectare	NFI*	Primary production	Land use Climate change Pollution
Tree species composition	Share of volume or crown cover per tree species	NFI*	Functionally important species and structures Biological diversity	Land use Climate change
Birds in coniferous and deciduous forests	Population indices for birds in coniferous and deciduous forest	TOV-E*	Biological diversity	Land use Climate change
NI trophic groups	Trophic grouping of indicators in the Nature Index for forests	Nature Index	Distribution of biomass between trophic levels	Land use Climate change Pollution Population management

* NFI: National Forest Inventory; TOV-E: Extensive monitoring of breeding birds

3.2.3 Variables for drivers

Variables for relevant drivers may help to identify possible causes for observed levels or trends for the indicators for ecosystem condition. We consider five main groups of such drivers (cf. also **Table 3.3**): land use (including infrastructure development), climate change, pollution (mainly eutrophication), direct population management (hunting, other population regulation), alien species with a likely substantial ecological effect. The various driver variables are listed in **Table 3.5** and briefly described below.

Land use

Forestry has the strongest and most extensive impact on Norwegian forests. Productive forest land covers about 70% of the forest area (Tomter & Dalen 2018). For most of the central coniferous forest areas in Eastern Norway, trees on more than 60% of productive forest land has so far been harvested by clear-cutting or other open harvesting (Storaunet & Rolstad 2020). Forestry includes various activities with ecological effects on the forest ecosystem, such as road building, ground preparation and ditching, planting of new and sometimes non-native trees, fertilisation, thinning and final harvest. In the reference condition large-scale modern forestry would not occur. We have represented some of these forestry activities with variables listed in **Table 3.5**.

Humans create various types of artificial, constructed land and technical infrastructure in the form of buildings, roads, power lines, energy production facilities etc. These may have extensive effects on natural diversity, by transforming ecosystems and fragmenting habitats. The sum of many different types of infrastructure within a given area increases the total load on species and ecosystems. Erikstad et al. (2013) have developed a map-based index for such overall infrastructure loads. It provides a score from 0 (no infrastructure) to 13.23 (100% infrastructure) for circles of 500 m radius covering the entire country. We have extracted statistics for forest areas.

Table 3.5 *Variables for drivers in forest.*

Variable	Explanation	Data source
Land use		
Annual harvested timber volume	Annual harvested timber volume for sale (except firewood)	Statistics Norway
Annual clear-cut area	Annual area clear-cut or cut with seed trees	NIBIO, Norwegian Agriculture Agency
Building of forest roads	Annual length of new forest roads 1950–2019	Statistics Norway
Annual area of planted forest	Annual planted area 1971–2019	Statistics Norway
Annual areal of ground preparation	Annual areal of prepared ground 1997–2019	Statistics Norway
Infrastructure index	Map-based index for total impact of technical infrastructure and constructed land	Erikstad et al. 2013
Climate change		
Summer temperature	Deviation in mean temperature for Jun–Aug from the normal period 1961–1990	Modelled data from MET
Winter temperature	Deviation in mean temperature for Dec–Feb from the normal period 1961–1990	Modelled data from MET
Annual precipitation	Deviation in annual precipitation from the normal period 1961–1990	Modelled data from MET
Days with precipitation	Deviation in annual number of days with precipitation from the normal period 1961–1990	Modelled data from MET
Days with snow cover	Deviation in annual number of days with snow cover from the normal period 1961–1990	Modelled data from MET
Growing season length	Deviation in length of the growing season from the normal period 1961–1990, calculated as number of days with mean temperature >5°C and no snow cover	Modelled data from MET
Pollution		
Nitrogen deposition by air/ precipitation	Annual amount of nitrogen deposited per hectare via air/precipitation	Modelled data from NILU
Forest fertilisation	Annual fertilised area	Norwegian Agriculture Agency
Direct population management		
Annual elk shot	Number of elk shot per season	Statistics Norway
Annual red deer shot	Number of red deer shot per season	Statistics Norway
Annual harvest of small game	Relative index for reported harvest of small game	Statistics Norway
Alien species		
Alien tree species	Proportion of alien conifer trees	National Forest Inventory
First time recording of alien forest species	Cumulative number of introduced species in non-wetland forest since 1800, all species and risk classes	Artsdatabanken 2018

Climate change

Scenarios for future climate development (Hanssen-Bauer et al. 2015) indicate that climate change will have considerable effects on the forest ecosystem, although climate change over the last 30 years appears to have had somewhat limited effects so far (e.g., Framstad 2021). Several different variables may capture different aspects of climate change. Data for all variables used here are interpolated daily data from the Norwegian Meteorological Institute (MET), with a spatial resolution of 1 km^2. The variables have been specified as deviations from the comparable values for the normal period 1961–1990. The climate for this period is specified by the expert group as appropriate for the reference condition (cf. Nybø & Evju 2017). The presented variable values thus represent deviations from the reference values for the respective variables. The most relevant variables are listed in **Table 3.5**.

Pollution
Pollution may cover both long-range pollution via air and precipitation as well as emissions from local sources. It may include heavy metals, various organic pollutants, ground level ozone, as well as sulphur and nitrogen compounds with acidification or eutrophication effects. In our context we consider the eutrophication effects from nitrogen deposition to be most likely to have noticeable ecological effects. We have included variables for, respectively, long-range nitrogen deposition and local forest fertilisation (**Table 3.5**).

Direct pollution management
Harvesting from wild animal populations mainly includes regulated hunting of game birds or mammals, as well as the government-sanctioned regulation of large carnivores. Harvesting of trees is generally considered as a form of land use, whereas other harvesting of plants mostly have limited effects on plant populations. We consider variables for changes in population levels of game species or large carnivores as potential condition indicators, whereas the harvesting represents a driver. We have included annual hunting data for some of the main game species (**Table 3.5**). The regulation of the populations of large carnivores is a direct consequence of management actions to achieve policy targets and the annual cull is not presented here.

Alien species
We consider the occurrence or amount of alien species as a measure of the possible impact of such species. The possible ecological effects of such species may be considered as potential condition indicators. Alien species include species which are assumed to have been established or have arrived in Norway after 1800 (Artsdatabanken 2018). We have collated a variable for the cumulative number of forest-related alien species ordered by their assumed first year of record after 1800. Many species, especially among fungi and invertebrates, may have been established long before they were first recorded. We also present data from the National Forest Inventory on the proportion of alien conifer tree species (measured in the same way as tree species composition for native species, cf. chapt. 3.2.2).

3.3 Assessment of the condition of forest ecosystems

3.3.1 Overall condition of forest ecosystems and ecosystem characteristics

The overall condition of forest ecosystems in Norway has a value below the limit value for good ecological condition (**Figure 3.2**). This is the case whether we calculate the condition value directly from the individual indicators (0.42, white diamond in the figure) or based on the values for the ecosystem characteristics (0.45, black diamond). By basing the calculation of overall condition on the indicators directly, each indicator is given the same weight. The calculation based on the values for the ecosystem characteristics gives more weight to indicators which have been assigned to more than one characteristic (**Table 3.2**). However, this does not appear to have much effect on the overall condition value in this case. How the overall condition value depends on the condition values of the various ecosystem characteristics and the underlying indicators is discussed below.

Primary production
The primary production of the ecosystem is the foundation for the entire plant-based food chain and thus a fundamentally important characteristic of the ecosystem. Deviations from good ecosystem condition may result in reduced or increased primary production compared to the production in an intact ecosystem. This is reflected in the two indicators for this characteristic, NDVI and Ellenberg N, both with lower and upper limit values for good ecological condition.

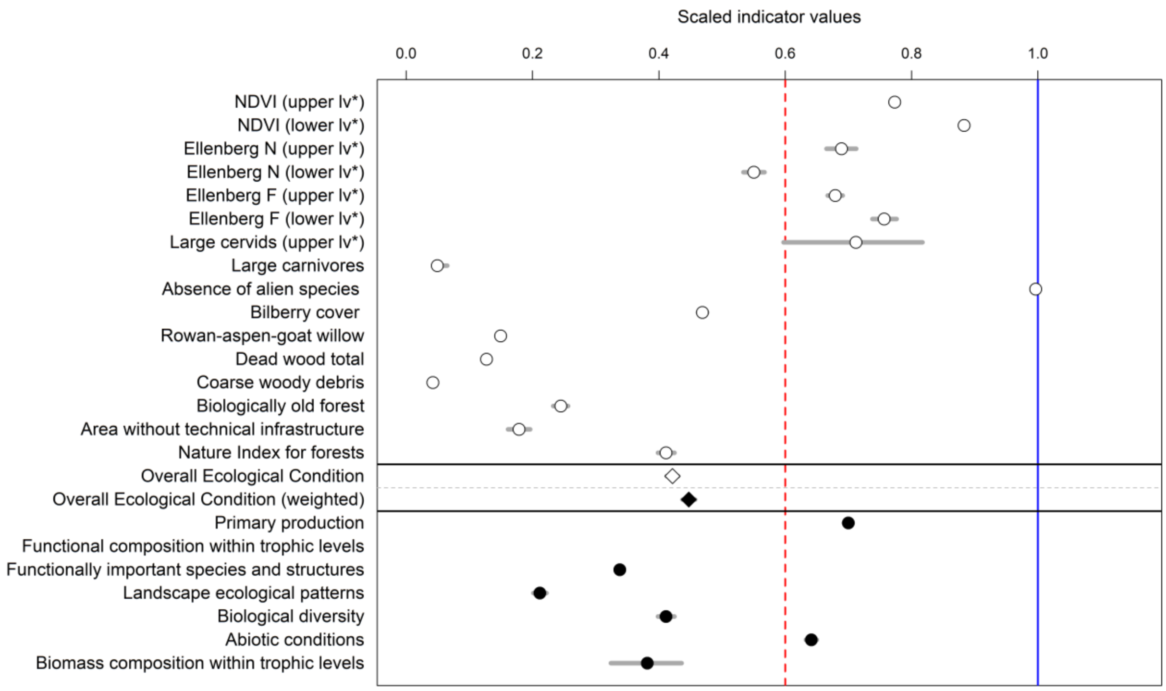

Figure 3.2 *Calculated condition for forest ecosystems in Norway. White circles show the scaled values for the individual indicators included in the calculation. The white diamond shows the overall condition value for the ecosystem based on these indicators directly, whereas the black diamond shows the overall condition value based on the condition values for the various ecosystem characteristics (black circles). The symbols show the median values for indicators or the mean condition values, and grey and black lines show the 95 % confidence interval (some are hidden by the symbols). The blue vertical line marks the reference value, and the red dotted line marks the limit value for good ecosystem condition.*

The condition value for the ecosystem characteristic *primary production* is 0.70, clearly above the limit value of for good ecological condition (**Figure 3.2**). The scaled value for NDVI is well above the lower and upper limit values. For Ellenberg N, the value is just below the lower limit value, indicating that the plant communities have less access to nitrogen than expected for ecosystems in good condition. The mean unscaled NDVI values show a weak increase over the last 10 years (cf. Figure 3.7 in Framstad et al. 2021). We have no time series for Ellenberg N.

The standing volume of trees represent a major part of the plant biomass. Data from the National Forest Inventory (Tomter & Dalen 2018) show that the standing volume of trees has increased substantially from the 1950s, with a total volume of 978 million m^3 (under bark) today[8]. This is quite close to the 1000 million m^3 maximum historic standing volume assumed by Rolstad et al. (2002). However, due to intensive forestry for more than a hundred years, the current forests have a completely different structure of tree species and size and age classes than would be expected for an intact forest ecosystem.

Distribution of biomass between different trophic levels

In an ecosystem near the reference condition, the species composition and the population level of the species should cover the various trophic levels and functional roles of the food web. If there is a lack of balance between trophic levels or much lower overall production in the ecosystem than in the reference condition, the ecosystem condition should be considered as degraded. In the ecosystem characteristic *distribution of biomass between different trophic levels*, we only

[8] Skogbruk (ssb.no)

have indicators for two such levels, for large cervids and large carnivores. To some extent the indicators NDVI and Ellenberg N for the characteristic *primary production* may represent plant abundance and be compared to the abundance of cervids and carnivores.

The condition value 0.38 for the ecosystem characteristic *distribution of biomass between different trophic levels* is considerably lower than the limit value for good condition (**Figure 3.2**). The scaled value for large carnivores (0.05) is especially low, whereas the scaled value for large cervids (0.71) is above the limit value. The populations of the large carnivores have been kept at low levels as a result of public policy. In contrast, the populations of elk and red deer have increased considerably over the last 100 years and are now considered to be much higher than in intact forests (cf. Figures 3.9 and 3.10 in Framstad et al. 2021).

The underlying indicators for the Nature Index for forests can be assigned to trophic groups and developed into trophic indices based on the scaled values of the indicators (cf. chapt. 3.2.2). These trophic indices confirm that the ecosystem characteristic *distribution of biomass between different trophic levels* is unbalanced. The trophic groups top predators and decomposers have very low values (< 0.40), whereas primary producers and medium predators have values clearly above 0.6, and the value for herbivores is just below 0.6 (**Figure 3.3**).

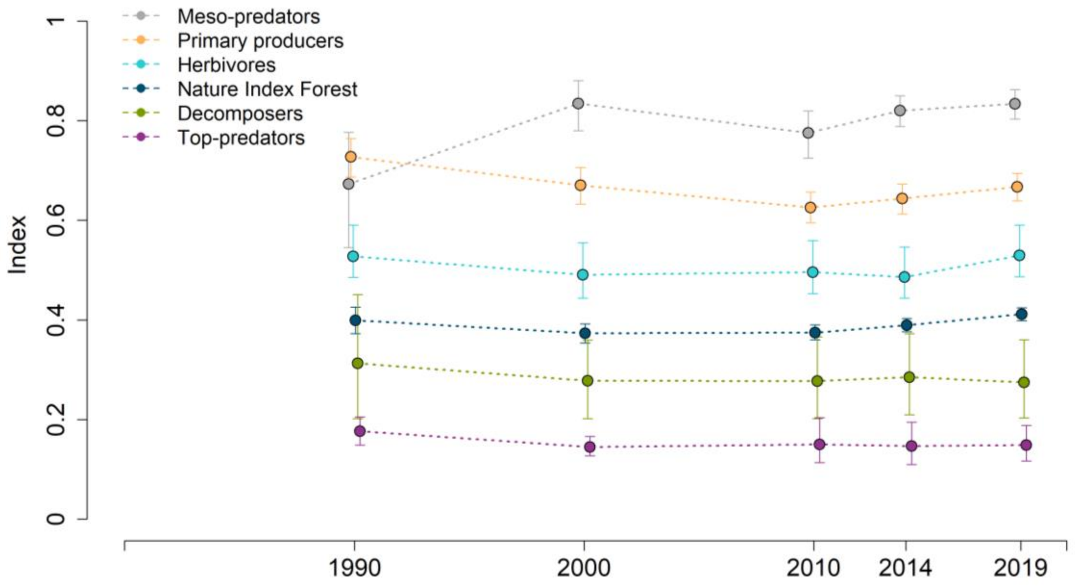

Figure 3.3 *The overall Nature Index for forests and five trophic indices based on grouping of the underlying indicators in the Nature Index. The overall Nature Index is included as an indicator in the calculation of condition for forest ecosystems, whereas the trophic indices are included as supplementary variables. Tre trophic indices include the following underlying taxa as indicators: primary producers (9 vascular plants, 7 bryophytes, 6 fungi, 4 other taxa), herbivores (5 mammals, 3 birds, 4 insects), medium (meso) predators (29 bird species, 2 insects), top predators (4 mammals, 2 bird), decomposers (5 fungi, 2 categories of dead wood).*

Functional composition within trophic levels
This ecosystem characteristic represents the composition of species with various functional roles within trophic levels. We have not managed to find relevant indicators for this characteristic for forests.

Functionally important species and biophysical structures
Certain species and biophysical structures may have great significance for various ecosystem functions, e.g., by providing or regulating habitats or resources for many other species. An

ecosystem in good condition should not have much lower supply of such functionally important species and structures than in the reference condition. Several indicators have been assigned to the ecosystem characteristic *functionally important species and biophysical structures*: absence of alien species, bilberry cover, rowan-aspen-goat willow, dead wood total, coarse woody debris, and biologically old forest. These indicators partly represent plant species important for many herbivores and pollinators, and partly structures of great importance as habitat and substrate for many different species. The absence of alien species is important as such species represent real or potential ecological risk.

The condition value 0.34 for the ecosystem characteristic *functionally important species and biophysical structures* is much lower than the limit value for good ecological condition (**Figure 3.2**). Most of the indicators have very low scaled values: dead wood total (0.13), coarse woody debris (0.04), rowan-aspen-goat willow (0.15), and biologically old forest (0.24). The value for bilberry cover (0.47) is also lower than the limit value, whereas the value for absence of alien species (1) is very close to the reference value. The indicators with low values have increased somewhat over the last 30 years (**Figure 3.4**).

Landscape ecological patterns

In a forest ecosystem in good condition, different habitat types, tree species, age classes and various resources that are important for species should occur in a quantity and with a spatial distribution that ensures the long-term survival of native species. For the calculation of the condition value for the characteristic *landscape ecological patterns*, we have used the indicators biologically old forest and area without technical infrastructure. These indicators represent the extent of old forest and area without technical infrastructure, respectively, but do not capture the degree of fragmentation or other measures of the spatial distribution of such areas. We currently lack indicators for these aspects of *landscape ecological patterns* (but see chapt. 3.5).

The condition value for the characteristic *landscape ecological patterns* (0.21) is considerably lower than the limit value for good ecosystem condition (**Figure 3.2**). Both indicators for this characteristic have very low scaled values: area without technical infrastructure 0.18, biologically old forest 0.24. Note that the value for the latter is probably somewhat lower than it really should be, since the age limit for deciduous forest is probably set too high for mountain birch, which in terms of area constitutes much of deciduous forest. The trends for these indicators go in different directions, with a slight increase for biologically old forest and a slight reduction for area without technical infrastructure (cf. **Figure 3.4** and Figure 3.16 in Framstad et al. 2021)

Biological diversity

An ecosystem in good condition should not have a substantially different species richness, species composition, or species turnover than in the reference condition. There are many ways to represent these aspects of biological diversity, but it is difficult to capture all aspects in a few indicators. We have chosen to represent the ecosystem characteristic *biological diversity* with a single indicator, the nature index for forest, which covers the condition of many species.

The condition value for the characteristic *biological diversity* 0.41 is below the limit value for good ecosystem condition (**Figure 3.2**). This corresponds directly to the scaled value for the nature index for forests (0.41). The nature index for forests shows a rather stable trend over the last 30 years (cf, **Figure 3.3**).

Birds represent a well-known part of the species diversity in forests and include many species with different adaptations and responses to various drivers. The national monitoring of breeding birds (TOV-E, Kålås et al. 2021a) provide data for assessing population changes over the last 10 years in selected species associated with coniferous and deciduous forests, respectively. There is considerable population variation for these species between years, with a slight increase for coniferous forest birds and no trend for deciduous forest birds for the last 10 years (cf. Figure 3.18 in Framstad et al. 2021). Kålås et al. (20121b) conclude that forest-related birds in general show stable trends since 2007.

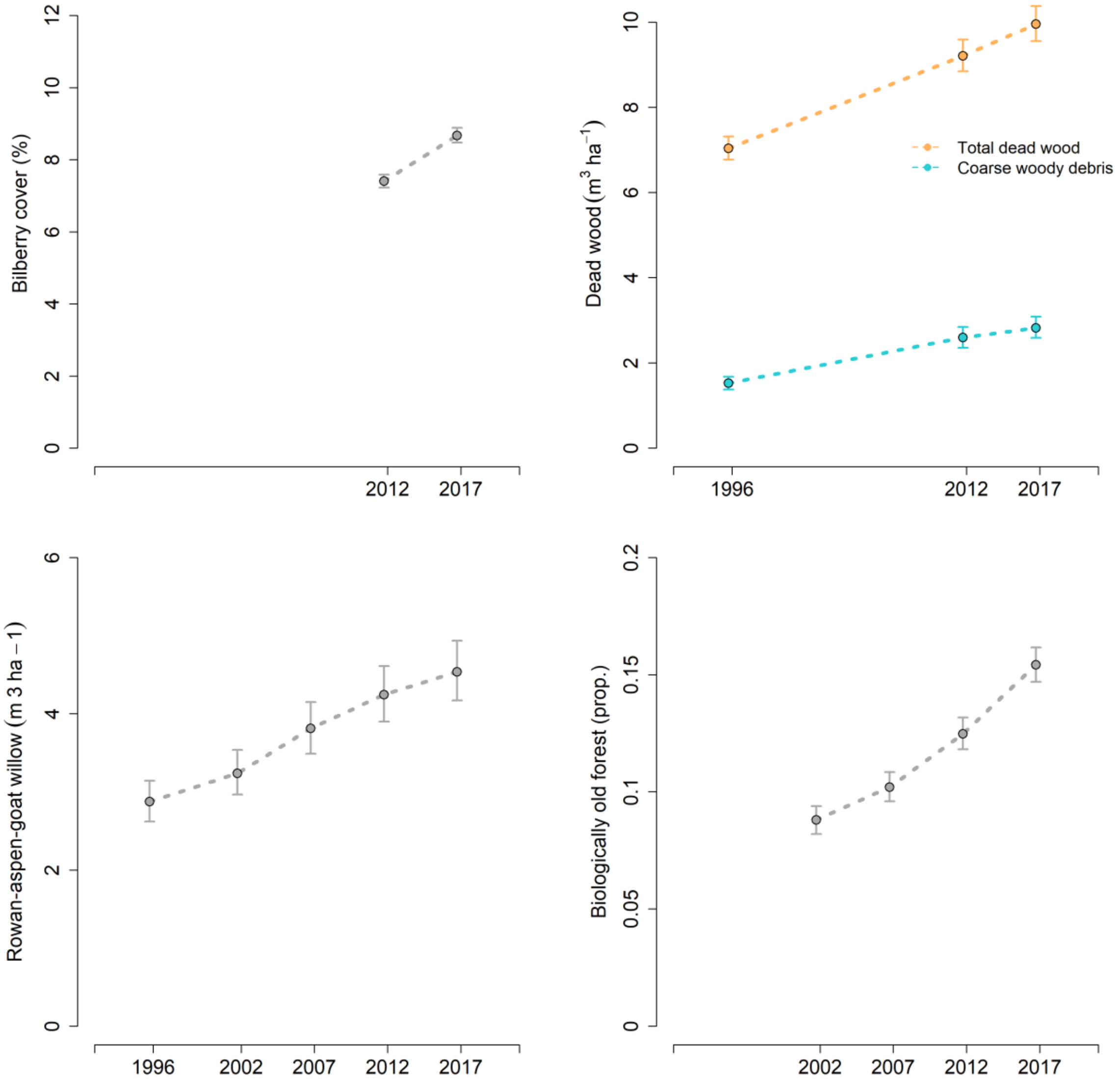

Figure 3.4 *Trends for the indicators* bilberry cover, dead wood, rowan-aspen-goat willow *and* biologically old forest*. All indicators are assigned to the ecosystem characteristic* functionally important species and biophysical structures*,* biologically old forest *is also assigned to the characteristic* landscape ecological patterns*.*

The tree species composition is a characteristic feature of the species diversity in forests. The National Forest Inventory has data for the cover of several tree species. Over the last 20 years, there are only minor changes in cover among the species, but some deciduous species other than birch appear to have increased slightly (**Figure 3.5**).

Abiotic factors

Physical and chemical relationships in the ecosystem can be of great importance for various ecosystem processes, not least related to the cycles of water and various nutrients. In an ecosystem in good condition, the variation in such relationships should not deviate much from the corresponding variation in the reference condition. For the characteristic abiotic factors, we currently have two indicators, Ellenberg N and Ellenberg F (both with lower and upper limit values). They represent the responses of the vegetation to, respectively, soil nitrogen and moisture.

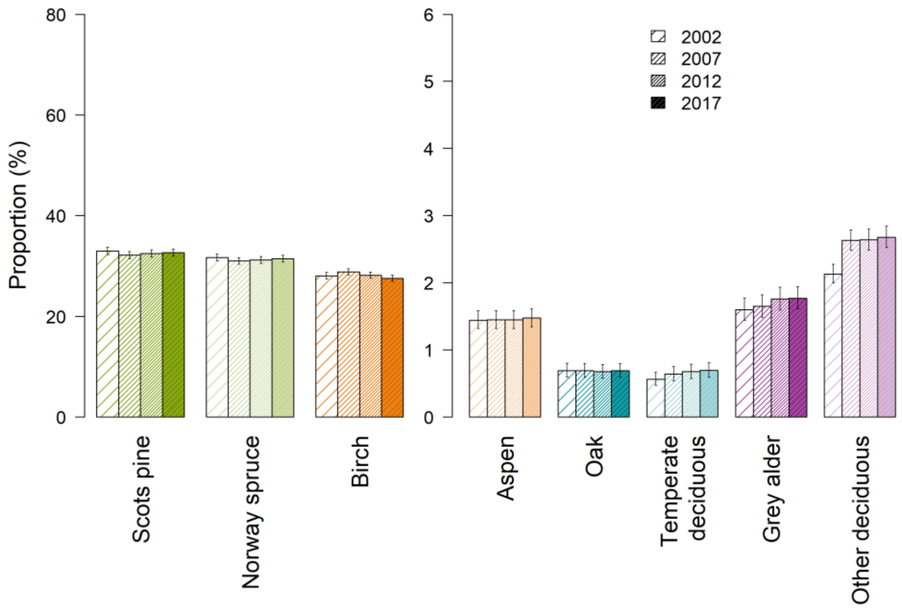

Figure 3.5 *Tree species distribution for forest below the coniferous forest limit outside Finnmark. Alien tree species are not included. Note the different scales on the y axes. Tree species distribution is a supplementary variable not included in the calculation of ecosystem condition.*

The condition value of the characteristic *abiotic factors* 0.64 is slightly above the limit value for good ecological condition (**Figure 3.2**). The scaled value for the Ellenberg N indicator is slightly below the lower limit value (0.55) and slightly above the upper limit value (0.69), whereas the scaled value for Ellenberg F is above both lower and upper limit values (0.76 and 0.68). Ellenberg N indicates that the vegetation responds to a somewhat lower supply of nitrogen than expected for an ecosystem in good condition.

Based on knowledge about the pattern and trends for long-range air pollution, critical loads for nitrogen effects on the vegetation are still exceeded in southwest Norway (Austnes et al. 2018). This does not seem to be captured by the values for the Ellenberg N indicator.

3.3.2 Aggregated values for indicators linked to main drivers

The most important main categories of drivers for each individual indicator are given in **Table 3.3**. Based on this assignment of indicators to drivers, we have calculated an aggregated condition value for indicators related to each main category of drivers. This may give an indication of the most important drivers for the calculated ecosystem condition value. The aggregated condition values for indicators related to the various drivers are shown in **Figure 3.6**.

Land use
Ten of the indicators are assumed to be particularly affected by land use (**Table 3.3**), mainly by various forestry activities, but for some also infrastructure development. They have an aggregated condition value of 0.39. Except for large cervids, NDVI and Ellenberg F, most relevant indicators have scaled values below the limit value for good condition (0.60). This applies especially to the indicators coarse woody debris, dead wood total, biologically old forest, rowan-aspen-goat willow and area without technical infrastructure, all with scaled values below 0.25.

Over the last 20 years (for years with available data), trends are positive for the indicators bilberry cover, coarse woody debris, dead wood total, biologically old forest and rowan-aspen-goat willow, all with data from the National Forest Inventory (Tomter & Dalen 2018; cf. **Figure 3.4**).

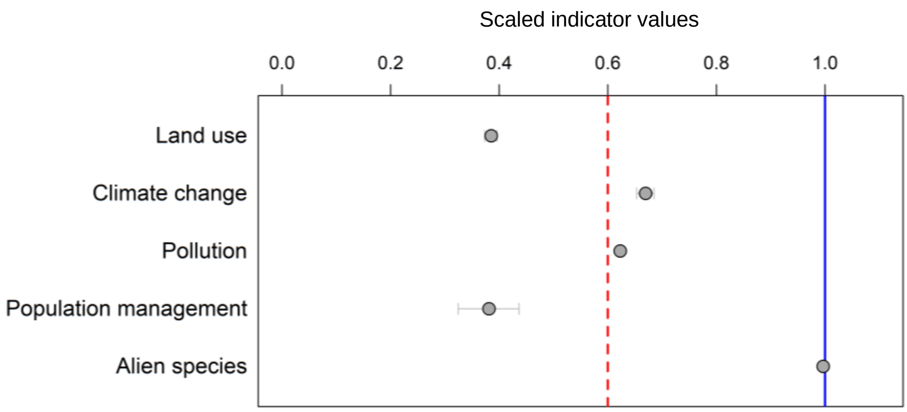

Figure 3.6 *Aggregated condition values for indicators that are assumed to be sensitive to main categories of anthropogenic drivers. Grey horizontal lines indicate 95% confidence intervals (some are hidden by the symbols). The blue vertical line marks the reference value, and the red dotted line marks the limit value for good ecosystem condition.*

Populations of elk and red deer have increased strongly over for several decades and are now considered too high for an ecosystem in good condition (cf. Figure 3.9 in Framstad et al. 2021). The trend for area without technical infrastructure is weak but negative, and there is little change for the indicator nature index for forests (cf. Figure 3.16 in Framstad et al. 2021 and **Figure 3.3**).

The positive trends for several of the condition indicators stand in contrast to the steadily increasing impact from forestry. About 450–500 km^2 are now felled annually, i.e., just over 0.5% of the productive forest area outside Finnmark[9]. This includes more than 10 million m^3 of timber for sale to industry[10], which in the last five years is equivalent to about 45% of annual timber growth[11]. Various forestry activities such as road construction, ground preparation and planting have also reached a great extent over recent decades. For example, since 1950 more than 49,000 km of forest roads have been built[12], i.e., almost 0.6 km of road per km^2 of productive forestry land. Since 1971, new trees have been planted on more than 11,000 km^2, i.e., about 13% of productive forestry land[13]. Storaunet & Rolstad (2020) have shown that the proportion of productive forest that has not previously been clear-cut has now been reduced to about 30%. If this trend continues, such non-clear-cut forest will only include forest in protected areas in a few decades. Many of the important resources for species diversity in forests, such as dead wood and old trees, are particularly associated with old forests that have not previously been clear-cut (Storaunet & Rolstad 2015). Hence, it is probable that several of the condition indicators, which now show positive trends, will reverse to negative trends in a few years.

The extent of infrastructure and strongly human-affected area is also increasing, as is illustrated in the reduction in area at least 1 km from technical infrastructure[14]. An index for the total impact from infrastructure and man-made areas has been developed by Erikstad et al. (2013), showing that forest regions in southern Norway and in the lowlands have a significantly higher human impact than elsewhere[15].

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[9] data from Resultatkontroll skogbruk/miljø from NIBIO or the Norwegian Agriculture Agency
[10] https://www.ssb.no/statbank/table/03795/
[11] Skogbruk (ssb.no)
[12] 03772: Bygging og ombygging av helårs bilveier og sommerbilveier (F) 1950 - 2020. Statistikkbanken (ssb.no)
[13] https://www.ssb.no/statbank/table/08705/
[14] Inngrepsfri natur (miljodirektoratet.no)
[15] https://vegar.users.earthengine.app/view/infrastrukturindeks

Climate change
Seven indicators are assumed to be particularly affected by climate change (**Table 3.3**), with increasing summer temperatures and length of the growing season as the most important climate impacts. These indicators have an aggregated condition value of 0.67, i.e., above the limit value for good ecosystem condition. The indicators bilberry cover and nature index for forests both have scaled values below 0.50. Ellenberg N is just below the lower limit value for good condition. Trends over the last decade for the indicators NDVI, bilberry cover and the nature index for forests are positive (cf. Figure 3.7 in Framstad et al. 2021; **Figures 3.3, 3.4**). The populations for elk and red deer have increased considerable over many decades (cf. figures in Framstad et al. 2021) but this is less a result of climate change and mainly due to land use change and direct population management of cervids and large carnivores.

The summer and winter temperatures show clear increases compared to their level in the normal period 1961–1990 (**Figure 3.7**). After about 2000, the length of the growing season is also well above the level for the normal period. Annual precipitation does not show a consistent trend, whereas the number of days with precipitation has increased. The number of days with snow cover has decreased, although with large annual variations.

Pollution
Only three indicators are assumed to be particularly affected by pollution, in particular nitrogen deposition (**Table 3.3**), NDVI and Ellenberg N (both with lower and upper limit values), and bilberry cover. These indicators have an aggregated condition value of 0.62, i.e., slightly above the limit value for good ecosystem condition. Bilberry cover has the lowest scaled value (0.47).

Data for nitrogen deposition through air and precipitation, as well as the pattern in the exceedance of critical loads for nitrogen for forest vegetation (Austnes et al. 2018), indicate that the nitrogen impact on the forest ecosystem is highest in the southwest and decreases northwards. A complicating factor is forest fertilisation, which has increased significantly in recent years after a period of relatively low fertilisation activity (Norwegian Agriculture Agency, in lit.). It is worth noting that recommended fertiliser levels are 150 kg N/ha, spread about 10 years before planned final harvest (Skogkurs 2016). Distributed over such a 10-year period, this corresponds to about three times the vegetation's critical loads for nitrogen deposition (Austnes et al. 2018), with probably the strongest ecological effects in the first couple of years after fertilisation.

Direct population management
Large cervids and large carnivores are the only indicators assumed to be particularly affected by direct population management (**Table 3.3**), by regular hunting and population regulation, respectively. The aggregated condition value is 0.38, i.e., well below the limit value for good condition. The low scaled value, 0.05, for large carnivores reduce the value. The value for large cervids, 0.71, is above the limit value. Population trends have generally increased for both cervids and carnivores, although with somewhat reduced population levels of elk, brown bear and lynx the last ten years (cf. Figures 3.9, 3.10 in Framstad et al. 2021). Population levels for the carnivores are a direct result of management targets. Populations of elk and red deer are affected by land use, climate conditions and hunting. Numbers of killed red deer have increased substantially in the last 50 years, while the number of killed elk has stagnated in the last 30 years[16].

Populations of various species of small game represent important components of the ecosystem. We have not developed a condition indicator for such species, but trends in the felling of such species may indicate possible effects of hunting. There is a clear decline in the overall number of small game killed during 1995–2020[17]. Decline in the felling of small game may be related to reduced populations (for various reasons) but may also be related to a decline in hunting activity.

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16 https://www.ssb.no/elgjakt, Hjortejakt - SSB
17 Småvilt- og rådyrjakt - SSB

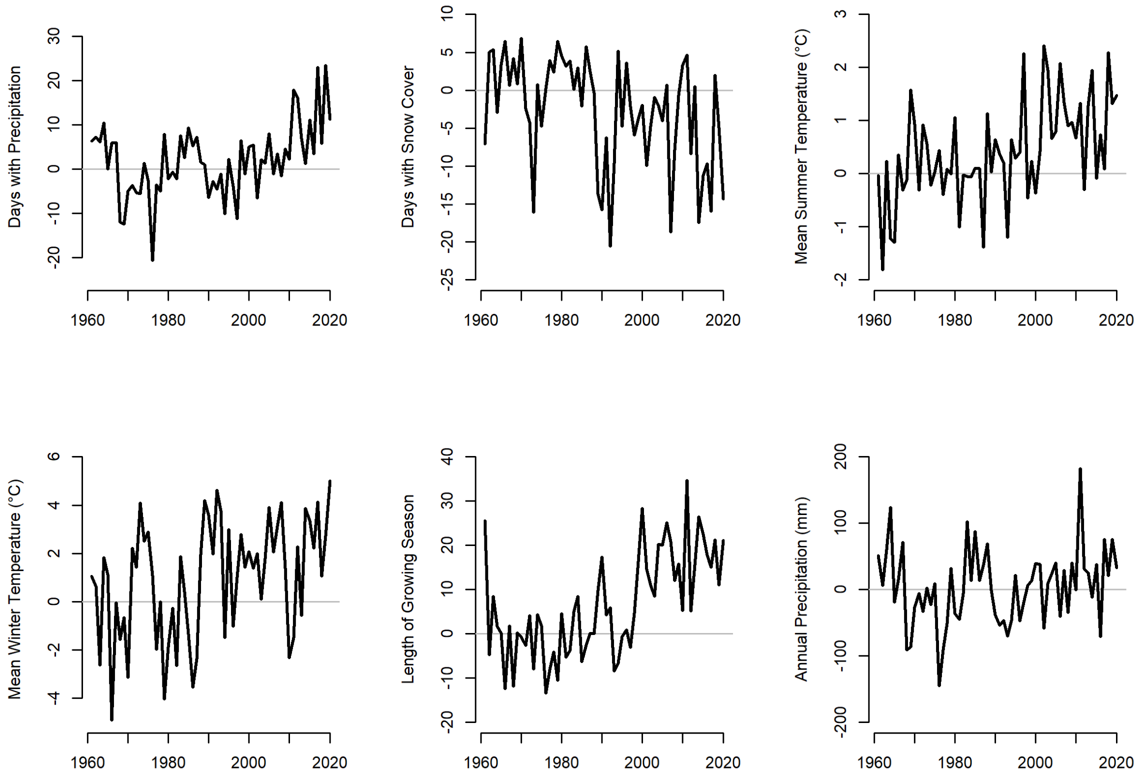

Figure 3.7 *Deviations in values of selected climate variables from their values in the normal period 1961–1990, for forest areas. Data are based on interpolated data from the Norwegian Meteorological Institute.*

However, the number of hunters who have paid hunting fees has increased from just under 190,000 in 2001/2002 to just over 200,000 in 2018/2019[18].

Alien species

There is only one indicator that represents the influence of alien species, the absence of alien species. The scaled value for this indicator is almost equivalent to the reference value (1). In the data from the monitoring program ANO in 2019–2020, few such species have been recorded, possibly due to few sample sites so far in regions with most frequent occurrence of such species. In general, it assumed that the number and quantity of alien species will increase (Hendrichsen et al. 2020). Collation of the cumulative number of recorded introductions of forest-associated alien species since 1800 show a steady increase to over 1240 such introductions today (Artsdatabanken 2018). Data from the National Forest Inventory of alien coniferous species show that they cover about 1% nationally, with around 4% in Western Norway (**Figure 3.8**).

[18] https://www.ssb.no/statbank/table/03508/

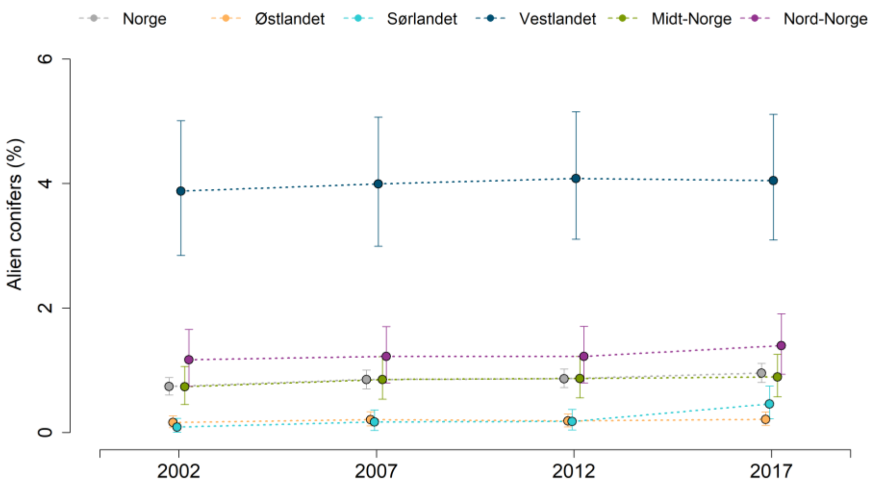

Figure 3.8 *Coverage of alien coniferous tree species in Norway and in different regions. Based on data from the National Forest Inventory.*

3.3.3 Summary of results for forests

The indicator values and condition estimates give a somewhat varied impression of forest ecosystem condition. The individual indicators cover different smaller parts of the whole, with different degrees of certainty for the indicator estimates. Below we will see all our data in context and assess how well they support the conclusions about the condition for forest ecosystems.

A summary of results based on levels and trends for condition indicators and supplementary variables are summarized in **Table 3.6**. The actual calculation of the condition for forest ecosystems is based on thirteen indicators (the three indicators with both lower and upper limit values count as one indicator each).

For forests in Norway, the calculated value for ecosystem condition is 0.42. Six indicators, in particular, contribute to this low condition value (scaled values in parentheses): large carnivores (0.05), coarse woody debris (0.04), dead wood total (0.13), rowan-aspen-goat willow (0.15), area without technical infrastructure (0.18) and biologically old forest (0.24). The nature index for forests (0.41) and bilberry cover (0.47) are also well below the limit value for good ecosystem condition. The other indicators have scaled values close to or well above the limit value for good ecosystem condition.

The assignment of the condition indicators to the ecosystem characteristics says something about how deviations from the reference condition are likely to affect the ecosystem. We have included both condition indicators and supplementary variables (**Table 3.6**).

- *Primary production*: This characteristic has an estimated condition value of 0.70, based on the indicators NDVI and Ellenberg N, i.e., with a moderate deviation from the expected value in the reference condition. The supplementary variable for biomass of trees also does not indicate a substantial deviation from the reference condition.
- *Distribution of biomass between different trophic levels*: This characteristic has an estimated condition value of 0.38, based on the indicators large cervids and large carnivores. The low value for large carnivores particularly contributes to a low condition value, whereas the value for large cervids is above the limit value for good condition. The indicators used for the characteristic primary production indicate that the primary production does not deviate much from the reference condition. The supplementary variables for the nature index trophic groups indicate that primary producers and intermediate predators deviate little from the reference condition, whereas especially top predators and decomposers deviate greatly. Hence, it is large carnivores that represent a substantial

imbalance between trophic levels, and this is confirmed by the trophic index for top predators for the supplementary variables.

- *Functional composition within trophic levels*: We currently have no condition indicators for this characteristic.
- *Functionally important species and biophysical structures*: This characteristic has an estimated condition value of 0.34, based on the indicators absence of alien species, bilberry cover, rowan-aspen-goat willow, biologically old forest, coarse woody debris and dead wood total. The condition value is much lower than expected in the reference condition, and it is especially the last four of the listed indicators that reduce the condition value. Neither the absence of alien species nor the supplementary variable for tree species composition indicates substantial deviations from the reference condition.

Table 3.6 *Summary of results for the characteristics of forest ecosystem in Norway, for the indicators included in the calculation of condition values and for supplementary variables (in italics). For indicators used in the calculation of condition values, scaled values are given. For supplementary variables the level is compared qualitatively to an assumed level in the reference condition: ++ very near, + near, - moderate deviation, -- strong deviation, ? uncertain. For both types of indicators time series (for unscaled values) are indicated with length in number of points and period, as well as trend: ↑ increasing, ↓ decreasing, ↔ stable, – too short time series.*

Ecosystem characteristics	Condition value	No. indicators	Indicators / *Supplementary variables*	Value	Time series: trend
Forests overall	***0.42***	***13***			
Primary production	0.70	2	NDVI (lower) NDVI (upper)	0.88 0.77	10 (2010-2019): ↔
			Ellenberg N (lower) Ellenberg N (upper)	0.55 0.69	1 (2019): –
			Biomass trees	+?	5 (1996-2017): ↑
Distribution of biomass between different trophic levels	0.38	2	Large cervids	0.71	5 (1990-2019): ↑
			Large carnivores	0.05	5 (1990-2019): ↑
			NI-primary producers	+	5 (1990-2019): ↓
			NI-herbivores	-	5 (1990-2019): ↑
			NI-medium predators	++	5 (1990-2019): ↑
			NI-top predators	--	5 (1990-2019): ↓
			NI-decomposers	--	5 (1990-2019): ↔
Functional composition within trophic levels	–	0	(ingen)		–
Functionally important species and biophysical structures	0.34	6	Absence of alien species	1.00	1 (2019): –
			Bilberry cover	0.47	2 (2012-2017): ↑
			Rowan-aspen-goat willow	0.15	5 (1996-2017): ↑
			Dead wood total	0.13	2(3) (1996. 2012-2017): ↑
			Coarse woody debris	0.04	2(3) (1996. 2012-2017): ↑
			Biologically old forest	0.24	4 (2002-2017): ↑
			Tree species composition	-?	4 (2002-2017): –
Landscape ecological patterns	0.21	2	Biologically old forest	0.24	4 (2002-2017): ↑
			Areal without technical infrastructure	0.18	6 (1988-2018): ↓
Biological diversity	0.41	1	Nature index for forests	0.41	5 (1990-2019): ↔
			Tree species composition	-?	4 (2002-2017): –
			Birds in coniferous forest	-?	10 (2011-2020): ↑
			Birds in deciduous forest	-?	10 (2011-2020): ↔
Abiotic factors	0.64	2	Ellenberg N (lower) Ellenberg N (upper)	0.55 0.69	1 (2019): –
			Ellenberg F (lower) Ellenberg F (upper)	0.76 0.68	1 (2019): –

- *Landscape ecological patterns*: This characteristic has an estimated condition value of 0.21, based on the indicators biologically old forest and area without technical infrastructure. Both these indicators have the same low scaled value and indicate a substantial deviation from the reference condition.
- *Biological diversity*: This characteristic has an estimated condition value of 0.41, based on the indicator nature index for forest, which represents the condition for many species and indirect indicators for species diversity in forests. The condition value gives a clear indication of a substantial deviation from the reference condition. The supplementary variables tree species composition, birds in coniferous forests and birds in deciduous forests do not provide a basis for assessing deviations from the reference state.
- *Abiotic factors*: This characteristic has an estimated condition value of 0.64, based on the indicators Ellenberg N and Ellenberg F. The condition value indicates a clear deviation from the reference condition.

The available data series for the condition indicators are generally short (maximum 30 years or ten data points) (**Table 3.6**). For the three indicators based on data from the monitoring programme ANO (Ellenberg N, Ellenberg F, absence of alien species), there are currently no time series. The trends may only tell us whether the indicators in recent years have to some extent moved away from or approached the reference condition. The five indicators based on the National Forest Inventory data (bilberry cover, rowan-aspen-goat willow, coarse woody debris, dead wood total, biologically old forest), mainly show a positive trend, although the changes are not large within the short time periods with data. Unscaled values for large cervids and large carnivores also show an increasing trend over the last 30 years, but with a decline for some of the species in the last 10 years. The populations for large cervids are considered higher than expected in the reference condition, so an increase represents a negative effect for the ecosystem condition. The nature index for forests shows a slight increase over the last ten years, but no clear change for the entire 30-year period. NDVI shows a slight increase for the ten years available here but in view of the annual variation we consider it as more or less stable. Area without technical infrastructure shows a slight reduction, as expected.

The individual indicators are to varying degrees sensitive to anthropogenic drivers. We have assigned the condition indicators to five main categories of such drivers (**Table 3.7**). We also have data for several individual drivers (cf. chapt. 3.3.2). The results indicate the following relationships between forest ecosystem condition and the main categories of drivers:

- *Land use*: Ten indicators are considered as particularly sensitive to land use, most of them related to the effects of forestry. Area without technical infrastructure is to a greater extent linked to various technical infrastructure (also forest roads). These indicators give an aggregated value of 0.39, i.e., considerably lower than the expected value in the reference condition. Various forestry activities cover ever larger parts of the forest area. This is also the case for the development of different infrastructure, affecting most of the forest area in southern Norway, with only parts of the forest area in northern Norway being less affected.
- *Climate change*: Seven indicators are considered particularly sensitive to climate change. Most of these are likely to respond to changes in temperature or growing season, but some such as Ellenberg F also respond to changes in precipitation. These indicators give an aggregated value of 0.67, indicating that the indicator values are clearly lower than expected in the reference condition, but probably not low enough to indicate a degraded ecosystem condition. Climate indicators show a clear increase in temperature and length of the growing season, as well as a tendency for more frequent precipitation. So far, the indicators have not shown major changes that can clearly be linked to observed climate change in the last 30 years.
- *Pollution*: Three indicators (NDVI, Ellenberg N, bilberry cover) are considered particularly sensitive to pollution in the form of nitrogen deposition. The aggregated value for these is 0.62, i.e., near the limit value for good ecosystem condition. Data for long-range transport of nitrogen indicate a significant reduction in recent decades, but still

exceedance of critical loads for vegetation in southwestern forest areas. In Eastern Norway, there has also been an increase in forest fertilisation in recent years. However, there is no clear correlation between the values of our condition indicators and the variables for nitrogen deposition.

- *Direct population management*: Only two indicators (large cervids, large carnivores) are considered particularly affected by direct population management. The aggregated value for these is 0.38, clearly lower than the limit value for good ecosystem condition. However, the population level of large carnivores is far from the level in the reference condition. Hunting of elk, red deer, and small game may represent as much a response to population levels as the reason for these observed levels.
- *Alien species*: There is only one indicator that in principle is particularly affected by alien species, namely the absence of alien species. The condition value for this is just below 1, i.e., as in the reference condition. However, both data for alien tree species and the increase in the number of all alien species associated with forests show considerable potential impact from such species. Such an impact has not yet been captured by our indicator.

Table 3.7 *Summary of results for forest condition indicators assigned to the most relevant drivers.*

	Aggregated value	No. indicators	Indicators included	Scaled value
Land use	0.39	10	NDVI (lower)	0.77
			NDVI (upper)	0.88
			Ellenberg F (lower)	0.76
			Ellenberg F (upper)	0.68
			Large cervids	0.71
			Bilberry cover	0.47
			Rowan-aspen-goat willow	0.15
			Dead wood total	0.12
			Coarse woody debris	0.04
			Biologically old forest	0.24
			Area without technical infrastructure	0.18
			Nature index for forests	0.41
Climate change	0.67	7	NDVI (lower)	0.88
			NDVI (upper)	0.77
			Ellenberg N (lower)	0.55
			Ellenberg N (upper)	0.68
			Ellenberg F (lower)	0.76
			Ellenberg F (upper)	0.68
			Large cervids	0.71
			Absence of alien species	1.00
			Bilberry cover	0.47
			Nature index for forests	0.41
Pollution	0.62	3	NDVI (lower)	0.88
			NDVI (upper)	0.77
			Ellenberg N (lower)	0.55
			Ellenberg N (upper)	0.68
			Bilberry cover	0.47
Direct population management	0.38	2	Large cervids	0.71
			Large carnivores	0.05
Alien species	1.00	1	Absence of alien species	1.00

3.3.4 How reliable are the conclusions?

The indicators' cover of the ecosystem characteristics

Ecosystems are complex, with a multitude of biological and non-biological entities bound together in a network of interactions and processes at different scales. We have very limited knowledge about many of these entities and processes. The challenge is twofold: How can the complexity of the ecosystem be broken down into meaningful and measurable components or properties, and how can we find available variables or indicators that allow us to quantify and assess these properties? The expert group, which developed the framework for assessing ecological condition (Nybø & Evju 2017), proposed that assessment of the ecosystem's structure, functions and productivity can be linked to seven characteristics of the ecosystem (cf. chapt. 2). We have taken these seven characteristics as our starting point.

The expert group had as part of its mandate that the ecosystem's condition should be assessed on the basis of a limited number of indicators, and that these should be based on existing data or monitoring. The number of indicators was not further specified in the mandate, nor was it explicitly discussed by the expert group. For the calculation of forest ecosystem condition, we have used 13 indicators. Given the ecosystem characteristics identified by the expert group, we can ask how well our indicators cover these characteristics.

Primary production is represented by the indicators NDVI and Ellenberg N, where NDVI is specified as annual values and Ellenberg N will eventually have values about five years apart. The NDVI index covers a general measure of the biomass or photosynthesis activity of plants ('green biomass'), where the dominant tree species probably make the strongest contribution. Our indicator NDVI represents the discrepancy between observed 'green biomass' and modelled expected values based on observations from protected areas, and not the absolute amount of such biomass. Ellenberg N expresses the overall response of vascular plants in the field layer to the nitrogen content or productivity of the soil (Tyler et al. 2021). Ellenberg N covers to a lesser extent the biomass of vascular plants as such, and not the primary production itself. It may be desirable to capture the contribution to primary production in a better way, both for total production and for different parts of the vegetation, e.g., the tree, shrub, and field layers. This will require other indicators, especially if it is desirable to cover the dynamics of actual primary production within the growing season.

Distribution of biomass between different trophic levels is represented by the indicators large cervids and large carnivores, both of which have annual values. These indicators cover important parts of the food chain through dominant vertebrates. However, we lack a good measure for the plant biomass relevant for cervids. The indicators we have for primary production do not directly cover this part of the primary production. There are also several other plant-based food chains that could have been represented, not least food chains based on plants and invertebrates, with faster turnover and therefore potentially great ecological significance. However, knowledge of such food chains is weak, and relevant data are mostly lacking. Food chains based on decomposer communities also have a very important ecological role in forests, but here we have even less knowledge and data.

Functional composition within trophic levels: We currently have no condition indicators for this characteristic. Relevant indicators may be developed for functional groups of plants or birds, but it can be challenging to determine reference values (cf. chapt. 3.5).

Functionally important species and biophysical structures are represented by the indicators absence of alien species, bilberry cover, rowan-aspen-goat willow, biologically old forest, coarse woody debris and dead wood total. Bilberry cover and rowan-aspen-goat willow represent plant species of great importance to several other species, especially as food for pollinators and winter food for herbivores. Biologically old forest and the indicators for dead wood represent special structures of great importance for many species associated with old forest. The absence of alien species represents the absence of negative impacts from alien species on native species and ecosystem processes. Many other functionally important species and structures could have been represented, such as top predators that can regulate the dynamics of underlying food chains, soil organisms such as mycorrhizal fungi and various decomposers with central importance for nutrient cycles in forests, as well as large and often old trees that offer important substrate and habitat for a wide variety of species. The latter is partly captured by biologically old forest, but not as explicitly as a possible indicator for large trees. In addition, there are several distinct forest types, adapted to special environmental conditions and disturbance regimes, with particular importance for species diversity. Together with the trees, soil organisms probably have the greatest importance for the forest ecosystem. It is also in the soil, as well as in and on dead wood, that more than half of the forest species live.

Landscape ecological patterns are represented by the indicators biologically old forest and area without technical infrastructure. These indicators represent the extent of potentially important habitat for species associated with natural forests. Here it could also be relevant with other indicators for important habitat, e.g., old natural forest (Storaunet & Rolstad 2020). However, such indicators of the extent of important forest area do not represent changes in the spatial distribution of such area, e.g., related to fragmentation and ecological connectivity between the individual patches (cf. Framstad et al. 2018). They also do not capture changes in the distribution of different forest habitat types with different natural dynamics and composition.

Biological diversity, specified by the expert group as diversity and turnover of genotypes and species, potentially covers a very large number of organisms that can be difficult to summarize with a few indicators. This characteristic is represented by the indicator nature index for forests, which in turn represents the condition of more than 80 species and indirect indicators for species diversity in forests. The nature index for forests nevertheless has insufficient coverage of many important species groups, not least among species-rich groups such as invertebrates, fungi, lichens, and bryophytes.

Abiotic factors are represented by the indicators Ellenberg N and Ellenberg F. These represent the response of vascular plants to the availability of nitrogen and moisture, respectively. These are relevant and important ecological factors in forests, but there are also several other important chemical and physical variables that characterise ecosystem condition. Soil chemical conditions such as the absolute and relative amount of carbon and nitrogen, as well as base cations such as calcium and magnesium, represent important aspects of ecosystem condition. The amount of soil organic matter is also an important indicator for condition.

From the summary above of the ecosystem characteristics and the indicators' coverage of these characteristics, it is obvious that additional indicators are desirable to cover important aspects of most of these characteristics. The indicator set covers all but one characteristic, but the coverage of the other characteristics is not sufficient to give a balanced picture of forest ecosystem condition. Hence, there is a strong need to further develop the set of indicators, but the lack of relevant data for such indicators is a serious limitation.

Underlying data for the indicators

A first prerequisite to use our indicators to assess forest ecosystem condition, is that they cover relevant aspects of the ecosystem condition, as specified by the seven characteristics of ecosystems. The summary above indicates that this is the case, although our indicators do not adequately cover all aspects of these characteristics.

Another prerequisite is that the underlying data are good enough. This includes whether the data measure what the indicators represent, whether the data provide a basis for drawing conclusions about the entire area we are to characterise, whether the data exist as time series that cover natural variation in indicator values for the period we are to characterise, and finally whether the data provide a basis for estimating indicator values with sufficient precision to be able to draw certain conclusions. Key information on the underlying data for the individual indicators is summarised in **Table 3.8**.

***Table 3.8** Assessment of the underlying data for the forest condition indicators. Length of time series is given as number of points (period).*

Indicators	Underlying data	Data source	Geographical representativity	Time series	Estimated uncertainty
NDVI	Mean deviation from modelled NDVI-value for forest area, June–Sept.	MODIS (MOD13Q1 V6 Terra Vegetation Indices 16-Day Global 250m)	All forest area, regularly distributed pixles	10 (2010-2019)	Bootstrap
Ellenberg N	Coverage of vascular plan species within 18 1 m^2-plots per site, combined with Ellenberg-scores for nitrogen per species	ANO[b]	All forest area, randomly placed sites	1 (2019)	Bootstrap
Ellenberg F	Coverage of vascular plan species within 18 1 m^2-plots per site, combined with Ellenberg-scores for moisture per species	ANO[b]	All forest area, randomly placed sites	1 (2019)	Bootstrap
Large cervids	Estimated density (individuals/km^2) per county	National Ungulate Monitoring	Values for each county/municipality	5 (1990-2019)	10000 simulated index values (based on approach in the nature index)
Large carnivores	Estimated number (individuals, family groups) per carnivore region	Rovdata[a]	Values for each carnivore region	5 (1990-2019)	10000 simulated index values (based on approach in the nature index)
Absence of alien species	Presence/absence within each of 18 plots of 250 m^2 per site	ANO[b]	All forest area, randomly placed sites	1 (2019)	Bootstrap
Bilberry cover	Percent cover per plot	NFI*	All forest area, plots i regular network*	2 (2012-2017)	Bootstrap
Rowan-aspen-goat willow	Volume (m^3/ha) per plot in productive forest	NFI*	All productive forest area, plots i regular network*	5 (1996-2017)	Bootstrap
Dead wood total	Volume (m^3/ha) of dead wood >10 cm in diameter per plot	NFI*	All forest area, plots i regular network*	2(3) (1996, 2012-2017)	Bootstrap
Coarse woody debris	Volume (m^3/ha) of dead wood >30 cm in diameter per plot	NFI*	All forest area, plots i regular network*	2(3) (1996, 2012-2017)	Bootstrap
Biologically old forest	Score per plot, based on dominant trees, stand age and site productivity	NFI*	All forest area, plots i regular network*	4 (2002-2017)	Bootstrap
Area without technical infrastructure	Map data for area at least 1 km from technical infrastructure	Norwegian Environment Agency	All forest area	6 (1988-2018)	Resampling (10 000 repeats) of estimate, expert-based uncertainty, where standard deviation = 5 % of estimate.
Nature index for forests	Scaled index value	Nature index	Values for each region; variable geographical cover for underlying indicators	5 (1990-2019)	10000 simulated index values (based on approach in the nature index)

* NFI: National Forest Inventory data recorded in 125 m^2-plots distributed in a regular network of 3x3 km (forest below the conifer tree limit except in Finnmark), 3x9 km (forest above the conifer tree limit except in Finnmark) or 9x9 km (forest in Finnmark).
[a] Rovdata: The national centre for monitoring and communication on large carnivores (www.rovdata.no)
[b] ANO: National spatially representative monitoring programme

Representation of indicators and underlying data: Most of the indicators are rather directly based on the underlying data. However, some indicators are derived from the data in such a way that readers may perceive their representation of the indicators differently.

- *Biologically old forest* is measured as a proportion of sampling plots in the National Forest Inventory (NFI) that satisfy the criteria for stand age, tree species dominance and site productivity. The term biologically old forest could have been defined differently and may then have given a somewhat different result. However, the current definition has been used in various reports from, e.g., NIBIO and NINA (e.g., Framstad et al. 2017, Stokland et al. 2020).
- *NDVI*: The underlying data are measured as the standard index value for NDVI (NIR-R)/(NIR+R) for individual pixels in the satellite image, whereas the indicator represents the deviation between measured and modelled index values (cf. chapt. 3.2.1).
- *Ellenberg N, Ellenberg F*: The underlying data are the cover of vascular plant species in individual inventory plots in the monitoring programme ANO. The indicator values are obtained by linking these cover data to modified Ellenberg scores for nitrogen and moisture, respectively, to yield a weighted average score for the vegetation in each plot (cf. chapt. 3.2.1).

Geographical representativeness of the data: The assessment of ecological condition for forest includes all forest area, as defined by the National Forest Inventory (NFI) (cf. chapt. 3.1). The underlying data for all indicators cover this area and can be considered as representative. However, the spatial resolution of the data varies for the individual indicators.

- Data from the NFI and ANO have been collected from statistically representative distributed sites. The NFI covers over 10,000 forest sites. In this report, ANO only covers 189 forest sites, with rather few sites in some regions (cf. alien species). ANO will include 1000 sites in total for all ecosystems for the whole country in a full five-year inventory cycle.
- Data for carnivores and cervids are given as a total estimate for carnivore regions and an estimated density per county for cervids, and then re-assigned to the regional division used here.
- Data for NDVI completely cover the entire country at spatial units given by the satellite instrument's resolution (250 m). Since cloud cover can hide the ground surface, the data are based on the integration of data from several satellite images, usually over a period of 16 days.
- Data for the nature index for forests are given as estimates per region, but data for the underlying indicators vary in both geographical coverage and resolution.

Cover of data variability in time: Data for all indicators cover only short (or no) time series and often at intervals of more than one year. This means that the data provide very limited opportunities to estimate trends or variation on relevant time scales. Ideally, the data should be available as annual observations over many decades, something rarely available for ecological data.

Estimation of indicator values with specified uncertainty: The underlying data for the individual indicators include both sample-based data from the NFI and ANO, complete data coverage for NDVI, total figures per county for large cervids as well as total figures for each region for large carnivores, the nature index for forest and area without technical infrastructure. Uncertainty for estimated indicator values is based on the variation in 10,000 simulations with random extraction of existing values, with a slightly different approach depending on the type of data.

In summary, the data represent a good foundation for providing credible estimates for the indicator values, and they are representative of the geographical variation in indicator values. However, the lack of long time series means that the data do not provide a good basis for judging trends or variation in the indicator values over time.

Certainty in the assessment of ecosystem condition
There is greater or lesser uncertainty associated with the determination of reference values for indicators. Scaled values for some of the indicators could thus be somewhat higher or lower than those we have calculated here, and this could affect the assessment of ecological condition. However, Pedersen & Nybø (2015) showed that considerable shifts in reference values for indicators in the Nature Index had only a modest effect on the overall Nature Index value. As the IBECA approach employs a quite similar scaling and aggregation method as for the Nature Index, the sensitivity of the overall condition value to errors in the indicator reference values should also be limited.

In addition, the unscaled indicator values, compared with knowledge of the relevant indicators in forests with little human impact, show that several of the indicators have values far below what we would expect in natural forests. This applies in particular to large carnivores, dead wood total and coarse woody debris (Stokland et al. 2012), the proportion of biologically old forest (Kuuluvainen 2009), and the area without technical infrastructure. For these indicators, it is thus very certain that the current indicator values imply that the ecological condition for forest deviates substantially from good condition.

For the indicators rowan-aspen-goat willow and bilberry cover, it is very likely that the unscaled values are below the levels we would expect in natural forests, as defined here (Lankia et al. 2012, Hardenbol et al. 2020). However, it may be somewhat more uncertain how far away they are, and whether this indicates that the forest ecosystem is not in good condition.

The *nature index for forests* is an aggregate index with more than 80 underlying indicators that represent different species and indirect indicators for species diversity. This index is calculated from scaled values for the underlying indicators. It is therefore difficult to assess how the value of the nature index for forests reflects the level in natural forests regardless of the scaling of underlying indicators. In the review of the Nature Index 2020 for forests, Storaunet & Framstad (2020) discussed the levels and trends for these indicators and concluded that the overall index value reflects a real deviation from the level in natural forests.

The considerable impact on forests is also supported by data for forestry activities and the extent of technical infrastructure (cf. chapt. 3.3.2). Various forestry activities cover most of the productive forest land and have led to significant changes in the structure of the forest. Similarly, most of the forest area is also affected by technical infrastructure. The management of large carnivores also indicates that the population levels for these species are far below the expected levels in natural forests.

The other indicators in the calculation of forest ecosystem condition have relatively high scaled values, and despite some uncertainty about the reference value, there is no basis for assuming that the deviation in unscaled values for these indicators is substantially below the levels in natural forests.

Overall assessment of the reliability of the results
The indicators' coverage of the ecosystem characteristics, levels and trends for condition indicators and drivers, as well as the uncertainty associated with the indicator estimates, provide a more or less comprehensive picture of the condition of forest ecosystems (**Table 3.9**):

- The indicators cover relevant aspects of the various characteristics of the ecosystem, but the coverage is deficient in that several important aspects are not sufficiently covered (cf. the review above). For the aspects covered, the indicators provide a relatively good basis for assessing the ecosystem condition.
- The levels of more than half of the indicators (given as unscaled indicator values) are so much lower than we would expect in natural forests, that it must be considered very likely that the condition of forest ecosystems deviates substantially from the reference condition, i.e., it is quite certain that the condition must be considered as degraded.

- The distribution of indicators on ecosystem characteristics indicates that it is the characteristics *landscape ecological patterns* and *functionally important species and biophysical structures* that deviate particularly from the reference condition. *Biological diversity* and *distribution of biomass between trophic levels* also clearly deviate from the reference condition.
- Trends for several of the indicators are increasing, which may indicate a slight improvement in the condition in recent years. However, the time series are too short to say whether the trends indicate any lasting improvement.
- The indicators' assignment to drivers indicates that land use and direct population management are the main reasons for the deviations from the reference condition. Climate change and alien species are likely to have a more negative impact in coming decades, whereas the future impact of pollution in the form of added nitrogen is more uncertain.

Table 3.9 *Overall assessment of the reliability of the results for the condition of forest ecosystems, based on the indicators' coverage of the ecosystem characteristics, level (compared to the reference condition) and trends for the indicators' unscaled values, as well as the effects of main drivers on the scaled values of indicators assigned to each characteristic. The right column indicates whether the condition is certainly good, probably deviates from good (Degraded), or certainly deviates from good condition (Very degraded), considering all aspects.*

Ecosystem characteristics	Condition value	Indicators	Indicator values: Levels	Indicator values: Trends	Effect of drivers	Condition
Primary production	0.70	Insufficient	Small deviation	Stable, increasing	Positive?	Good
Distribution of biomass between different trophic levels	0.38	Insufficient	Large deviation	Increasing	Negative	Degraded
Functional composition within trophic levels	–	None				
Functionally important species and biophysical structures	0.34	Insufficient	Large deviation	Increasing	Negative	Very degraded
Landscape ecological patterns	0.21	Insufficient	Large deviation	Varying	Negative	Very degraded
Biological diversity	0.41	Insufficient	Large deviation	Increasing	Negative	Degraded
Abiotic factors	0.64	Insufficient	Some deviation	Uncertain	Positive?	Good
Overall assessment	**0.42**	**Insufficient**	**Large deviation**	**Varying**	**Negative**	**Degraded**

3.4 Forest ecosystems in the future

The current condition of forest ecosystems in Norway is reviewed and documented above. This shows that the condition deviates substantially from the expected condition of intact forests. Mainly three factors contribute to this result:

- *Forestry's transformation of large parts of the natural forest into production forest*, which has led to a very low proportion of old forest and old trees, as well as small amounts of dead wood (especially coarse woody debris) and reduced volumes of the tree species rowan, aspen and goat willow. These are important resources for many of the species associated with old natural forests, including many of the species that are now considered endangered (Artsdatabanken 2021). The operating model of forest stand management also involves a transformation of the forest landscape, towards even-aged forest stands and a high degree of fragmentation of remaining old forest. The lack of natural disturbances such as forest fires also contributes to a different composition and structure of tree species and age classes than we find in natural forests.

- *Ever-increasing development of infrastructure* for transport, energy and buildings leads to increasing habitat loss and fragmentation of forest areas. The area affected by technical infrastructure is large and increasing.
- *The management of large carnivores* is based on keeping the carnivore populations at a minimum level of viability, far below the expected population levels in intact natural forest.

We may ask how these factors, and the condition of forest ecosystems, may change during the next decades until 2050. This will partly depend on the forest's ecological processes, given current environmental conditions and political and economic constraints. The part of the forest that currently has a certain natural forest character, such as old, selectively harvested forest without heavy impacts from clear-cutting or road construction, will gradually develop an even stronger natural forest character with greater proportions of large, old trees and amounts of dead wood of all categories. With the foreseen climate development in the next decades, the trees will probably grow a little faster (due to a longer growing season and increased CO_2 concentration in the air) and somewhat faster develop a natural forest character. The current efforts to prevent forest fires will, however, to a great extent reduce natural renewal of this natural forest. Such forest will therefore lack some important habitat characteristics of natural forests.

Political objectives and decisions and economic constraints for the forest industry are of greater importance for the future development of the ecological condition of forests. Forest protection will obviously secure forest areas where the forest's own ecological processes to a large extent will contribute to the development of natural forests with increasing amounts of old trees and dead wood. However, many small nature reserves will limit the possibilities of allowing natural disturbances such as forest fires to run freely (Framstad et al. 2017). Such small reserves are also exposed to adverse effects from the surroundings (edge effects), since a large part of the area is close to the outer boundary of the reserve. The authorities' goal of protecting 10% of the forest area means approximately a doubling of the current level. With a focus on the most important remaining areas of old forest, such protection will be an important contribution to preserving the forest's natural diversity. However, this foreseen protected forest area by itself is too small to provide any substantial improvement in the condition of forest ecosystems in Norway. The management of the rest of the forest area will be of far greater importance.

Granhus et al. (2014) show that mature forests for harvesting in the next decades will mainly be found in the traditional forestry areas in eastern and central Norway. This is where new mature forest will be available in substantial quantities, and there is already a well-developed infrastructure for extracting the timber. These are largely areas that have already been clear-cut once, and which are now in the process of developing new harvestable trees. From the forest sector and the authorities, however, proposals have been made for several measures to increase the extraction and use of timber as part of the 'green shift'. These measures include more intensive operation on established forestry land, in the form of increased use of ground preparation, planting, stand management, forest fertilisation, and shorter harvest cycles. It also includes increased road construction and cutting in old, formerly selectively felled forests that gradually have developed a natural forest character. As a climate mitigation measure, trials have also been carried out with the planting of trees, mainly spruce, on former agricultural land and forest land with low stocking density. All these measures will eventually lead to lower levels for several indicators of ecosystem condition (cf. Storaunet & Rolstad 2020).

The extensive plans of the authorities for further development of infrastructure for transport and energy, as well as the desires for increased development of cabins near nature areas and for housing and industry in the peri-urban areas, indicate that loss and fragmentation of forest areas will continue and possibly increase in the years towards 2050. This will lead to a further reduction in the area without technical infrastructure.

The populations of large carnivores have a great ability for population growth based on today's very low levels and good access to game as prey. However, the political targets for the populations of large carnivores and the related management of their populations fully determine how the populations of these species will fare in the future.

Overall, several aspects of current policy related to forestry and land management, climate mitigation, transport and land use indicate that the condition of forest ecosystems will deteriorate further in the decades to come.

3.5 Further development necessary for forest indicators

In the discussion above, we have identified some areas where the current system for assessment of ecosystem condition has shortcomings. This concerns inadequate coverage of ecosystem characteristics and lack of data for some important parts of the ecosystem. In addition, we need to improve the basis for setting reference values and limit values for good ecosystem condition. These shortcomings are desirable and possible to remedy by further developing the system.

In the assessment of the condition of forest ecosystems, we have emphasised the condition indicators included in the calculation of ecosystem condition according to the IBECA approach. In addition, we have assessed whether certain supplementary variables seem to support or weaken the results based on the condition indicators. There is already underlying data for these supplementary and other variables. By developing reference values and limit values for these indicators, they may also be included in the calculation of ecosystem condition. This includes biomass of trees from the National Forest Inventory (NFI) and coniferous and deciduous forest birds from the monitoring program TOV-E (**Table 3.10**).

Data from the NFI and the monitoring program ANO, as well as map databases, provide an opportunity to develop some new indicators. This applies to the amount of very degraded, coarse woody debris and area of old natural forest, as defined by Storaunet & Rolstad (2020) (both with data from the NFI), functional groups of vascular plants (data from ANO), as well as connectivity of the forest area and the area of old forest (data from various map databases).

An important aspect of the forest ecosystems currently not represented by indicators is structures and functions in soil. Both selected soil chemical and biological indicators may be relevant. Soil chemical properties related to the ratio between carbon and nitrogen, as well as available base cations (including calcium) and possibly the amount of toxic labile aluminium (LAl) may be relevant. Also, the amount of soil organic matter, an important part of the carbon stocks in forests, may be relevant. Of soil organisms, various forms of mycorrhizal fungi and different groups of decomposers are particularly relevant. However, nationwide, representative data for these possible new indicators are currently not available. Data for these can be collected through the monitoring programmes NFI or ANO. Relevant indicators must be specified, and appropriate monitoring variables and collection protocols must be developed, to provide relevant data for such indicators. The use of environmental DNA is probably essential to obtain data on soil biology in a cost-effective way.

These possible new indicators will contribute to better coverage of each of the seven ecosystem characteristics. Although, e.g., *functionally important species and biophysical structures* are already rather well covered by indicators, especially indicators for soil chemistry and soil biology will cover important shortcomings. Two of the proposed indicators also cover *functional composition within trophic levels*, a characteristic currently not covered by indicators. The proposed indicators for connectivity of forests and old-growth forests, respectively, will cover the lack of indicators for the spatial distribution and fragmentation of these land types for the characteristic *landscape ecological patterns*. Since the bird species included in the possible indicators for coniferous and deciduous forest birds are also included in the nature index for forests (already a condition indicator), it should be considered whether these bird indicators should be included in the condition calculation.

As the national insect monitoring is being established, it should be considered whether indicators can be developed based on data form this monitoring. Insects represent a very species-rich group that covers a wide range of ecological functions. Several different indicators are conceivable based on data from the insect monitoring, e.g., as pollinators, dispersal vectors for fungi, or by grouping species into broad functional groups by food or habitat.

It is also necessary to assess the approaches for determining reference values and limit values for good ecosystem condition for several of the current condition indicators, as well as to better document the scientific basis for these values. Setting reference and limit values for several of the proposed indicators will probably be challenging. The main approaches that are briefly described in chapter 2 can be used, but it would be too demanding to develop specific proposals here.

Table 3.10 *Potential new indicators for the condition of forest ecosystems, respectively where data already exist or may soon become available and where new data collection will be necessary. It is also specified which ecosystem characteristics these indicators may cover and the potential data source, whether existing or by potential new data collection.*

Indicator	**Characteristics**	**Data source***
Indicators where data already exist		
Biomass of trees	Primary production Distribution of biomass between trophic levels	NFI
Functional groups of vascular plan species	Functional composition within trophic levels	ANO
Coniferous and deciduous forest birds	Functional composition within trophic levels Biological diversity	TOV-E
Very decomposed, coarse woody debris	Functionally important species and biophysical structures	NFI
Area of natural forest (as defined by Storaunet & Rolstad 2020)	Functionally important species and biophysical structures	NFI
Connectivity of forest area	Landscape ecological patterns	AR5/AR50
Connectivity of old forest	Landscape ecological patterns	SR16
Indicators requiring new data collection		
Soil chemistry – C/N	Abiotic factors	ANO, NFI
Soil chemistry – Ca/LAl	Abiotic factors	ANO, NFI
Soil organic matter	Abiotic factors	ANO, NFI
Mycorrhizal fungi, various groups	Functionally important species and biophysical structures	ANO, NFI
Decomposers in soil, various groups	Functionally important species and biophysical structures	ANO, NFI
Insect diversity, various groups	Functional composition within trophic levels Biological diversity	National insect monitoring

* Data sources: NFI – National Forest Inventory, ANO – National representative monitoring of plants and nature types, TOV-E – National representative monitoring of breeding birds, AR5/AR50 – National map data series for land cover and other properties, SR16 – National forest resource map data

4 The condition of mountain ecosystems

4.1 Definition of mountains

The expert group applied a bioclimatic definition for mountains as land above or north of the climatically defined forest limit (Nybø & Evju 2017). Here, we have used a different definition of mountains, as all land above or north of a modelled actual forest limit based on the occurrence of coherent forest polygons in the map series AR5 and AR50 (Ahlstrøm et al. 2019, Heggem et al. 2019). This is the same forest limit developed for and used in the Norwegian Nature Index (Blumentrath & Hanssen 2010; Jakobsson & Pedersen 2020). This forest limit is also quite consistent with the forest definition used by the Norwegian Forest Inventory (cf. chapt. 3.1). This implies that our definition of mountains covers the alpine bioclimatic zone as defined by Moen (1998), as well as open areas above our modelled forest limit in the bioclimatic north boreal zone and the northernmost areas on the Norwegian mainland defined by Moen as a south Arctic zone. These open areas of the north boreal zone are mainly created by human exploitation of trees and grazing resources (Bryn et al. 2013).

The expert group recommended that the condition of mountain ecosystems should be assessed for each individual alpine zone. However, we have not subdivided mountains further, mainly due to the difficulties of developing indicators for each zone.

In the assessment of the condition of mountain ecosystems, we have calculated scaled indicator values and condition valued for both separate geographical regions and the whole country (cf. **Figure 4.1**). As the overall regional condition values are rather similar, we do not present or discuss these below (cf. forests).

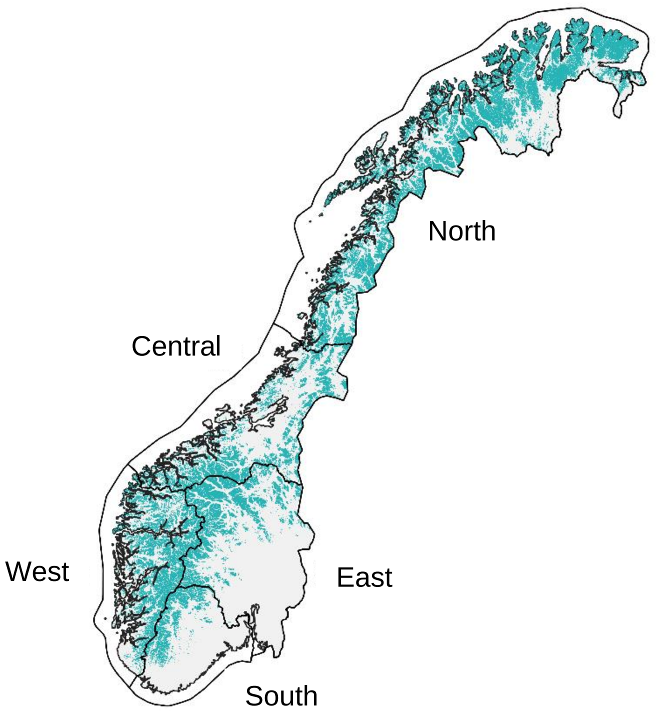

Figure 4.1 *Distribution of mountain area (blue) for various regions in Norway.*

4.2 Mountain condition indicators and other variables

As for the condition assessment for forest ecosystems, we have collated several indicators which we use to calculate the condition value for mountain ecosystems according to the IBECA approach. We have also presented a few supplementary variables that provide additional information on the ecosystem condition. In addition, we have collated information on various anthropogenic drivers, to see if these may indicate possible causes for levels or trends of condition indicators. The various indicators and other variables are presented in the subchapters below.

4.2.1 Indicators used in the calculation of condition values

The individual indicators
The indicators used in the calculation of the condition of forest ecosystems are shown in **Table 4.1** and described below. A more technical description of the indicators is given in **Appendix 2**.

The data for the indicators come from various sources (cf. **Table 4.1** and the text below) and may vary in both the length of time series (from 1 to 60 years) and the temporal resolution. As current data we have used the available data for the 5-year period 2016–2020 (as aggregated or mean values if more than one year of data is available).

NDVI trend is an index closely correlated with the changes in amount of green vegetation with active photosynthesis. NDVI is often used as a measure of standing plant biomass or primary production (Pettorelli et al. 2005, cf. chapt. 3.2.1). Data for NDVI are available for the period 2000–2019. For mountains, deviations from the reference condition could mean that the primary production, measured as the average NDVI value for the growing season, either increases or decreases substantially during the period with data. The NDVI value may be reduced due to, e.g., infrastructure construction or overgrazing, or may increase because of increased productivity due to climate change or fertilisation. The indicator is therefore calculated as the slope for a linear regression of average NDVI values during the growing season against year. The data are based on NDVI values per 16-day periods for June–September from a random selection of 25,000 MODIS pixels of 250 x 250 m within our defined mountain area. In the reference condition there should be no significant trend, i.e., the reference value for the indicator is 0. For the definition of the limit values, it would have been optimal to have NDVI data from MODIS for a reference period, but since this time series starts in the year 2000, this is not possible. Therefore, we base the limit values on the distribution of slope values from models of NDVI against time, where the time variable has been randomised for each pixel. The lower and upper limit values for good ecosystem condition are set to the 0.025 and 0.975 quantiles for the distribution of slope values in these randomised models. Hence, a systematic change in the average NDVI value over time, with a slope that is greater or smaller than the respective upper or lower limit value, means that the indicator shows that the ecosystem is not in good condition.

Reindeer: We assume here that both wild reindeer and domestic reindeer (*Rangifer tarandus*) represent the current population of large grazing animals in the mountains, in addition to livestock. Reindeer populations are of great importance within the ecosystem, both by exerting a strong impact on the vegetation and as prey or carrion for predators. Wild reindeer and domestic reindeer will have the same type of impact on the ecosystem, only modified by differences in population level and migration patterns. In the reference condition, we assume that the mountain areas throughout the country should be used by wild reindeer populations regulated by natural influences from weather and climate, food supply and natural population levels of large predators. The indicator value is based on the current populations of domestic reindeer and wild reindeer, given by Kjørstad et al. (2017) for the individual wild reindeer areas and as the average population for the last five years for the domestic reindeer areas (www.reinbase.no). Hence, we assumed that the share of the current total wild reindeer and domestic reindeer populations is distributed on mountains and forests according to the same relative area of mountains and forests in the respective wild reindeer and domestic reindeer areas. The reference value is a calculated density of wild reindeer for all mountain areas under the reference condition. This reference density is based on an empirical relationship between the density of the population targets of wild reindeer (Kjørstad et al. 2017) and the terrain variation in the wild reindeer areas (measured by Terrain Ruggedness Index TRI, Riley et al. 1999), given by the formula Reference density = 1.0759 * EXP (-0.001 * TRI). This relationship is assumed to apply to all mountain area, also for the domestic reindeer areas and mountain areas without reindeer today. In addition, we have assumed that natural populations of large predators will lead to a somewhat lower density in the reference condition than the population targets given in Kjørstad et al. (2017). The reference density given by the formula above is therefore reduced by 25%. Given the size of the different mountain areas and their average TRI values, the total reference population for wild reindeer can be calculated. This is a two-sided indicator, where both low and high reindeer populations can indicate deviations from the reference condition. Hence, lower and upper limit values have been set for the indicator, given as 60% and 200% of the reference value, respectively. The minimum and maximum values are set to 0 and 10 times the reference value, respectively. We have chosen an asymmetric scale function since population levels below the reference value seem more critical to the ecosystem than levels above the reference value. The data comes from Kjørstad et al. (2017) for wild reindeer and from www.reinbase.no for domestic reindeer.

Small rodents: The indicator value is set to the average level of population peaks of small rodents in the mountains (mainly *Lemmus lemmus* and *Microtus oeconomus*) in the last decade (cf. Ehrich et al. 2020). Small rodents are key species in the mountain ecosystem with great importance for plants, birds and other mammals. The reference value is based on idealised population variation under natural dynamics with population peaks at intervals of 3–4 years, with an empirical basis from long-term studies and observations from various mountain areas. The limit value for good ecosystem condition is set at 60% of the reference value. The data are based on long-term population monitoring at selected sites, as well as information from other monitoring and various reports on population peaks (Framstad & Eide 2021). The data have been downloaded from the Nature Index Database.

Willow grouse: The indicator value is the annual estimated density of adult grouse (*Lagopus lagopus*) in the breeding season, calculated as an average for the last five years (Nilsen & Rød-Eriksen 2020). The reference value is based on the average nesting density, estimated at 36 grouse per km^2 for suitable grouse habitat. The limit value for good ecosystem condition is set at 60% of the reference value. The data come from Hønsefuglportalen[19], based on annual censuses of the grouse population in August, conducted by landowners and others.

Ptarmigan: The indicator value for ptarmigan (*Lagopus muta*) is a relative population index based on censuses during the breeding season, calculated as an average for the last five years. The reference value is based on the estimated breeding population in a specific year in the available data series and an expert assessment of how much the population in that year may deviate from the reference value based on knowledge of factors with a negative effect on the population in recent decades. Estimated populations for other years are then scaled in relation to the estimated population in the year that is assessed against the reference value. The limit value for good ecosystem condition is set at 60% of the reference value. The data come from the monitoring programme TOV-E, based on annual censuses of breeding birds (Kålås et al. 2021a).

Arctic fox: The indicator value is the estimated number of reproducing individuals of Arctic foxes (*Vulpes lagopus*) in mountain areas with known historical occurrence of Arctic foxes (Eide et al. 2020a). The calculation of the number of individuals is based on a closed capture/recapture model based on findings of unique individuals recorded in the national monitoring program for mountain foxes. The Arctic fox represents a characteristic element in the food chain for mammals in the mountains. Since the reproduction of Arctic foxes varies greatly between years depending

[19] Hønsefulgportalen (nina.no)

on population levels of small rodents, the indicator value is based on moving averages for 3-year periods. The reference value is based on knowledge of the territory size of Arctic foxes in mountain areas with different productivity. The limit value for good ecosystem condition is set at 60% of the reference value. The data come from the national monitoring program for Arctic foxes (Eide et al. 2020a) and have been downloaded from the Nature Index Database.

Wolverine: The indicator value is the number of individuals of wolverines (*Gulo gulo*) for the individual mountain regions, based on model estimates for the population in each large carnivore region (Bischof et al. 2019). Wolverines are currently the most important top predator in the food chain for mammals in the mountains, a role earlier shared with wolves. The reference value is

Table 4.1 *Indicators in the calculation of ecological condition for mountains, with data sources.*

Indicator	Explanation	Data source
NDVI trend	Annual change in NDVI values 2000–2019¸ two-sided indicator with values, respectively, lower or higher than the reference value	MODIS satellite data
Reindeer	Total population of domestic and wild reindeer for mountains within defined areas for domestic and wild reindeer	Kjørstad et al. 2017, reinbase.no
Small rodent	Mean level of population peaks last 10 years	TOV* and other
Willow grouse	Density of adult birds per km^2, mean for last 5 years	Hønsefuglportalen
Ptarmigan	Relative population level in breeding season, mean for last 5 years	TOV-E*
Arctic fox	Number of reproducing individuals	Monitoring programme for Arctic fox
Wolverine	Number of individuals	Rovdata
Golden eagle	Mean number of territories in 2015–2019	Rovdata
Absence of alien species	Proportion of area without occurrence of alien vascular plant species with med high ecological risk	ANO*
Area without technical infrastructure	Proportion of mountain area at least 1 km from technical infrastructure	Norwegian Environment Agency
Connectivity of mountain area	Change in connectivity between units of mountain area as consequence of technical infrastructure	N50 map above forest line
Nature index for mountains (modified)	Aggreged scaled modified nature index value for mountains	Nature index
Ellenberg N	Ellenberg score for the affinity of plant species for nitrogen, weighted with the frequency of vascular plant species; two-sided indicator with values, respectively, lower or higher than the reference value	ANO*
Ellenberg L	Ellenberg score for the affinity of plant species for open areas, weighted with the frequency of vascular plant species; two-sided indicator with values, respectively, lower or higher than the reference value	ANO*
Vegetation heat requirement	Cumulative coverage of species with high heat requirements	ANO*
Area of glaciers	Areal of glaciers	NVE
Snow depth	Deviation from the normal period 1961–1990 for mean snow depth in December–May, as mean for last 5 years	senorge.no
Snow cover duration	Deviation from the normal period 1961–1990 for number of days with snow cover in October–June, as mean for last 5 years	senorge.no
Winter rain	Deviation from the normal period 1961–1990 for sum of precipitation (mm) on days with mean temperature >2°C i January–March, as mean for last 5 years	senorge.no

* ANO: Spatially representative nature monitoring; TOV: Terrestrial nature monitoring; TOV-E: Extensive terrestrial nature monitoring

determined as an expert assessment of suitable area in different counties and potential density of reproductive units (Lande et al. 2003), converted to the number of individuals. The limit value for good ecosystem condition is set at 60% of the reference value. The data come from Rovdata[20] and is downloaded from the Nature Index database.

Golden eagle: The indicator value is the estimated number of occupied territories of golden eagles (*Aquila chrysaetos*) in the period 2015–2019 (Mattisson et al. 2020). We make no distinction between territories inside and outside the mountain area since the territories are often large, and most include areas on both sides of the forest limit. The reference value is based on the same expert assessment of the total golden eagle population as used in the Nature Index and is based on knowledge of changes in anthropogenic drivers over time. The limit value for good ecosystem condition is set at 60% of the reference value. The data come from the monitoring of golden eagles managed by Rovdata (Mattisson et al. 2020) and is downloaded from the Nature Index Database.

Absence of alien species is specified as the proportion of the mountain area without alien vascular plant species with very high, high or potentially high ecological risk (Artsdatabanken 2018). In the reference condition, such alien species should not occur, and the reference value is therefore set to 100%. The limit value for good ecosystem condition has been assessed by experts at 95% (Nybø et al. 2019). The incidence of alien species in the mountains is probably very low today, but with climate change and increased activity of humans in the mountains, alien species may become more frequent in the future. The data for the assessment of the indicator *absence of alien species* come from the monitoring programme ANO (Tingstad et al. 2019), where coverage of alien species is recorded in a circle of 250 m^2 at each of 18 points at each plot (see details for Ellenberg N). The data are based on 2340 mountain points in 201 randomly placed plots for all mountain areas from the years 2019–2021.

Area without technical infrastructure is specified as the proportion of the mountain area that is at least 1 km from heavier technical interventions such as roads, power lines and other physical infrastructure (but not buildings). Under the reference condition, there will be no such infrastructure, and the reference value is therefore set to 100%. The limit value for good ecosystem condition is set at 60% of the reference value. The dataset is produced by the Norwegian Environment Agency and is downloaded from the map portal of GeoNorge.

Connectivity of mountain area represents changes in the connectivity or coherence of separate mountain areas due to the development of man-made infrastructure (roads, power lines, cultivated land, buildings, etc.). Trails are not counted as man-made infrastructure. The indicator is calculated as the average distance from the centre of each mountain area (given as a contiguous collection of mountain pixels) to the nearest infrastructure object or forest area. The reference value is the corresponding average distance from the mountain areas to the nearest forest area, where the mountain areas are not divided or affected by infrastructure. The indicator also represents the reduction of core area and the corresponding increase in edge area due to fragmentation by infrastructure. The limit value for good ecosystem condition is set to 60% of the reference value. The data are the land cover classes open area and forest in the map data N50, as well as the infrastructure elements private or public roads, power lines and buildings.

Nature index for mountains (modified) is an index produced by Naturindeks.no. The index is originally based on 30 indicators, mainly mountain species, but here we use a modified version of the original index as one indicator of ecological condition. This index is included as an indicator of ecological condition since it summarises the condition of several species. It thus provides a better representation the ecosystem characteristic *biological diversity* (see below) than a few species-based indicators for which we have available data. The nature index for mountains (modified) used here differs somewhat from the version in the Nature Index for Norway 2020

[20] https://rovdata.no/

(Jakobsson & Pedersen 2020). Two indicators that lack values for 2019 (alpine willows and lichen heaths) are omitted here. In addition, the indicators are weighted differently in that all indicators initially are given the same weight, i.e., there is no difference between 'key indicators' and other indicators, or between indicators in different trophic groups. However, the indicators are weighted based on the share of the mountain area for which they have values. A more balanced weighting across the 28 indicators[21] gives us a more representative picture of the indicators' response to various natural and anthropogenic drivers in the mountains. The data for the nature index for mountains (modified) include data that are also included for some of the other indicators (ptarmigan, willow grouse, golden eagle, Arctic fox, wolverine, small rodents, wild reindeer/domestic reindeer). However, these are assigned other ecosystem characteristics, and as indicators some of them are designed differently than in the nature index for mountains (modified). Since the index is based on scaled indicators with their respective reference values (Jakobsson & Pedersen 2020), the reference value here is 1. The limit value for good ecological condition is set at 60% of the reference value.

Ellenberg N is an index based on scores for the affinity of vascular plant species to the amount of available organic nitrogen in soil (soil fertility). The plants' association with nitrogen is specified by Ellenberg et al. (1991) on a scale from 1 to 9, later adapted to British and north-western European conditions by Hill et al. (1999). Low values indicate that a species prefers nitrogen-poor soil, whereas high values mean that a species prefers nitrogen-rich soil. By calculating a weighted average of Ellenberg N scores based on the relative abundance of the various species, an Ellenberg N score can be derived for the vegetation at a site. This Ellenberg N score indicates the availability of organic nitrogen in the soil for the vegetation at the site. The reference condition is determined from the distributions of Ellenberg N values for generalised species lists for minor nature types in mountains within the major types T3 (mountain heath, leeside, tundra), T7 (snow bed), T14 (exposed ridge), T22 (gras-dominated heath of mountain and tundra) in the EcoSyst hierarchy (Halvorsen et al. 2020), corresponding to the mapping units at scale 1:5,000 (Töpper et al. 2018). Since both low and high values for Ellenberg N can indicate deviations from good ecosystem condition, lower and upper limit values have been calculated based on the 95% prediction interval of the reference distributions (Töpper et al. 2018). Values above the upper limit value for Ellenberg N may indicate eutrophication by nitrogen pollution, whereas values below the lower limit value may indicate nitrogen deficiency due to increased biomass extraction. The vegetation data for the Ellenberg N indicator for mountains come from the monitoring programme ANO (Tingstad et al. 2019). Data are collected for vascular plant communities at 18 ANO points in randomly placed sampling plots of 500 x 500 m. Vascular plant coverage is recorded in a 1 x 1 m square at each point. The data from ANO for the assessment of the Ellenberg N indicator for mountains in this report are based on 1872 mountain points in 192 randomly placed plots for all mountain areas, covering the years 2019–2021.

Ellenberg L is a similar index to Ellenberg N but applies to the affiliation of vascular plant species to growing sites with different light availability. Scores for Ellenberg L range from 1 to 9, with 1 indicating plants associated with dark habitats and 9 plants associated with light habitats. Otherwise, the calculation of the reference value and limit value for good ecosystem condition is done in the same way as for Ellenberg N. Both low and high values for Ellenberg L may indicate deviations from the reference condition. In mountains, lower values than the reference value for Ellenberg L may, e.g., be due to overgrowing with shrubs and trees, whereas higher values may be due to a reduction in the cover of shrubs and trees due to snow breaks, attacks by defoliating moths or grazing. The data come from ANO and are based on 1872 mountain points in 192 randomly placed plots from all over the country (cf. Ellenberg N above).

[21] Species included in the indicator *nature index for mountains (modified)*: *Aulacomnium turgidum, Anastrophyllum joergensenii, Anastrophyllum donnianum, Atractylocarpus alpinus, Scapania nimbosa, Papaver radicatum, Kalmia procumbens, Ranunculus glacialis, Luscinia svecica, Charadrius morinellus, Eremophila alpestris, Lagopus muta, Buteo lagopus, Pluvialis apricaria, Anthus pratensis, Falco rusticolus, Aquila chrysaetos, Calcarius lapponicus, Lagopus lagopus, Corvus corax, Turdus torquatus, Plectrophenax nivalis, Oenanthe oenanthe, Vulpes lagopus, Gulo gulo,* small rodents, domestic reindeer and wild reindeer *(Rangifer tarandus),*

Vegetation heat requirement is an indicator that describes how the heat requirements of individual plant species vary in the vegetation on a scale from 1 to 14 (Tyler et al. 2021). In the mountain vegetation, species characterised by low heat requirement values (1–5) occur, where species with somewhat higher values (4-5) have lower coverage than species with lower values (1-3). With increasing temperature due to global climate change, it is expected that the coverage of mountain species with higher heat requirement values will increase as a share of total coverage. Eventually, species with higher heat requirements than what is common in mountains in the reference condition will also colonise mountain ecosystems. The vegetation heat requirement indicator quantifies the cumulative coverage (relative to the total coverage) of species from highest to lowest heat requirements and compares this with an expectation based on generalised species lists for minor nature types within the major types T3, T7, T14 and T22 (cf. Ellenberg N). The reference condition was determined through the cumulative coverage in the generalised species lists from the highest heat requirement values down to a defined value, depending on the minor type, which reflects the inflection point of the cumulative distribution of coverage along the heat requirement gradient. Since the distribution of heat requirement values is strongly skewed towards the lowest values of 1 and 2, only high values for the vegetation heat requirement will in practice indicate deviations from good ecosystem condition. Therefore, we consider this indicator to be one-sided, and only an upper limit value is calculated based on the 0.95 quantile of the reference distribution. Values above the upper limit value for the vegetation heat requirement indicate an increase in coverage of the most heat-demanding mountain species and potentially also colonisation of lowland species. The vegetation data for the indicator vegetation heat requirement come from the monitoring programme ANO (cf. Ellenberg N), The data from ANO for the indicator vegetation heat requirement in this report is based on 1853 mountain points in 191 randomly located plots for all mountain areas from the years 2019–2021.

Area of glaciers is specified as the total area of glaciers recorded in the latest update by the Norwegian Water Resources and Energy Directorate (NVE) (Andreassen et al. 2022). NVE has previously estimated the area of glaciers based on the delimitation of the land classes for permanent snow and ice in the N50 map series, with data from aerial photographs taken in the period 1947–1985 (Winsvold et al. 2014). We have chosen to use this data set as a basis for the reference value for this indicator, since the collated data largely overlaps with the climate normal period 1961–1990, which we have used as a basis for the climate in the reference condition. According to NVE, some smaller glacier fragments and permanent snowfields that have been recorded in their latest satellite-based mapping have not been recorded in the analyses based on N50 map data. This means that our reference value is probably somewhat lower than the real reference value would have been if the previous survey had been based on the same methods as the last survey. Since the glaciers have been consistently shrinking in area since the year 2000, this means that the scaled indicator gives an underestimation of the deviation from the reference value. This underestimation is assumed to be small and of marginal importance. The limit value for good ecosystem condition is set to 60% of the reference value.

Snow depth is specified as the average snow depth (mm) in the period December–May, calculated as the average deviation from the mean snow depth in the normal period 1961–1990 for the last five-year period. The reference value is thus 0. This is in principle a two-sided indicator, where both higher and lower snow depth values compared with the value for the normal period can be regarded as deviations from the reference condition. However, due to ongoing climate change, a reduction in snow depth is the interesting alternative to assess. Therefore, we only include deviations below the reference value. The limit value for good ecosystem condition is set at 2 standard deviations for the snow depth in the normal period and can be interpreted as a value that had been categorised as extreme in that period. The data come from senorge.no, specified as interpolated snow depth per km^2 per day.

Duration of snow cover is specified as the number of days with snow cover (snow depth > 0 cm) in the period October–June, calculated as the average deviation from the mean duration of snow cover in the normal period 1961–1990 for the last five-year period. The reference value is thus 0. Like snow depth, this is in principle a two-sided indicator, where both fewer and more days with snow cover compared to the normal period can be counted as deviations from the reference condition. However, due to the trend og ongoing climate change, we only include deviations below the reference value. The limit value for good ecosystem condition is set at 2 standard deviations for days with snow cover in the normal period and can be interpreted as a value that had been categorised as extreme in that period. The data come from senorge.no, specified as interpolated snow depth per km^2 per day.

Winter rain is defined as accumulated precipitation (mm) for days with a daily average temperature > 2°C, over the period January–March. The indicator is calculated as the average deviation from the mean amount in winter rain in the normal period 1961–1990 for the last five-year period. The reference value is thus 0. The reason for including the indicator is that increased rainfall during a period when precipitation in the reference period would normally fall as snow is negative for many species. Especially species living under the snow will be negatively affected if the snow cover is changed by rain or if ice layers or crusts are formed. Ice formation can also make it harder for grazing animals to find food in the winter. We consider this as a one-sided indicator, where several days of winter rain compared to the normal period are considered deviations from the reference condition. The limit value for good ecosystem condition is set at 2 standard deviations for the amount of winter rain in the normal period and can be interpreted as a value that had been categorised as extreme in that period. The data come from senorge.no, specified as interpolated data for daily precipitation and daily average temperature per km^2 per day.

Indicators assigned to ecosystem characteristics

The indicators described above have been assigned to ecosystem characteristics as shown in **Table 4.2** (cf. chapt. 2 and 3.2.1). The assignment is based on qualitative assessments of how the indicators may inform our understanding of the condition of each characteristic. The assignment of the indicators to the individual characteristics is briefly justified as follows:

- *Primary production*: This characteristic is represented by NDVI trend, which provides a measure of changes in the amount of green vegetation (cf. description above). Previously (and for forests), the Ellenberg indicators were considered to represent this characteristic. As the Ellenberg indicators reflect the species composition in response to various growing conditions and not primary production as such, we did not include Ellenberg indicators for the characteristic *primary production* for mountains.
- *Distribution of biomass between different trophic levels*: This characteristic is represented by eight indicators: NDVI trend, reindeer, small rodents, willow grouse, ptarmigan, Arctic fox, wolverine, and golden eagle. Most of these indicators do not directly represent biomass, but abundance levels for the species. NDVI trend represents changes in the plant biomass. The indicators are linked through the food chains NDVI–small rodents–Arctic fox, NDVI–reindeer–wolverine/golden eagle, and NDVI–grouse–Arctic fox/golden eagle. We have not constructed an indicator based on ratios between biomass or quantity at each trophic level but have chosen to assess quantity for each indicator individually. We can then assess whether deviations from the reference condition may be due to lower or higher abundance levels for indicators within one or more trophic levels.
- *Functional composition within trophic levels*: This characteristic is represented by seven indicators: reindeer, small rodents, willow grouse, ptarmigan, Arctic fox, wolverine and golden eagle, where herbivores and predators of both mammals and birds constitute different functional groups within the respective trophic levels. We have not constructed indicators based on ratios between the abundances of individual herbivores and predators, respectively, but want to be able to assess deviations for each indicator within each trophic level.
- *Functionally important species and biophysical structures*: This characteristic is represented by the indicators absence of alien species with a high ecological risk, reindeer and small rodents. Reindeer and small rodents are key species that are of great importance to many other species in the ecosystem, both as important grazers of vegetation and as prey. The absence of alien species is included here since such species with

a high ecological risk may potentially lead to significant changes in the mountain ecosystem, even though such species currently have a very low incidence.

- *Landscape ecological patterns*: This characteristic is represented by the indicators area without technical infrastructure and connectivity of mountain area. The indicators represent characteristics of the mountain ecosystem that are important especially for species with large habitats and/or high mobility, such as grouse, reindeer, and large predators.
- *Biological diversity*: This characteristic includes one indicator, the nature index for mountains (modified), based on assessments of abundances of 28 species, compiled into a measure of the state of biological diversity in mountains (Jakobsson & Pedersen 2020).
- *Abiotic factors*: This characteristic is represented by seven indicators: Ellenberg N, Ellenberg L, vegetation heat requirement, area of glaciers, snow depth, snow cover duration and winter rain. These represent partly the association of vascular plant species to habitats with different environmental conditions (nutrients, light, temperature) and partly climate-related variables with complex effects on the living conditions of plants and animals.

The number of indicators per characteristic varies and some indicators represent several characteristics. The characteristic *distribution of biomass between trophic levels* has the most indicators (8), and the characteristics *primary production* and *biological diversity* have only one each. The choice of only one indicator for *biological diversity* was made on purpose, as this indicator represents the condition for many species (cf. above). Aggregated condition values for the individual characteristics are based on the scaled values for the indicators included (cf. chapt. 2).

Table 4.2 *Assignment of mountain condition indicators to the seven ecosystem characteristics.*

Indikator	**Primary production**	**Distribution of biomass between trophic levels**	**Functional composition within trophic levels**	**Functionally important species and structures**	**Landscape ecological patterns**	**Biological diversity**	**Abiotic factors**
NDVI trend	x	x					
Reindeer		x	x	x			
Small rodents		x	x	x			
Willow grouse		x	x				
Ptarmigan		x	x				
Arctic fox		x	x				
Wolverine		x	x				
Golden eagle		x	x				
Absence of alien species				x			
Area without technical infrastructure					x		
Connectivity of mountain area					x		
Nature index for mountains (modified)						x	
Ellenberg N							x
Ellenberg L							x
Vegetation heat requirement							x
Area of glaciers							x
Snow depth							x
Snow cover duration							x
Winter rain							x
Number of indicators	1	8	7	3	2	1	7

Indicators assigned to direct drivers
To make it easier to understand possible causes of observed level or changes in ecosystem condition and as a guide to potential management, we have assigned the condition indicators to various anthropogenic direct drivers. **Table 4.3** shows the assignment of the indicators to the main classes of such drivers: different types of land use (including infrastructure development), climate change, pollution (here mainly eutrophication), direct management of wild populations (hunting, culling or population strengthening), and effects of harmful alien species. We have indicated the most important categories of drivers for each indicator, based on expert assessment. Only direct effects are considered here, not indirect effects via other parts of the ecosystem (e.g., effects of land use on predators via prey). The individual indicators may be influenced by several drivers, in practice up to three.

Altogether 15 indicators are considered to be heavily or moderately affected by climate change and 10 by land use. Six of these indicators are affected by both drivers. Fewer indicators are particularly affected by the other drivers and these are often also affected by climate change or land use. This assignment of indicators to drivers is the basis for calculating overall values for the indicators assigned to each driver (cf. chapt. 2).

Table 4.3 *Mountain condition indicators assigned to main categories of anthropogenic direct drivers. Land use includes infrastructure development. Pollution mainly represents eutrophication.*

Indicator	Land use	Climate change	Pollution	Direct population management	Alien species
NDVI trend	x	x	x		
Reindeer	x	x		x	
Small rodents		x			
Willow grouse		x		x	
Ptarmigan		x		x	
Arctic fox	x	x		x	
Wolverine	x			x	
Golden eagle	x				
Absence of alien species	x	x			x
Area without technical infrastructure	x				
Connectivity of mountain area	x				
Nature index for mountains (modified)	x	x		x	
Ellenberg N		x	x		
Ellenberg L	x	x			
Vegetation heat requirement		x			
Area of glaciers		x			
Snow depth		x			
Snow cover duration		x			
Winter rain		x			
Number of indicators	10	15	2	6	1

4.2.2 Supplementary variables

Data for other variables may also provide information on the condition of ecosystems. These may cover aspects of the ecosystem characteristics that the ordinary condition indicators only partially or do not cover. In addition, they can give a more detailed or different impression of the relevant characteristics. This is specified for the individual variables below, their data sources, and how they are associated with the ecosystem characteristics and important drivers (**Table 4.4**).

Trophic groups in the nature index for mountains (NI trophic groups) represent a grouping of the indicators included in the Nature Index 2020 for mountains (Jakobsson & Pedersen 2020): primary producers (3 vascular plant species, 2 vegetation types, 5 bryophyte species), herbivores (3 mammal indicators, 2 bird species), small/medium predators (10 bird species) and top predators (2 mammal species, 2 bird species). These trophic groups are not included as condition indicators since the underlying indicators overlap to a great extent with the condition indicator nature index for mountains (modified). The underlying data for these individual indicators come from different sources (cf. Jakobsson & Pedersen 2020). Trophic groups in the Nature Index 2020 for mountains are linked to the characteristic *distribution of biomass between different trophic levels* and are particularly affected by the drivers land use, climate change and direct population management.

Mountain birds represent an overall index for relative population changes in rather common bird species associated with mountain habitats: *Pluvialis apricaria, Anthus pratensis, Lucinia svecica, Oenanthe oenanthe,* and *Turdus torquatus*. All species are also included in the *nature index for mountains (modified)* as a condition indicator for calculating ecosystem condition. We have therefore chosen not to include this bird index as a separate condition indicator. The data come from the national monitoring program TOV-E (Kålås et al. 2021a). Annual census results for the various species are scaled in relation to the abundance level in a given census year (2011), where the relative value is set at 1. Mountain birds are linked to the characteristic *biological diversity* and are particularly affected by the drivers land use and climate change.

Cover of shrubs and trees indicates to what extent shrubs and trees influence the mountain ecosystem at different distances from the forest limit. The variable is measured as the coverage of shrubs and trees, respectively. We have not yet arrived at a reference value for this variable. The data come from the monitoring programme ANO (Tingstad et al. 2019), where the coverage (%) of different vegetation layers is recorded in a circle of 250 m^2 for 2338 mountain points in 201 randomly placed plots in 2019–2021, for all mountain areas. Coverage of shrubs and trees is linked to the characteristic *functionally important species and biophysical structures* and is particularly affected by land use, climate change and pollution (nitrogen deposition).

Table 4.4 *Supplementary mountain variables, their data sources and linkages to ecosystem characteristics and important anthropogenic drivers.*

Variable	Description	Data source	Ecological characteristic	Direct drivers
NI trophic groups	Trophic grouping of indicators in the nature index for mountains	Nature index	Distribution of biomass between different trophic levels	Land use Climate change Direct population management
Mountain birds	Aggregated relative abundance index for five common mountain birds	TOV-E	Biological diversity	Land use Climate change
Cover of shrubs and trees	Coverage of shrubs and trees at distance from the forest limit	ANO	Functionally important species and biophysical structures	Land use Climate change Pollution

4.2.3 Variables for drivers

Variables for relevant drivers may help to identify possible causes for observed levels or trends for the indicators for ecosystem condition. We consider five main groups of such drivers (cf. **Table 4.3**): land use (including infrastructure development), climate change, pollution (mainly eutrophication), direct population management (hunting, culling, population strengthening), alien species with a likely substantial ecological effect. The various driver variables are listed in **Table 4.5** and briefly described below.

Table 4.5 *Variables for anthropogenic direct drivers in mountains.*

Variable	Explanation	Data source*
Land use		
Livestock on outfield grazing	Number of sheep, goats and cattle in areas with organised grazing	NIBIO: OBB
Infrastructure index	Map-based index for aggregated influence of technical infrastructure and artificial land	Erikstad et al. 2013
Cabins by elevation intervals	Number of cabins at various elevation intervals	SSB
Climate change		
Summer temperature	Deviation in mean temperature for June–August from the normal period 1961–1990	Modelled data from MET
Winter temperature	Deviation in mean temperature for December–February from the normal period 1961–1990	Modelled data from MET
Annual precipitation	Deviation in annual precipitation from the normal period 1961–1990	Modelled data from MET
Annual number of days with precipitation	Deviation in annual number of days with precipitation from the normal period 1961–1990	Modelled data from MET
Length of growing season	Deviation in the length of the growing season from the normal period 1961–1990, calculated as the number of days mean temperature >5°C and no snow cover	Modelled data from MET
Pollution		
Nitrogen deposition via air/ precipitation	Annual deposition of nitrogen per hectare and year via air/precipitation	Modelled data from NILU
Direct population management		
Hunting of wild reindeer	Number of wild reindeer shot per season	SSB
Slaughter of domestic reindeer	Number of domestic reindeer slaughtered per year	www.reinbase.no
Hunting of grouse	Relative index for reported hunting of willow grouse and ptarmigan	SSB
Alien species		
First recording of alien species	Cumulative number of introduced species associated with mountains since 1900, all taxa and risk categories	Artsdatabanken 2018

* See text for more detailed explanation

Land use

Land use in the mountains is traditionally linked to different types of harvesting of plant resources as feed for livestock, by grazing in outfields and collection of hay and twigs (Austrheim et al. 2015). With the great changes in agriculture over the last 100 years, livestock mountain grazing and forage harvesting has changed considerably in extent and character. The forest is in the process of taking back parts of the area that traditional agricultural use previously kept open (Bryn 2008, Bryn & Hemsing 2012, Bryn & Potthoff 2018). We lack nationwide consistent data for the extent and intensity of the use of mountain areas for grazing and harvesting over time. However, the Norwegian Institute for Bioeconomy (NIBIO) has collated data since 1981 for the number of farm animals in the system for organised outfield grazing (OBB)[22]. These figures may give an impression of the variation in outfield grazing during the last decades (counties without mountain area are not included). Otherwise, the agricultural censuses every ten years give an overview of the total number of different livestock species for the last 100 years.

Mountain areas have also been affected by the development of various forms of infrastructure such as buildings, roads, railways, dams, and power lines. Man-made artificial areas and infrastructure have a clear impact on biodiversity through loss and fragmentation of habitats. Erikstad et al. (2013) developed a map-based index to aggregate such overall human impacts. It provides

[22] Beitestatistikk - talgrunnlag - Nibio

a score from 0 (no infrastructure) to 13.23 (100% infrastructure) for circles of 500 m radius covering the entire country. We have extracted statistics for mountain areas.

In addition, it may be relevant to consider trends or geographical distributions of specific types of infrastructure. We have included an overview of the distribution of holiday homes at different elevations (SSB[23]), giving an impression of the extent such buildings affect mountain areas.

Climate change
Scenarios for future climate trends (Hanssen-Bauer et al. 2015) indicate that climate change will have a substantial impact on the mountain ecosystem. So far, biological effects of climate change over the last 30 years seem to be limited in the mountains (Framstad 2021), but some of the changes in the forest limit, increased occurrence of boreal plant species in the mountains (Klanderud & Birks 2003, Grytnes et al. 2014), attacks of birch-defoliating moths (Jepsen et al. 2013) and shifts in small rodent population dynamics (Kausrud et al. 2008) can probably be attributed to climate change. Several different variables may capture different aspects of climate trends. The data for all variables below are interpolated daily data from the Norwegian Meteorological Institute with a spatial resolution of 1 km^2. The variables are formulated as deviations from the corresponding variable values for the normal period 1961–1990. The presented variable values thus represent deviations from the reference values for the respective variables. The most relevant variables are listed in **Table 4.5**. Note that variables for the duration and depth of the snow cover are included as condition indicators (chapt. 4.2.1).

Pollution
Pollution can include both long-distance pollution via air and precipitation as well as emissions from local sources. It can include heavy metals, various organic pollutants, ground-level ozone, as well as acidifying or eutrophying chemical compounds. In this context, the possible effects of nitrogen deposition through air/precipitation seem most relevant. Nitrogen deposition will mainly give a fertilising effect but can also have an acidifying effect. Nitrogen deposition may affect both the species composition of terrestrial organisms and important ecosystem processes. In the reference condition, such excess nitrogen deposition will not take place. We have included a variable for long-range nitrogen deposition (Austnes et al. 2018) (**Table 4.5**).

Direct population management
Hunting and other population regulation of wild animals mainly affect game species of birds and mammals, and the regulation of large carnivore populations. Other harvesting of plants and animals in the mountains could be included here, but the most important of these, grazing of livestock and forage harvesting, are usually regarded as an aspect of land use. We have also included the slaughter of domestic reindeer as a possible driver variable. Here we consider hunting activity as a driver, whereas the population levels of some game species are considered as condition indicators. Population regulation of large carnivores is a direct result of adopted policy, where the culling is adapted to specific population targets for each species. Hence, we have not included such population regulation as a driver in a more general sense. In the reference state, hunting should only take place to such an extent that most of the population dynamics of the species is due to natural factors. We have included three variables for the impact of hunting or harvesting, based on data from reinbase.no[24] and SSB[25,26] (**Table 4.5**).

Alien species
The occurrence or quantity of alien species may be seen as a measure of possible impact from such species on the ecosystem. Measures of ecological effects of such species may be regarded as possible condition indicators. Alien species include species that are assumed to have been

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[23] *12511: Fritidsbygg, etter høyde over havet, innenfor og utenfor tettbygd fritidsbyggområde, og størrelse på område (K) 2016 - 2019. Statistikkbanken (ssb.no)*
[24] Reinbase.no - Overvåkingsprogram for tamrein - Reindrift og rovvilt
[25] Villreinjakt (ssb.no)
[26] Småvilt- og rådyrjakt - SSB

established in or arrived in Norway after the year 1800 (Artsdatabanken 2018). Several such species may be relevant, but there are insufficient data for the occurrence of most of them. In mountains, the occurrence of alien species is low and most likely limited to areas near the forest limit. We have compiled information on the first recording of alien species associated with the mountain (Artsdatabanken 2018) and use the cumulative number of such species as a measure of alien species as a driver.

4.3 Assessment of the condition for mountain ecosystems

4.3.1 Overall condition for mountains and the ecosystem characteristics

The overall condition for mountain ecosystems in Norway has a value just above the limit value for good ecosystem condition (**Figure 4.2**). This is the case whether we calculate the condition value directly from the individual indicators (0.68, white diamond in the figure) or based on the values for the ecosystem characteristics (0.64, black diamond). By calculating the overall condition based on the indicators directly, each indicator is given the same weight. The calculation based on the values for the ecosystem characteristics gives more weight to indicators which have been assigned to more than one characteristic (cf. **Table 4.2**). However, this appears to have only a marginal effect on the overall condition value in this case. How the overall condition value depends on the condition values of the various ecosystem characteristics and the underlying indicators is discussed below.

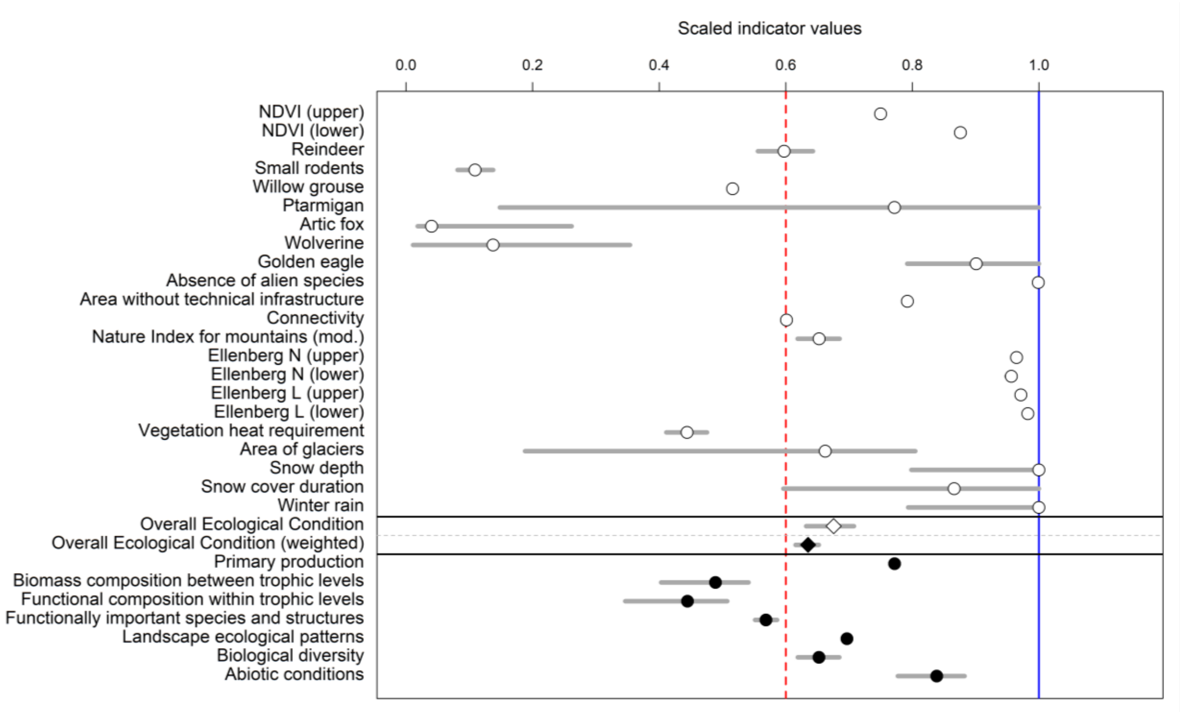

Figure 4.2 *Calculated condition for mountain ecosystems in Norway. White circles show the scaled values for the individual indicators included in the calculation. The white diamond shows the overall condition value for the ecosystem based on these indicators directly, whereas the black diamond shows the overall condition value based on the condition values for the various ecosystem characteristics (black circles). The symbols show the median values for indicators or the mean condition values, and grey and black lines show the 95 % confidence intervals (some are hidden by the symbols). The blue vertical line marks the reference value, whereas the red dotted line marks the limit value for good ecosystem condition.*

Primary production

The primary production in the ecosystem is the basis for the entire plant-based food chain and is thus a key feature of the ecosystem. Deviations from good ecosystem condition can mean either reduced or increased primary production compared with production in an intact mountain ecosystem. This is reflected in the indicator this characteristic, NDVI trend, which has lower and upper limit values for good ecological condition. NDVI trend indicates a change in the amount of green biomass for the period 2000–2019 (cf. chapt. 4.2.1).

The condition value for the characteristic *primary production* in mountains (0.77) is clearly above the limit value for good ecosystem condition (**Figure 4.2**). NDVI trend is the only indicator for this characteristic. It expresses annual change in NDVI for the period 2000–2019. As a two-way indicator, it has a lower and an upper scaled value of 0.88 and 0.75, respectively. This means that there are stronger and more deviations from the reference state (i.e., no NDVI change) towards increased NDVI than towards reduced NDVI.

Distribution of biomass between different trophic levels

In an ecosystem close to the reference condition, the species composition and abundances of the species should cover the various trophic levels and roles in the food web as far as the ecosystem's total primary production allows. A large imbalance between trophic levels or a much lower production than in the reference condition, indicate that the ecosystem deviates from the reference condition. The condition value for the characteristic *distribution of biomass between trophic levels* is based on several indicators for the trophic levels plants, herbivores and predators. The NDVI trend indicator represents a change in the amount of plant biomass. The indicators include the herbivores reindeer, small rodents, willow grouse and ptarmigan, as well as the predators wolverine, Arctic fox and golden eagle. See description of the indicators in chapter 4.2.1.

The condition value 0.49 for the characteristic *distribution of biomass between different trophic levels* is clearly below the limit value for good ecosystem condition (**Figure 4.2**). In particular, the indicators Arctic fox, wolverine and small rodents are well below the limit values, with scaled values of 0.04, 0.14 and 0.11, respectively. The indicator value for willow grouse (0.52) is slightly below the limit value, whereas the value for reindeer (0.60) is approximately at the limit value. For the other indicators of this characteristic, the scaled values are well above the limit value for good ecosystem condition. Trends over the last decades vary for populations of predators and herbivores (where we have time series), with a decrease for small rodents, increases for Arctic fox, wolverine and willow grouse (**Figure 4.3**).

The indicators included in the Nature Index for mountains can be grouped into indices for different trophic levels. These indices are included here as supplementary variables (cf. chapt. 4.2.2), due to considerable overlap with the condition indicator nature index for mountains (modified). The trends for primary producers and predators are rather stable, but herbivores decline. The indices for herbivores and top predators are so low that they indicate an ecosystem with considerable deviation from the reference condition, whereas the index values for primary producers and medium-sized predators are higher (**Figure 4.4**).

Functional composition within trophic levels

This characteristic represents the composition of species with different functional roles within the same trophic level. This can include species with different habitat preferences, feeding strategies, life history or dispersal traits. An ecosystem in good condition should have a composition of species that covers the various functional roles close to that in the reference condition. In calculating the condition value for the characteristic *functional composition within trophic levels*, several indicators for herbivores and predators are included, respectively, reindeer, small rodents, willow grouse, ptarmigan, and wolverine, Arctic fox, golden eagles These represent large and small mammals and birds, with different feeding strategies.

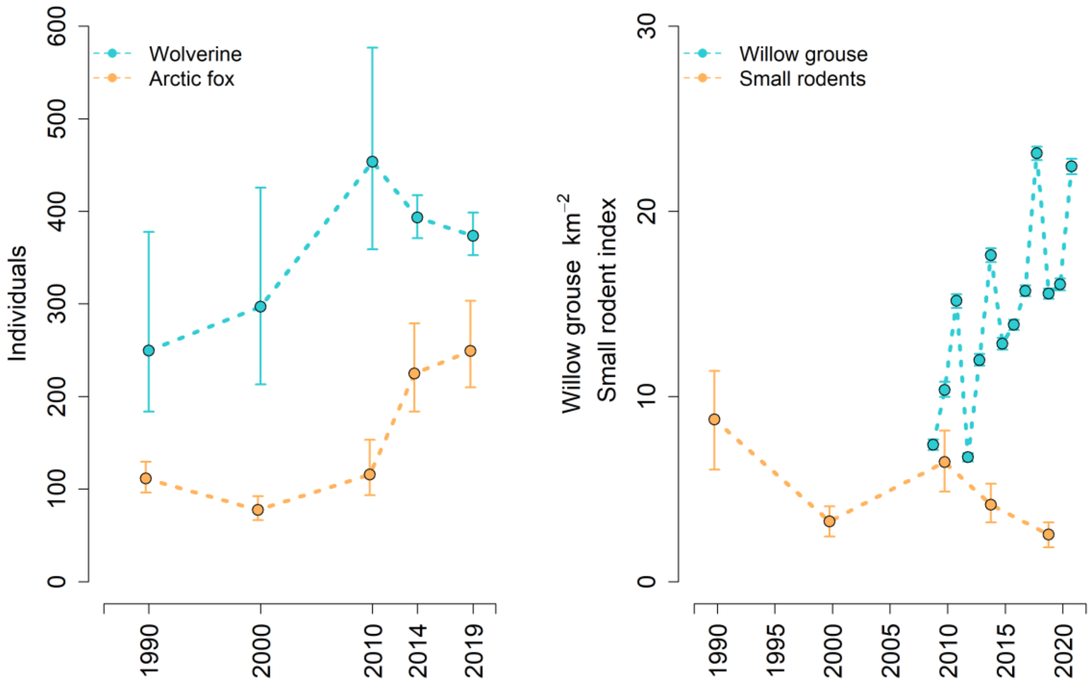

***Figure 4.3** Trends for populations of wolverines, Arctic fox, willow grouse and small rodents (note different units).*

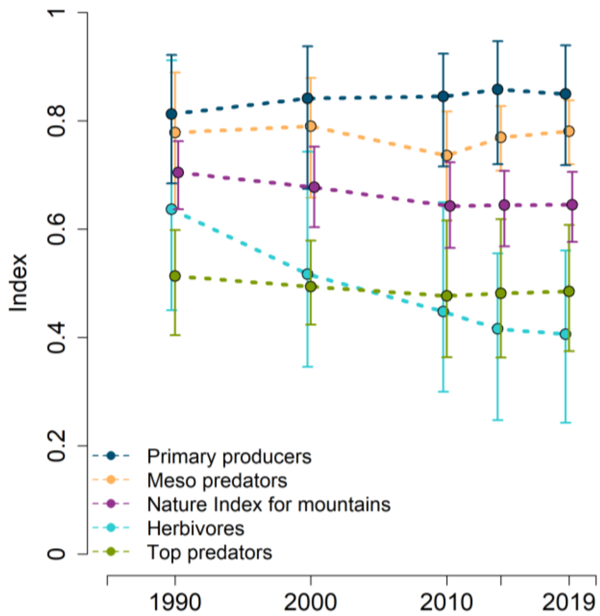

***Figure 4.4** Trends for the* nature index for mountains (modified) *and for the trophic groups based on the underlying indicators for the original Nature Index for mountains. See description of the groups in chapter 4.2.2.*

The condition value 0.44 for the characteristic *functional composition within trophic levels* is clearly below the limit value (**Figure 4.2**). As for the characteristic *distribution of biomass between trophic levels*, Arctic fox, wolverine, and small rodents have scaled values, 0.04, 0.14 and 0.11, respectively, far below the limit values for good ecosystem condition. The values for the indicators willow grouse (0.52) and reindeer (0.60) are just below or at this limit, whereas values for ptarmigan (0.77) and golden eagle (0.90) are well above.

Functionally important species and biophysical structures
Certain species and biophysical structures may be of great importance for the functions of the ecosystem, e.g., by creating or regulating habitat or food resources for many other species. An ecosystem in good condition should not have substantially less of such functionally important species and structures than in the reference state. This characteristic includes the indicators absence of alien species, reindeer and small rodents (cf. chapter 4.2.1).

The condition value 0.57 for the characteristic *functionally important species and biophysical structures* is just below the limit value for good ecosystem condition (**Figure 4.2**). The value for the absence of alien species is equal to the reference value (1), the value for reindeer (0.60) is equal to the limit value for good ecosystem condition, whereas the value for small rodents (0.11) is much below this limit value.

The cover of shrubs and trees also represents an important functional structure in the mountain ecosystem, in that such plants affect the local climate, snow conditions and other habitat properties of importance to both plant and animal species. We have not been able to determine a reference value for the cover of shrubs and trees, nor do we have a time series. However, the cover of shrubs and trees at different distances from our modelled forest limit gives an impression of where this functional structure is most dominant. Most observations with high cover of shrubs or trees occur mainly in low-lying mountain areas near the north boreal zone. (cf. Figure 3.12 in Framstad et al. 2022)

Landscape ecological patterns
In an ecosystem in good condition, various habitats and resources that are important for species should occur in a quantity and with a spatial distribution that ensures the long-term survival of native species. The condition value for the characteristic *landscape ecological patterns* is based on the indicators area of mountains without technical infrastructure and connectivity of mountain area.

The condition value 0.70 for the characteristic *landscape ecological patterns* is higher than the limit value for good ecosystem condition (**Figure 4.2**). The indicator area without technical infrastructure has a scaled value of 0.79, whereas connectivity of mountain area has a value of 0.60. Area without technical infrastructure has a slight downward trend (cf. Figure 3.13 in Framstad et al. 2022). We do not have a corresponding time series for connectivity of mountain areas.

Biological diversity
An ecosystem in good condition should not have a substantially different species richness, species composition or species replacement rate than that found in the reference condition. There are many ways to represent these aspects of biological diversity, but it is difficult to capture all aspects in a few indicators. We have chosen to represent the property *biological diversity* with a single indicator, the nature index for mountains (modified), which, however, covers the condition of many species, given by the species' abundance levels (cf. chapt. 4.2.1).

The condition value 0.65 for the characteristic biological diversity is slightly above the limit value for good ecosystem condition (**Figure 4.2**), corresponding to the scaled value for the nature index for mountains (modified) (0.65). The nature index for mountains (modified) shows a slight decline during the period (**Figure 4.4**).

Birds form a well-known part of species diversity and include several species with different adaptations and responses to various drivers. Data from the nationwide monitoring of breeding birds (TOV-E, Kålås et al. 2021a) provide a basis for assessing abundance changes over the last ten years for a few mountain species (cf. chapt. 4.2.2). The aggregated mountain bird index shows some interannual variation in relative abundance levels but no consistent trend for the last ten years (cf. Figure 3.16 in Framstad et al. 2022).

Abiotic factors
Physical and chemical conditions in the ecosystem can be of great importance for various ecosystem processes, not least related to the cycles of water and nutrients. In the mountains, the snow conditions will also be of great importance for both species and various ecosystem functions. In an ecosystem in good condition, the variation in such conditions should not deviate much from the corresponding variation in the reference condition. For the characteristic abiotic factors, we have included seven indicators, three represent plants' responses to soil nitrogen content, light, and temperature (respectively, Ellenberg N, Ellenberg L, vegetation heat requirement), whereas four represent the climate's effects on snow and ice conditions (area of glaciers, snow depth, snow cover duration, winter rain), For the Ellenberg indicators, both low and high values may represent deviations from the reference condition, and for these we have set lower and upper limit values. We consider the vegetation heat requirement, area of glaciers and the indicators for snow only as one-sided indicators since current climate trends will generally change these indicators in one direction.

The condition value 0.84 for the characteristic abiotic factors is well above the limit value for good ecosystem condition (**Figure 4.2**). Scaled values for the two-sided indicators Ellenberg N and Ellenberg L are very close to the reference value (all values ≥ 0.96). The scaled value for the vegetation heat requirement (0.44) is, however, well below the limit value for good condition, indicating that the vegetation has changed towards greater coverage of more heat-demanding species. This signal is mainly due to increased coverage of mountain species with higher heat requirements; we currently see very limited colonisation by north boreal species.

The area of glaciers has declined significantly since the normal period 1961–1990 (Andreassen et al. 2022), but the scaled indicator value (0.66) is just above the limit value for good ecosystem condition. Snow cover duration has also decreased, but the scaled indicator value (0.87) is well above the limit value. Scaled values for both snow depth and winter rain (both 1.00) show no deviation from the reference value. Trends for snow depth, snow cover duration and winter rain exhibit great variation between years, but there is a certain tendency for somewhat lower values for snow depth and snow cover duration after the year 2000 than before **Figure 4.5**).

From knowledge of the impact of long-distance air pollution (Austnes et al. 2018), one would expect that the characteristic *abiotic factors* would to some extent be affected. The Ellenberg N indicator does not appear to capture this, although data for nitrogen deposition from air and precipitation indicate that the critical loads of 5 kg N/ha for most vegetation types have been exceeded for parts of south-western Norway (Austnes et al. 2018).

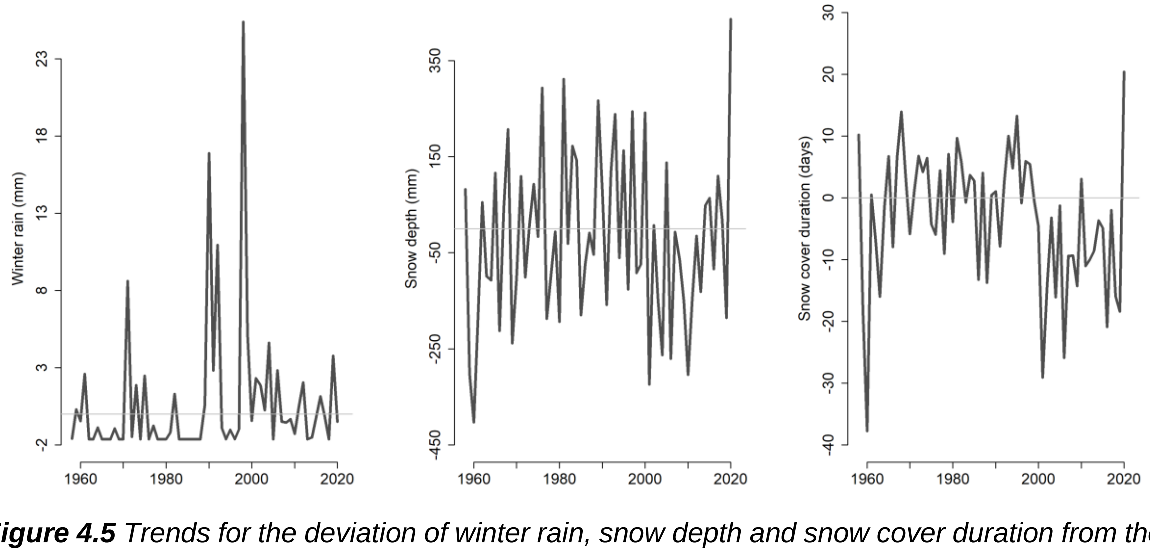

***Figure 4.5** Trends for the deviation of winter rain, snow depth and snow cover duration from the respective mean values during the normal period 1961–1990, for mountain areas in Norway.*

4.3.2 Overall values for indicators linked to main drivers

For each indicator in the calculation of ecological condition for mountains, we have assigned the assumed most important direct drivers (**Table 4.3**). Based on this assignment between indicators and drivers, we have calculated an overall value for indicators associated with each main category of drivers. This may give an indication of the drivers that are most important for the overall assessment of the condition for mountain ecosystems. The total value for indicators assigned to each of these categories of drivers is shown in **Figure 4.6**.

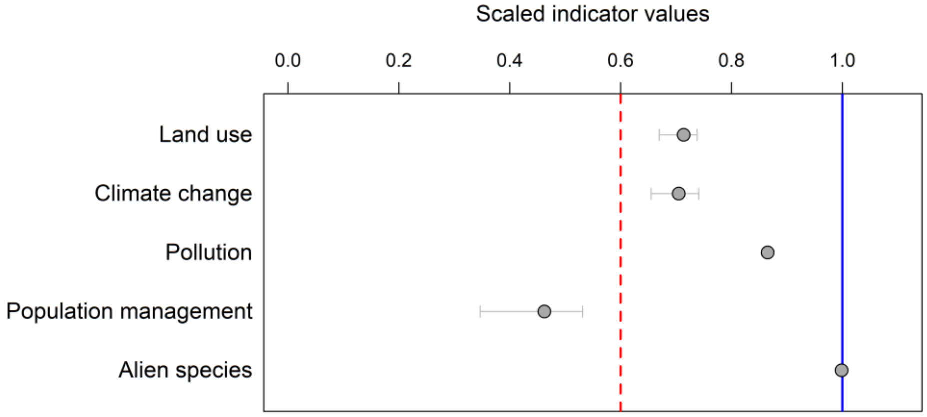

Figure 4.6 *Aggregated values for indicators associated with main categories of anthropogenic direct drivers for mountains. Horizontal lines indicate 95% confidence intervals (some are hidden by the symbols). The blue vertical line represents the reference value, whereas the red dotted line represents the limit value for good ecosystem condition.*

Land use

Ten indicators are assumed to be particularly affected by land use (**Table 4.3**), mainly related to changes in the use of mountains and nearby forests for agricultural purposes, as well as the development of cabins, roads, and other infrastructure and associated human activities. These indicators have a mean value of 0.71. Especially the indicators Arctic fox and wolverine (scaled values of 0.04 and 0.14, respectively) contribute to a low value for this driver. Reindeer (0.60), connectivity of mountain area (0.60), and nature index for mountains (modified) (0.65) also have values well below their reference values, but at or slightly above the limit value for good ecosystem condition. For other indicators that are assumed to respond to land use, the scaled values are above 0.75.

Populations of Arctic foxes and wolverines are under strong direct management, with measures for population strengthening (Eide et al. 2017) and population regulation[27], respectively. To some extent the low scaled values for these indicators are also due to effects of land use or infrastructure development, especially various human activities associated with infrastructure (Rød-Eriksen et al. 2020). Combined effects of several drivers are also the case for other indicators.

There have been large changes in the use of grazing resources in the mountains and nearby forests in the last 100 years (Austrheim et al. 2015, Bryn et al. 2013). However, there have been modest changes in the number of different grazing animals in agriculture, with a decline in the number of cattle from about 146,000 in 1939 to 86,000 in 2019 and an increase in winter-fed

[27] https://www.regjeringen.no/no/tema/klima-og-miljo/naturmangfold/innsiktsartikler-naturmangfold/rovvilt-og-rovviltforvaltning/id2076779/

sheep from 850,000 in 1907 to about 1 million after 2009[28]. For the last 40 years, the number of sheep and lambs on outfield summer grazing has varied around 1.4 million, whereas the number of cattle has increase from just over 20,000 to over 85,000[29]. The most important change in recent decades is the increase in cattle grazing in outfields, although current mountain farming activities are quite different from the traditional grazing and harvesting of previous centuries (Austrheim et al. 2015).

The impact of infrastructure and amount of strongly human-affected land also increase in the mountains, as illustrated by the reduction in area at least 1 km from technical infrastructure[30]. Nevertheless, the index for total impact from infrastructure and strongly human-affected land developed by Erikstad et al. (2013), shows that a large proportion of the mountain area is little affected by infrastructure, as measured by this index.

Holiday homes and various tourist facilities in the mountains or nearby forests form an important part of the impact from infrastructure in the mountains, both in terms of their land use and in the associated human activities. Today about 440,000 holiday homes exist in Norway, and almost 6,700 new cabins are built annually[31]. However, a relatively small proportion of these cabins are located in the mountains above the forest limit or in nearby forests[32]. Nevertheless, in an analysis based on data from 2011, Haagensen (2014) shows that as many as 75,000 cabins are located within or near protected areas, 13,000 cabins are located in nature without other major infrastructure, and 58,000 cabins are located in or near the wild reindeer grazing areas.

Climate change

Altogether 15 indicators are assumed to be particularly affected by climate change (**Table 4.3**). Increasing summer temperature and length of the growing season are believed to have the greatest ecological effects, by directly influencing ecological processes or the life history parameters of species, or indirectly through changes in snow conditions or other properties of the habitat. These indicators have a mean value of 0.70, i.e., somewhat lower than expected for the reference condition, but above the limit value for good ecosystem condition. The indicators Arctic fox, small rodents, vegetation heat requirement and willow grouse have scaled values of 0.04, 0.11, 0.44 and 0.52, respectively, i.e., lower than the limit value for good condition. Reindeer (0.60), nature index for mountains (modified) (0.65) and area of glaciers (0.66) have scaled values at or slightly above the limit value, whereas other indicators have scaled values above 0.75.

Although there is considerable interannual variation, both summer and winter temperatures and the length of the growing season have increased since about 1990 (**Figure 4.7**). The annual precipitation shows no clear trend compared to the normal period 1961–1990, but the number of days with precipitation shows a clear increase over the last decade. The duration of the snow cover (number of days with snow cover) does not show as clear a decrease as one might expect. Average snow depth through the winter or the total amount of winter rain do not show any clear trends (**Figure 4.5**).

The many condition indicators that are considered particularly sensitive to climate change vary greatly in their scaled values, from 0.04 for Arctic fox to 1.00 for snow depth and winter rain. Some of these indicators are also affected by other factors, such as land use and population management. The mean value (0.70) for all the climate-sensitive indicators does not indicate that climate change is especially important for the scaled values of these indicators. However, the trends for temperature and length of the growing season show that the climate has clearly changed in recent decades. Our indicators may not be very sensitive to the climate changes we

[28] https://www.ssb.no/a/histstat/publikasjoner/histemne-05.html

[29] *Beitestatistikk - talgrunnlag - Nibio*

[30] Inngrepsfrie naturområder i Norge - Miljødirektoratet (miljodirektoratet.no)

[31] Hytter og fritidsboliger (ssb.no)

[32] *12511: Fritidsbygg, etter høyde over havet, innenfor og utenfor tettbygd fritidsbyggområde, og størrelse på område (K) 2016 - 2019. Statistikkbanken (ssb.no)*

have observed so far, or they may have a delayed response. In the latest red list for species in Norway (Artsdatabanken 2021), climate change is considered as the most important driver for endangered mountain species. Such endangered species may be more sensitive to climate change than the generally more common species included in our indicators.

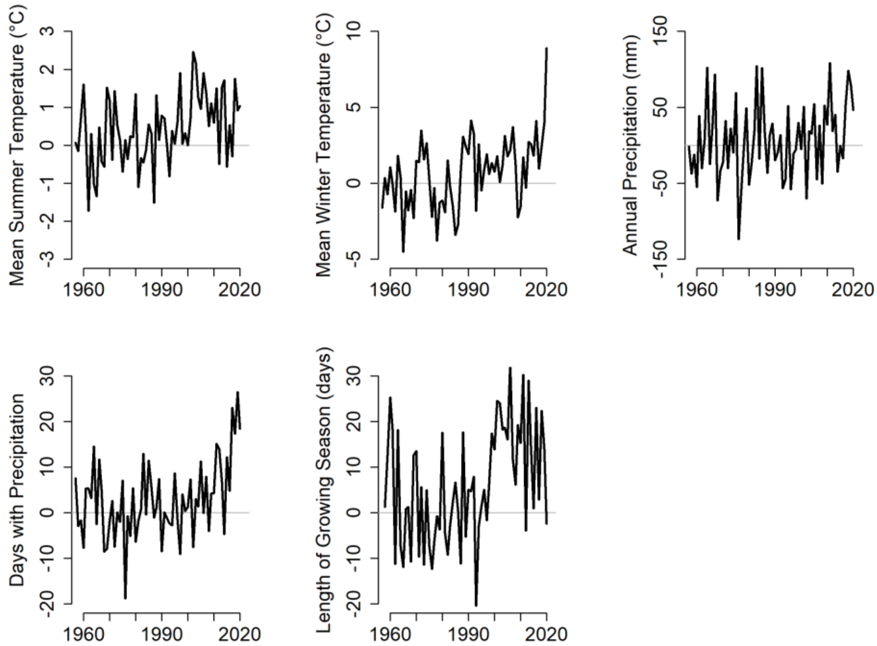

Figure 4.7 *Trends in the deviation of summer and winter temperatures, growing season length, annual precipitation and annual number of days with precipitation from the mean values during the normal period 1961–1990, for mountain areas.*

Pollution

Only two indicators are assumed to be particularly affected by pollution, particularly nitrogen deposition, NDVI trend and Ellenberg N (**Table 4.3**). Their mean value is 0.87, i.e., clearly higher than the limit value for good ecosystem condition. The value for NDVI trend (lower/upper 0.88/0.75) is a bit below the reference value, whereas the value for Ellenberg N (lower/upper 0.96/0.96) is close to the reference value.

Data for nitrogen deposition through air and precipitation, as well as the pattern of exceedance of the vegetation's critical load for nitrogen (Austnes et al. 2018), indicate that the nitrogen impact is highest in the southwest and decreases northwards. The decline since the 1990s has recently stagnated. In the southwest, deposition is still above 5 kg N/ha/year, the critical load for most vegetation types.

Direct population management

Direct population management of wild species includes hunting or regulation (culling) of the population for certain species. It may also include measures to strengthen the population of other species. Four indicators are assumed to be particularly affected by population management (**Table 4.3**), partly through regular hunting or harvesting (reindeer, willow grouse, ptarmigan) and partly by population regulation (wolverine). Measures to strengthen the population of Arctic foxes have been in effect in Norway since 2005 (Eide et al. 2020a), resulting in a positive trend for this species over the past 15 years. The mean value of these indicators is 0.46, i.e., well below the limit value for good ecosystem condition. In particular, the indicators Arctic fox and wolverine contribute to this low value, with scaled values of 0.04 and 0.14, respectively. For wolverine, this is mainly due to the population being kept at a much lower level than would be expected in an intact ecosystem. Reindeer (0.60) and the nature index for mountains (modified) (0.65) have scaled values equal to or just above the limit value for good ecosystem condition.

The population trends for the species varies somewhat, with an increase for Arctic foxes and willow grouse since 2010, a stable trend for wolverines, and a slight decrease for the nature index for mountains (modified) (**Figures 4.3, 4.4**). For wolverines and Arctic foxes, the population levels are a direct consequence of the management measures. The reindeer population is also to a large extent directly affected by management and hunting (for wild reindeer) but it is also affected by climate change and infrastructure development. Hunting represents an important impact on grouse populations, but here land use, climate change and effects of other changes in the ecosystem are also of great importance.

The number of killed wild reindeer through hunting has decreased considerably since the mid-1990s[33]. This probably reflects an adjustment of hunting in response to reduced populations due to several influences other than hunting alone (cf. Kjørstad et al. 2017). From the middle of the 2000s, the slaughter of domestic reindeer has varied considerably between years in Finnmark but has been more stable in other domestic reindeer areas[34]**.** The number of grouse killed has had a significant decrease since the mid-2000s[35]. This is probably due to both population reduction, partly due to hunting (Sandercock et al. 2011, Israelsen et al. 2020), and gradually stronger regulations of hunting since 2000.

Alien species

Only one indicator represents the influence of alien species, absence of alien species. The scaled value for this indicator is equal to the reference value (1). The current data from the monitoring programme ANO contain very few occurrences of alien species, which is as expected for mountains. In general, it is assumed that the number and quantity of alien species will increase in all ecosystems (Hendrichsen et al. 2020). Reported occurrences of alien species associated with mountains so far show only a total of 17 introductions, 6 of plants and 11 of animals, since 1900 (Artsdatabanken 2018).

4.3.3 Summary of the results

The indicator values and condition estimates give a somewhat varied impression of the condition for mountain ecosystems. The individual indicators cover different smaller parts of the whole, with different degrees of certainty for the indicator estimates. Below we will see all our data in context and assess how well the conclusions about the condition for mountain ecosystems are supported.

The results based on levels and trends for condition indicators and supplementary variables are summarized in **Table 4.6**. The actual calculation of the condition for mountain ecosystems is based on 19 indicators (the three indicators with both lower and upper limit values count as one indicator each).

The overall value for the condition for mountain ecosystems is 0.68. Particularly, the indicators Arctic fox (0.04), small rodents (0.11), wolverine (0.14) and vegetation heat requirements (0.44) contribute to a rather low value. Reindeer (0.60), connectivity of mountain area (0.60), nature index for mountains (modified) (0.65) and area of glaciers (0.66) all have scaled values at or slightly above the limit value for good ecological condition. The other indicators have scaled values (≥ 0.75) well above the limit value.

[33] Villreinjakt (ssb.no)
[34] Reinbase.no - Overvåkingsprogram for tamrein - Reindrift og rovvilt
[35] https://www.ssb.no/statbank/table/03886/

Table 4.6 *Summary of results for the characteristics of mountain ecosystems in Norway, for the indicators included in the calculation of condition values and for supplementary variables (in italics). For indicators used in the calculation of condition values, scaled values are given. For supplementary variables the level is compared qualitatively to an assumed level in the reference condition: ++ very near, + near, - moderate deviation, -- strong deviation, ? uncertain. For both types of indicators time series (for unscaled values) are indicated with length in number of points and period, as well as trend: ↑ increasing, ↓ decreasing, ↔ stable, – too short time series.*

Ecosystem characteristics	Condition value	No. indicators	Indicators / *Supplementary variables*	Value	Time series: trend
Mountains overall	***0.68***	***21***			
Primary production	0.77	1	NDVI trend (lower) NDVI trend (upper)	0.88 0.75	1 (2000-2019): –
Distribution of biomass between different trophic levels	0.49	8	NDVI trend (lower) NDVI trend (upper) Reindeer Small rodents Willow grouse Ptarmigan Arctic fox Wolverine Golden eagle *NI-primary producers* *NI-herbivores* *NI-medium predators* *NI-top predators*	0.88 0.75 0.60 0.11 0.52 0.77 0.04 0.14 0.90 + - + -	1 (2000-2019): – 1 (2015-2020): – 5 (1990-2019): ↓ 12 (2009-2021): ↑ 11 (2009-2020): ↔ 5 (1990-2019): ↑ 5 (1990-2019): ↔ 1 (2015-2020): – 5 (1990-2019): ↔ 5 (1990-2019): ↓ 5 (1990-2019): ↔ 5 (1990-2019): ↔
Functional composition within trophic levels	0.44	7	Reindeer Small rodents Willow grouse Ptarmigan Arctic fox Wolverine Golden eagle	0.60 0.11 0.52 0.77 0.04 0.14 0.90	1 (2015-2020): – 5 (1990-2019): ↓ 12 (2009-2021): ↑ 11 (2009-2020): ↔ 5 (1990-2019): ↑ 5 (1990-2019): ↔ 1 (2015-2020): –
Functionally important species and biophysical structures	0.57	3	Absence of alien species Reindeer Small rodents *Cover of shrubs/trees*	1.00 0.60 0.11 –	1 (2019-2021): – 1 (2015-2020): – 5 (1990-2019): ↓ 1 (2019-2021)
Landscape ecological patterns	0.70	2	Area without technical infrastructure Connectivity of mountain area	0.79 0.60	4 (2002-2017): ↓ 1 (2020): –
Biological diversity	0.65	1	Nature index for mountains (modified) *Mountain birds*	0.65 *-?*	5 (1990-2019): ↓ 10 (2011-2020): ↔
Abiotic factors	0.84	7	Ellenberg N (lower) Ellenberg N (upper) Ellenberg L (lower) Ellenberg L (upper) Vegetation heat requirement Area of glaciers Snow depth Snow cover duration Winter rain	0.96 0.96 0.98 0.97 0.44 0.66 1.00 0.87 1.00	1 (2019-2021): – 1 (2019-2021): – 1 (2019-2021): – 2 (ca 1960, 2018-2019): ↓ 61 (1960-2020): ↓ 61 (1960-2020): ↓ 61 (1960-2020): ↔

The assignment of condition indicators to ecosystem characteristics says something about how large deviations from the reference condition are likely to affect the ecosystem. We have included both condition indicators and supplementary variables (**Table 4.6**).

- *Primary production*: This characteristic has a calculated condition value of 0.77, based on the indicator NDVI trend, indicating a somewhat stronger increase in primary production than expected in the reference condition. This implies a deviation from the expected value in the reference condition, but not large enough to indicate a degraded ecosystem condition.
- *Distribution of biomass between different trophic levels*: This characteristic has a calculated condition value of 0.49, based on the indicators NDVI trend, reindeer, small rodents,

willow grouse, ptarmigan, Arctic fox, wolverine and golden eagle. Arctic fox, wolverine, small rodents and partly willow grouse and reindeer pull the value down, whereas the other indicators are above the limit value for good condition. The supplementary variables of trophic groups based on indicators in the Nature Index for mountains also indicate that primary producers and intermediate predators deviate little from levels in the reference condition, whereas herbivores and top predators deviate to a great extent. In the calculation of condition value, the predators Arctic fox and wolverine contribute to a substantial imbalance in the distribution of biomass between these trophic levels. Small rodents and reindeer also contribute to an imbalance between the trophic levels, with, respectively, lower small rodent population peaks and partly higher reindeer populations than expected in the reference condition. This impression is confirmed by the trophic indices for herbivores and top predators, based on indicators in the Nature Index for mountains.

- *Functional composition within trophic levels*: This characteristic has a calculated condition value of 0.44, based on the indicators reindeer, small rodents, willow grouse, ptarmigan, Arctic fox, wolverine and golden eagle. The same indicators contribute to the low value here as for the previous characteristic. Low population levels for Arctic fox and wolverine represent the imbalance among predators, whereas partly high populations of reindeer and low population peaks of small rodents cause the imbalance among herbivores.
- *Functionally important species and biophysical structures*: This characteristic has a calculated condition value of 0.57, based on the indicators absence of alien species, reindeer and small rodents. The condition value is just below the limit value for good ecosystem condition. Small rodents and partly reindeer contribute to a low value. The absence of alien species does not indicate any deviation from the reference condition. The supplementary variable cover of shrubs and trees does not indicate any deviation from the reference condition.
- *Landscape ecological patterns*: This characteristic has a calculated condition value of 0.70, based on the indicators area without technical infrastructure and connectivity of mountain area. The connectivity of mountain area, with a scaled value equal to the limit value, reduces the overall condition value.
- *Biological diversity*: This characteristic has a calculated condition value of 0.65, based on the indicator nature index for mountains (modified), which represents the condition for several species associated with mountains. The condition value is a little above the limit value for good ecosystem condition. The supplementary variable for mountain birds does not indicate whether the characteristic *biological diversity* deviates from the reference condition.
- *Abiotic factors*: This characteristic has a calculated condition value of 0.84, based on the indicators Ellenberg N, Ellenberg L, vegetation heat requirement, area of glaciers, snow depth, snow cover duration and winter rain. The condition value indicates a small deviation from the reference condition, but clearly above the limit value for good ecosystem condition. The vegetation heat requirement has a scaled value below the limit value, the *area of glaciers* has a scaled value slightly above the limit value, and the other indicators have values closer to the reference value.

The available data series for the condition indicators are generally short (maximum 30 years or ten data points, but 60 years for indicators based on climate data) (**Table 4.6**). For the four indicators based on data from ANO (Ellenberg N, Ellenberg L, vegetation heat requirement, absence of alien species) and for reindeer, golden eagles, and connectivity of mountain area we currently have no time series. The NDVI trend indicator is based on a time series 2000–2019 but is expressed through one variable that reflects the time trend. The trends for other indicators may only tell us if the indicators have moved away from or approached the reference level in recent years. The four indicators based on data from the Norwegian Water Resources and Energy Directorate (NVE) and the Norwegian Meteorological Institute show that the area of glaciers and snow cover duration have decreased somewhat in the last 30 years, whereas there is no clear trend for snow depth or

***Table 4.7** Summary of results for mountain condition indicators assigned to the most relevant drivers.*

	Aggregated value	No. indicators	Indicators included	Scaled value
Land use	0.71	10	NDVI trend (lower) NDVI trend (upper) Reindeer Arctic fox Wolverine Golden eagle Absence of alien species Area without technical infrastructure Connectivity of mountain area Nature index for mountains (modified) Ellenberg L (lower) Ellenberg L (upper)	0.88 0.75 0.60 0.04 0.14 0.90 1.00 0.79 0.60 0.65 0.98 0.97
Climate change	0.70	15	NDVI trend (lower) NDVI trend (upper) Reindeer Small rodents Willow grouse Ptarmigan Arctic fox Absence of alien species Nature index for mountains (modified) Ellenberg N (lower) Ellenberg N (upper) Ellenberg L (lower) Ellenberg L (upper) Vegetation heat requirement Area of glaciers Snow depth Snow cover duration Winter rain	0.88 0.75 0.60 0.11 0.52 0.77 0.04 1.00 0.65 0.96 0.96 0.98 0.97 0.44 0.66 1.00 0.87 1.00
Pollution	0.87	2	NDVI (lower) NDVI (upper) Ellenberg N (lower) Ellenberg N (upper)	0.88 0.75 0.96 0.96
Direct population management	0.46	6	Reindeer Willow grouse Ptarmigan Arctic fox Wolverine Nature index for mountains (modified)	0.60 0.52 0.77 0.04 0.14 0.65
Alien species	1.00	1	Absence of alien species	1.00

winter rain. Unscaled values for populations of herbivores and predators show variable trends over the last 10–30 years, with a small decrease (small rodents), increase (willow grouse, Arctic fox, wolverine) or being very variable (ptarmigan). The nature index for mountains (modified) and area without technical infrastructure both show a gradual decline.

The individual indicators are to a varying degree influenced by anthropogenic direct drivers. We have assigned the condition indicators to five main categories of such drivers (**Table 4.7**). We also have data for various drivers within each main category (cf. chapt. 4.2.3). The results provide the following relationships between the calculated ecosystem condition and the individual main categories of drivers:

- *Land use*: Altogether 10 indicators are considered as particularly influenced by land use, partly related to effects of changes in traditional agricultural practices (grazing, harvesting), but mainly related to infrastructure development such as construction of roads, cabins, power lines etc, and the increase in associated human activities. These indicators give an aggregated value of 0.71, i.e., above the limit value for good ecosystem condition. Several of the indicators with low values are also considerably influenced by other factors such as climate change and population management. However, changes in land use and infrastructure development are extensive and must be considered to have a substantial effect on the relevant indicators, although not all have low scaled values.

- *Climate change*: Altogether 15 indicators are considered as particularly influenced by climate change. Most of these are assumed to respond to changes in temperature or growing season, as well as changes in glaciers and snow conditions due to climate change. These indicators give an aggregated value of 0.70, i.e., above the limit for good ecosystem condition. Climate indicators show a clear increase in temperatures and length of the growing season. Except for the area of glaciers, values for most condition indicators do not yet clearly reflect observed climate change over the last 30 years.
- *Pollution*: Two indicators (NDVI trend, Ellenberg N) are considered as particularly influenced by pollution in the form of nitrogen deposition. The aggregated value for these is 0.87, i.e., well above the limit value for good ecosystem condition. Data for deposition of nitrogen by air or precipitation indicate a significant reduction in recent decades, but levels still exceed the critical loads for vegetation in southwestern mountain areas. However, there is no clear relationship between the values for our condition indicators and observed changes in nitrogen deposition.
- *Population management*: Six indicators are considered as particularly affected by hunting or direct population management measures. The aggregated value for these is 0.46, i.e., clearly below the limit value for good ecosystem condition. Scaled values for the indicators Arctic fox and wolverine are far below the level for good condition. Scaled values for willow grouse and reindeer are also low. Hunting of wild reindeer and willow grouse, as well as the slaughter of domestic reindeer, may rather represent responses to reduced population levels than causes for the observed population levels.
- *Alien species*: Only one indicator is in principle considered as particularly affected by alien species (absence of alien species). With a value of 1, it is very close to the reference condition. So far, only a few alien species relevant for this indicator (vascular plants with the least high potential risk) have been documented in the mountains.

4.3.4 How reliable are the conclusions?

For the calculation of the condition for mountain ecosystems, we have used 19 indicators. These indicators are assigned to the ecosystem characteristics as defined by the expert group (Nybø & Evju 2017). We may ask how well our indicators cover these characteristics.

Primary production is represented by the indicator NDVI trend, specified as the change in annual values for the period 2000–2019. NDVI represents a measure of the amount of green vegetation, where species with a high density of green biomass contribution most. Productivity varies greatly in the mountain landscape due to underlying local and regional environmental gradients in bedrock, climate and seasonal snow cover. Hence, it is not possible to set a general value for NDVI under good ecological condition. Instead, we let our indicator NDVI trend represent the change in observed green biomass over time. Previously, the indicators Ellenberg N and Ellenberg L have been considered as relevant for this characteristic (Nybø et al. 2019), and Ellenberg N is included for primary production in the assessment of forest ecosystem condition (chapt. 3). For mountains, we have concluded that the Ellenberg indicators are less suited as measures of primary production since they mainly reflect changes in functional species composition in response to varying environmental site conditions. They are therefore not included for the characteristic *primary production* in the assessment of mountain ecosystem condition. However, it may be desirable to capture the contribution from primary production in other ways, both collectively and for different parts of the vegetation, e.g., partitioned for shrub and field layers. This will require the development of new indicators and partly new underlying data, especially if the dynamics of primary production within the growing season shall be covered.

Distribution of biomass between trophic levels is represented by eight indicators that cover primary production (NDVI trend), herbivores (reindeer, small rodents, willow grouse, ptarmigan) and predators (wolverine, Arctic fox, golden eagle). NDVI is correlated with the biomass of green vegetation and represents a rough measure of the trophic level of primary producers. However, we lack indicators for other parts of this trophic level, such as total standing biomass above and below ground. Our indicators for herbivores cover important parts of food chains dominated by vertebrates, which also include the represented predators. However, we lack other important components in vertebrate-dominated food chains, such as the predators stoats, weasels, red foxes and wolves, as well as a number of bird species at various trophic levels. Wolves as a top predator in an intact mountain ecosystem would be important for the dynamics of reindeer, other predators and scavengers. However, we completely lack indicators of invertebrates, fungi and microorganisms at all trophic levels, including important trophic functions such as herbivores, predators, parasites, symbionts and decomposers. Invertebrates and microorganisms are often part of food chains with faster turnover and therefore have potentially great ecological importance. However, knowledge of these groups of organisms and their functions is weak, and the data are mostly lacking.

Functional composition within trophic levels is represented by seven indicators that cover different functional groups within herbivores and predators. These are the same indicators for mammals and birds as for the characteristic *distribution of biomass between trophic levels*. The distinctions between large and small species and between birds and mammals represent the functional differences. There are many other functional characteristics associated with vertebrates, such as feeding strategies and other roles in the ecosystem, which would be relevant to include, but where data are lacking. This applies even more to various functional groups among plants, fungi, invertebrates and microorganisms, species groups not included for this characteristic due to lack of data.

Functionally important species and biophysical structures are represented by three indicators: absence of alien species, reindeer and small rodents. Alien species are currently of very little importance in Norwegian mountain ecosystems, but this may change in the future. Reindeer are the most important large herbivores in the mountains, where their large populations and presence throughout the year have considerable effects on the vegetation and as food for predators and scavengers. Small rodents are key species that have a great impact on the vegetation and several other species through their regular large population peaks. However, there are several other functionally important species and structures that should have been represented. Among the most important of these are the structure and cover of functional groups among vascular plants, mosses, and lichens, which regulate microclimate and nutrient transport, and provide habitat and food for other trophic groups. Soil organisms such as mycorrhizal fungi and various decomposers have key roles in nutrient turnover in the ecosystem. Various functional groups of invertebrates such as pollinators and various groups with mass occurrences (e.g., defoliating moths) are also relevant.

Landscape ecological patterns are represented by the indicators *area* without technical infrastructure and connectivity of mountain area. These indicators partly represent the amount of mountain area that is little affected by technical infrastructure and human activity. Connectivity of mountain area provides a measure of how well patches of mountain area are connected, and thus how well it satisfies requirements for species dispersal and size of home ranges. The extent of important habitats, such as snow beds and lichen heaths, and the spatial distribution of such habitats, also represent landscape ecological patterns that should be include, but where we lack nationwide data.

Biological diversity summarizes aspects of diversity such as species diversity, species replacement and genetic diversity within species. *Biological diversity* is important for the ecosystem's function, for resistance to environmental changes, as well as the ability to recover from extreme events (resilience). This characteristic is represented by the indicator nature index for mountains (modified), which represents the condition of biological diversity in terms of abundances for 28 selected species. The nature index for mountains (modified) has insufficient coverage of many important species groups, not least among species-rich groups such as invertebrates, fungi, and lichens. This indicator also does not capture aspects of species richness, degree of species replacement or genetic diversity.

Abiotic factors are represented by four indicators of ice and snow conditions with great importance for the livelihoods of many species. In addition, three indicators are included for plant species' responses to various local environmental site conditions, such as responses to light, temperature and access to nitrogen. These are relevant and important ecological factors, but there are also several other important chemical and physical conditions that may reflect deviations from the reference condition. Soil chemical conditions such as the absolute and relative amount of carbon and nitrogen, as well as concentrations of base cations like calcium and magnesium, say a lot about the condition of the soil. The amount of soil organic carbon is an important indicator for describing the role of the soil in the carbon cycle and thus in the climate system.

Based on this summary review of the ecosystem's characteristics and the indicators' coverage of these characteristics, it is obvious that several additional indicators are needed to cover important aspects of most of the ecosystem characteristics. The indicator set covers all characteristics, but the coverage is very uneven between trophic levels and groups of organisms. Hence, there is a strong need to further develop this set of indicators, but the lack of relevant data for such indicators is a serious limitation.

Underlying data for the indicators
For the indicators to be able to describe the condition of mountain ecosystems, the underlying data must be suitable. This includes (1) whether the data actually measures what the indicators are intended to represent (relevance), (2) whether the data provide a basis for drawing conclusions about the entire area we are to characterise (area representativeness), (3) whether the data cover natural variation in indicator values for the period we are to characterise (variance), and (4) whether the data provide a basis for estimating indicator values with sufficient precision to be able to draw certain conclusions (sensitivity). Key information on the underlying data for the individual indicators is summarised in **Table 4.8**.

The representation of the indicators and the underlying data: Most of the indicators are fairly directly based on the underlying data. However, some indicators are derived from the basic data in a way that may make it difficult to understand what the indicators represent.

- *NDVI trend*: The basic data for NDVI is measured as the standard index value for red (R) and near-infrared (NIR) light, (NIR-R) / (NIR+R), for a random sample of 25,000 pixels for the whole mountain area. The indicator represents an annual change in NDVI by the slope for a linear regression of average NDVI values in the growing season against year, for the period 2000–2019 (cf. chapt. 4.2.1).
- *Ellenberg N, Ellenberg L*: The basic data are the coverage values for vascular plant species recorded in individual sampling points in the monitoring programme ANO. The indicator values are obtained by connecting the coverage values to modified Ellenberg scores for nitrogen and light, respectively (cf. chapt. 4.2.1).
- *Vegetation heat requirement*: As for the Ellenberg indicators, the basic data are the coverage values for vascular plant species recoded in individual sampling points in ANO. The indicator value is obtained by connecting these coverage values to scores for the heat requirement of each species (cf. chapt. 4.2.1).

Geographical representativeness of the underlying data: This assessment covers the ecosystem condition of the entire mountain area, defined as the area above (or north of) our modelled forest limit. The underlying data for the indicators cover all or most of this area and can be considered as geographically representative. However, the spatial resolution of the data varies for the individual indicators.

- Data for NDVI trend are based on a representative sample from a comprehensive set of spatial units given by the resolution of the satellite images (250 m). Since cloud cover can hide the ground surface, the data are collated from data from several satellite images, usually over a period of 16 days.

- Data from ANO have been collected from a substantial number of statistically representative sites. The current data from ANO for mountains for the years 2019–2021 come from 191 (for 1 m^2 squares) and 201 (for 250 m^2 circles) sample plots. This will include a total of about 1000 plots distributed on various ecosystems throughout the country (of which about 1/3 in the mountains) at each full inventory cycle.
- Data for wolverines are given as a total estimate for each large carnivore region and then assigned to the regional division used here.
- Data for Arctic foxes include all mountain areas where reproduction of Arctic foxes has historically been recorded. This means that some marginal mountain areas along parts of the coast are not included.
- Data for small rodents include mountain areas where existing data or qualitative observations are used as a basis for assessing the population of small rodents in peak years. This does not include some mountain areas along parts of the coast.
- Data for the nature index for mountains (modified) are given as estimates per region, but data for the underlying indicators vary in both geographical coverage and resolution.

The underlying data's cover of variation in time: Data for all indicators (except climate-based indicators) cover only short (or no) time series and often at intervals of more than one year. This means that the data provide very limited opportunities to estimate trends or variation at relevant time scales. Ideally, the data should be available as annual observations over many decades, something rarely available for ecological data.

Estimation of indicator values with specified uncertainty: The underlying data for the individual indicators include both sample-based data from ANO, comprehensive discrete data for NDVI, absolute or relative population numbers or densities for species, aggregated indices such as the nature index for mountains, and 'absolute' measures for area of glaciers and area without technical infrastructure. Uncertainty for estimated indicator values is generally quantified from the variation in 10,000 simulations with random extraction of existing values, with a somewhat different approach depending on the type of underlying data (cf. chapt. 2). The uncertainty as such is based on various sources, the most common being bootstrapping of observational data and uncertainty related to statistical population models (see **Table 4.8**).

In summary, the data represent a good foundation for providing reliable estimates for the indicator values, and they are representative of the geographical variation in indicator values. However, the lack of long time series means that the data do not provide a good basis for judging trends or variation in the indicator values over time.

Certainty in the assessment of ecosystem condition

There is some uncertainty associated with determining reference values for the indicators. Scaled values for some of the indicators could thus be somewhat higher or lower than those we have calculated here, and this could affect the assessment of ecosystem condition. However, as pointed out for forest ecosystems (chapt. 3.3.4), sensitivity analyses of the effect of errors in the indicator reference values for the Nature Index (Pedersen & Nybø 2015), indicate that the overall calculated ecosystem condition value according to the IBECA approach may also be rather insensitive to errors in the setting of reference values.

In addition, the unscaled indicator values, compared with knowledge of the relevant indicators in nature with little human impact, show that several of the indicators have values significantly below what we would expect for intact mountain ecosystems. This applies especially to Arctic foxes, small rodents and wolverines. The low values for these indicators indicate that the current condition of mountain ecosystems deviates substantially from the reference condition.

Table 4.8 *Assessment of the underlying data for the mountain condition indicators. Length of time series is given as number of points (period).*

Indicators	Underlying data	Data source*	Geographical representativity	Time series	Estimated uncertainty
NDVI trend	Trend of NDVI values for mountain area for June–September during 2000-2019	MODIS satellite (MOD13Q1 V6 Terra Vegetation Indices 16-Day Global 250m)	All mountain area, randomly sampled pixels	21 (2000-2019)	Bootstrapping of pixels
Reindeer	Populations of wild and domestic reindeer in respective reindeer areas	Kjørstad et al. (2017); www.reinbase.no	All mountain area, incl. area without reindeer today	1 (2016-2020)	Expert assessment: assumed coefficient of variation of 10% and 5% for population estimates for wild and domestic reindeer, respectively
Small rodents	Mean population peaks per 10 yrs	TOV and other sources.	All mountain area with specified values (excluding some mountain areas along the coast)	5 (1990-2019)	Expert assessment, with same assessment as in the Nature Index
Willow grouse	Estimated densities of adult grouse in August, mean for last 5 yrs	Hønsefuglportalen	All mountain area	12 (2009-2021)	Model uncertainty
Ptarmigan	Relative breeding population index, mean for last 5 yrs	TOV-E	All mountain area	11 (2009-2020)	Model uncertainty
Arctic fox	Number of reproducing individuals, as mean for 3 yr periods	Monitoring programme for Arctic foxes	All mountain area with historical records of Arctic fox breeding	5 (1990-2019)	Model uncertainty
Wolverine	Number of individuals for mountain region, based on model estimates for large carnivore regions	Rovdata	All mountain area	5 (1990-2019)	Model uncertainty
Golden eagle	Estimated total number of territories last 5 yrs	Rovdata	All mountain area	1 (2016-2020)	Model uncertainty
Absence of alien species	Presence/absence within each of 18 plots of 250 m^2 per site	ANO	All mountain area, randomly placed sampling sites	1 (2019-2021)	Bootstrapping of observation units, spatial variation
Area without technical infrastructure	Map data for area at least 1 km from technical infrastructure	Norwegian Environment Agency	Verdier for fjell i hver region	6 (1988-2018)	Lacking uncertainty estimate
Connectivity of mountain area	Map data for mountain polygons, forest and infrastructure	N50 map series	All mountain area	1 (2020)	Lacking uncertainty estimate
Nature index for mountains (modified)	Scaled index value per region	Nature Index	Verdier for hver region; dekning for underliggende indikatorer varierer	5 (1990-2019)	Aggregated uncertainty based on 28 indicators (same as for the Nature Index)
Ellenberg N	Cover of vascular plant species in 18 1 m^2 squares per site, combines with Ellenberg scores for nitrogen per species	ANO	All mountain area, randomly placed sampling plots	1 (2019-2021)	Bootstrapping of observation units, spatial variation
Ellenberg L	Cover of vascular plant species in 18 1 m^2 squares per site, combines with Ellenberg scores for light per species	ANO	All mountain area, randomly placed sampling plots	1 (2019-2021)	Bootstrapping of observation units, spatial variation

Indicators	Underlying data	Data source*	Geographical representativity	Time series	Estimated uncertainty
Vegetation heat requirement	Cover of vascular plant species in 18 1 m^2 squares per site, combines with score for heat requirement per species	ANO	All mountain area, randomly placed sampling plots	1 (2019-2021)	Bootstrapping of observation units, spatial variation
Area of glaciers	Estimated total area based on Sentinel 2	Norwegian Water Resources and Energy Directorate	All mountain area	2 (ca. 1960, 2018-2019)	Specified as 3% by NVE and interpreted as ±3% equal to 95% confidence interval
Snow depth	Mean snow depth December-May	www.senorge.no	All mountain area, interpolated values per km^2	61 (1960-2020)	Bootstrapping of observation data
Snow cover duration	Number of days with snow cover	www.senorge.no	All mountain area, interpolated values per km^2	61 (1960-2020)	Bootstrapping of observation data
Winter rain	Sum of precipitation for January-March for days with mean temperature >2°C, interpolated values	www.senorge.no	All mountain area, interpolated values per km^2	61 (1960-2020)	Bootstrapping of observation data

* Data sources: ANO – National geographically representation monitoring of vegetation and nature types (Tingstad et al. 2019); TOV – integrated monitoring of vegetation, birds, small rodents etc in selected sites (Framstad 2021); TOV-E – extensive, geographically representative breeding bird monitoring (Kålås et al. 2021a); Hønsefuglportalen – Hønsefulgportalen (nina.no); Rovdata – Rovdata - Hjem

For the indicators of vegetation heat requirement, willow grouse and area of glaciers, it is very likely that the unscaled values are below the levels we would expect in intact mountains. However, it may be less certain how far away they are, and whether this reflects a degraded condition for mountain ecosystems. The indicators NDVI trend, ptarmigan and area without technical infrastructure also probably have lower values than expected for intact mountains, but these values are not so low that they indicate degraded condition.

The nature index for mountains (modified) is an aggregated index with 28 underlying indicators that represent abundances of different species (in the version used here). This index is based on scaled values for the underlying indicators and an unscaled index value cannot be assessed. Eide et al. (2020b) discussed these indicators in the Nature Index 2020 for mountains and concluded that the overall index value reflects a clear deviation from the level in intact mountain ecosystems. However, they point out that the underlying data are uncertain due to extensive use of expert judgement and limited geographical coverage for several indicators.

Data for various types of land use, such as the extent of cabins, roads and other technical infrastructure, also indicate that the mountain ecosystem deviates from intact nature. The management of large carnivores also means that the population level for wolverines is far below the expected level in intact mountains.

The other indicators in the calculation of mountain ecosystem condition have relatively high scaled values, and despite some uncertainty about the reference value, there is little reason to assume that the deviations in unscaled values for these indicators are substantially below the level in intact mountains.

Overall assessment of the reliability of the results

The indicators' coverage of the ecosystem characteristics, levels and trends for condition indicators and drivers, as well as uncertainty related to the indicator estimates, give a rather comprehensive picture of the condition for mountain ecosystems (**Table 4.9**):

- The indicators cover relevant aspects of the individual ecosystem characteristics, but the coverage is deficient in that several important trophic levels and groups of organisms are not sufficiently covered (cf. the review above). For the aspects covered, the indicators provide a relatively good basis for assessing the ecosystem condition.
- The levels for four of the indicators (given as unscaled indicator values) is so much lower than we would expect in intact mountain ecosystems, that it must be considered very likely that the mountain ecosystem condition deviates substantially from the reference condition. Five other indicators are probably very close to the limit for good ecosystem condition, with scaled values just below or just above the limit value.
- The distribution of indicators on ecosystem characteristics indicates that the characteristics *distribution of biomass between different trophic levels, functional composition within trophic levels,* and *functionally important species and biophysical structures* particularly deviate from the reference condition. However, the characteristics *landscape ecological patterns* and *biological diversity* also deviate quite clearly from the reference condition. The condition assessment for the individual ecosystem characteristics has greater uncertainty than the overall condition assessment.
- Time series for most indicators are missing or too short to say whether the trends indicate that the indicators are approaching or deviating from the reference condition.
- The indicators' assignment to anthropogenic drivers indicates that direct population management is an important cause for the overall deviation from the reference condition. Indicators assigned to land use and climate change also have low values. The negative effects of climate change are likely to become clearer in the coming decades. Trends for pollution are more uncertain.

The overall condition value for mountain ecosystems is 0.68, based on the indicators directly, and 0.64 if the condition value is based on the condition values for the characteristics. The confidence intervals for the overall condition values are above the limit value of 0.60 for good ecosystem condition. Consequently, the condition for mountain ecosystems can be considered as good. Nevertheless, we consider the overall condition for mountain ecosystems as uncertain (**Table 4.9**). The reasons are that the calculated condition values are near the limit value and our overall assessment of the indicators' inadequate coverage of characteristics, lack of time series for underlying data, and that most drivers tend to become more negative.

Table 4.9 *Overall assessment of the reliability of the results for the condition of mountain ecosystems, based on the indicators' coverage of the ecosystem characteristics, levels (compared to the reference state) and trends for the indicators' unscaled values, as well as the effects of the main drivers on the scaled values of indicators assigned to each characteristic. The right-hand column indicates whether the condition is certainly good or deviates from good (i.e., is degraded) or is uncertain, all aspects considered.*

Ecosystem characteristics	**Condition value**	**Indicators**	**Indicator values**		**Effect of drivers**	**Condition**
			levels	**trend**		
Primary production	0.77	Insufficient	Some deviations	Increasing	Negative	Good
Distribution of biomass between different trophic levels	0.49	Somewhat insufficient	Partly large deviations	Varying	Negative	Degraded
Functional composition within trophic levels	0.44	Somewhat insufficient	Partly large deviations	Varying	Negative	Degraded
Functionally important species and biophysical structures	0.57	Insufficient	Partly deviations	Varying	Negative	Uncertain
Landscape ecological patterns	0.70	Insufficient	Some deviations	Decreasing	Negative	Uncertain
Biological diversity	0.65	Insufficient	Some deviations	Decreasing	Negative	Uncertain
Abiotic factors	0.84	Somewhat insufficient	Small deviations	Varying	Positive, Negative	Good
Overall assessment	**0.68**	**Insufficient**	**Some deviations**	**Varying**	**Negative**	**Uncertain**

4.4 Mountain ecosystems in the future

The current condition for mountain ecosystems in Norway is reviewed and documented above, based on the relevant condition indicators and data for various anthropogenic drivers. This shows that the condition deviates substantially from the expected condition for intact mountain ecosystems and that the overall condition value is only just above the limit value for good ecosystem condition. The following factors contribute to this result:

- *Development of infrastructure for transport, energy and buildings* has led to habitat loss, fragmentation and disturbance of mountain areas, especially at lower elevation near the forest limit. The human activities that accompany such development, especially cabins and tourist facilities of increasing size, of increasing standard, and with increasing associated infrastructure (water, electricity, roads), also cause considerable disruption and negative impacts on many species.
- *The management of large carnivores* aims to keep their populations at a minimum viable level, far below the expected population level in intact ecosystems. This is negatively impacting several characteristics of ecosystem condition, reflecting their importance in a functioning ecosystem.
- *Climate change is having an increasing impact on the mountain ecosystems*. This is shown directly by a sharp reduction in the glacier area. It is an important driver behind the increased occurrence of species with high temperature requirements. It is also a

contributing reason for the increase in primary production (measured by changes in NDVI) and the low population levels for Arctic foxes and small rodents. This suggests that system-wide impacts of climate change are already detectable.

We may ask how these factors, and the condition of mountain ecosystems, will change in the next decades until 2050. This will partly depend on the ecological processes, given the current environmental and societal constraints. With the probable climate development in the next decades (Hanssen-Bauer et al. 2015), combined with the continuation of current trends for land use in mountain areas, trees and bushes will expand into the open areas above the forest limit and more boreal species will become established. On the other hand, alpine species with low temperature requirements may be negatively affected both by temperature per se and by increased competition for light from the boreal invaders. Climate change will also reduce the extent of snow beds, perennial snow fields and glaciers, with effects on runoff and water supply, as well as habitat for many species.

Political goals and decisions about the management of the mountain areas will also be of great importance for the condition of mountain ecosystems. Formal protection will obviously secure mountain areas against the establishment of buildings and other technical infrastructure, allowing ecological processes to run more freely. Protected areas in the mountains already have a considerable extent and cover about 34% of the area. In addition to protecting nature and biodiversity, the management of national parks shall also facilitate outdoor recreation and contribute to local economic activity. Grazing of livestock and domestic reindeer, combined with control of large carnivores, will continue in protected areas. This will ensure that human impacts in the mountains will also be considerable in protected areas.

The mountains are already significantly affected by buildings in the form of cabins and various facilities, roads and power lines. Developments in recent decades are likely to continue. By 2030, it is estimated that 130 km^2 will be occupied by new holiday homes, and about 85% of these will be located in less central municipalities (Rørholt & Steinnes 2020), mainly in or near mountain regions. The use of the mountain areas for various outdoor recreation activities must be expected to increase, due to an increasing population and purchasing power, and more international tourists, especially in areas close to established infrastructure or with special natural attractions.

Official plans for the development of infrastructure for transport and energy are ambitious. New major transport infrastructure will mainly affect the lowlands and will probably have less impact on mountain areas. Development of cabins will, however, imply further expansion of public and private roads in and near the mountain areas. Plans for expansion and upgrading of the power grid are more likely to affect some mountain areas. This is also the case for the expansion of wind power, where some new accepted or applied projects remain to be built[36].

Further development of infrastructure for transport and energy, as well as local pressure for increased development of cabins and tourist facilities in or near the mountain areas, indicate that gradual loss and fragmentation of the mountain areas will continue over the next decades. This will lead to a further reduction in the area without technical infrastructure. With increased use of the mountain areas for various outdoor recreation activities, this will lead to additional loads for species in the mountains.

The populations of large carnivores have a great ability for population growth based on today's very low populations and good access to prey. However, the authorities' population targets and management of the carnivore populations completely control the future development for these species.

[36] NVE Vindkraft

Overall, future climate change and trends in policies for outfield management, energy, transport and land use indicate that the condition of mountain ecosystems will deteriorate in the decades to come. The ecological condition for mountains will probably be characterised as degraded in a few decades, unless political measures are taken to counteract the negative trends.

4.5 Further development necessary for mountain indicators

In the discussion of the results for the assessment of the condition of mountain ecosystems (above), we have pointed out shortcomings in the current system, such as insufficient coverage of ecosystem characteristics and lack of data for important parts of the ecosystem. In addition, we need to improve the foundation for setting reference values and limit values for good ecosystem condition. These shortcomings may be remedied by further development of the system.

The seven ecosystem characteristics that cover various aspects of the ecosystems' structure, functions and productivity (Nybø & Evju 2017) mainly describe the ecosystems' structure, rather than their functions. This is reflected in the vast majority of indicators available to describe these characteristics. Conclusions about changes in ecosystem functions must therefore usually be based on changes in associated ecosystem structures. Most often, however, the frequency of data collection of such ecosystem structures is annual or less frequent, at best allowing us to give a rough impression of the dynamics of the ecosystem and its functions. This represents a fundamental challenge in covering many ecosystem functions.

The assessment of mountain ecosystem condition is based on a set of condition indicators included in the calculation of condition. In addition, we have considered other variables with available data, some included as supplementary variables. By developing reference values and limit values for good ecosystem condition, these variables may be developed into condition indicators. This includes coverage of various plant groups like shrubs and trees, lichens and bryophytes, selected species such as *Empetrum nigrum, Vaccinium myrtillus*, and other dwarf shrubs, all with data from the monitoring programme ANO (**Table 4.10**). The index for mountain birds, based on data from the monitoring program TOV-E, can also be developed into a condition indicator if suitable reference and limit values can be determined. However, the overlap with the indicator nature index for mountains (modified) must be considered.

Important aspects of the mountain ecosystem not currently represented by indicators are structures and functions in soil (**Table 4.10**). Soil chemical properties related to the ratio of carbon to nitrogen, as well as available base cations (including calcium) and possibly the amount of toxic (labile) aluminium may be relevant. The amount of soil organic matter is an important source of variation in growth conditions for plants. Various forms of mycorrhizal fungi and different groups of decomposers are particularly relevant among soil organisms. However, nationwide, representative data for these possible new indicators are currently lacking. Data may in principle be collected through the monitoring programme ANO. Relevant indicators must be specified, and suitable monitoring variables and protocols developed to provide relevant data for such indicators. The use of environmental DNA is probably necessary to obtain data on soil biology in a cost-effective way.

Insects and other invertebrates make up a very large part of the species diversity and cover many ecological functions, including pollination and decomposition of organic material. Results from the national insect monitoring may be used to develop several relevant indicators for different functional groups. However, the national insect monitoring is not currently planned for mountain areas, and it is difficult to think of other approaches to obtain relevant data for insects.

These possible new indicators will contribute to better coverage of several of the seven characteristics of ecosystems. They will help to improve the coverage of the characteristic *functionally important species and biophysical structures* that currently has limited coverage. It will also be important to include indicators for plants for the characteristic *functional composition within* *trophic levels*, where we currently only have vertebrates. The proposed new indicators for insects, soil biology and chemistry will also help to cover important aspects and very species-rich parts of the ecosystem.

There is also a need to assess the approaches for determining reference values and limit values for good ecosystem condition for several of the current condition indicators, as well as to document the scientific basis for these values better. Here, both compilation of existing knowledge and new research will be necessary. The main approaches that are briefly described in chapter 2 can be used, but it would be too demanding to go further into specific proposals here.

Table 4.10 *Potential new indicators for the condition of mountain ecosystems, respectively where data already exist or may soon become available and where new data collection will be necessary. It is also specified which ecosystem characteristics these indicators may cover and the potential data source, whether existing or by potential new data collection.*

Indicator	**Ecosystem characteristics**	**Data source**
Indicators where data already exist		
Functional groups of vascular plants	Functional composition within trophic levels	ANO
Coverage of shrubs and trees	Functionally important species and biophysical structures	ANO
Coverage of lichens and bryophytes	Functionally important species and biophysical structures	ANO
Coverage of various dwarf shrubs	Functionally important species and biophysical structures	ANO
Mountain birds	Functional composition within trophic levels Biological diversity	TOV-E
Indicators requiring new data collection		
Soil chemistry – C/N	Abiotic factors	ANO
Soil chemistry – Ca/labile Al	Abiotic factors	ANO
Soil organic matter	Abiotic factors	ANO
Mycorrhizal fungi, various groups	Functionally important species and biophysical structures	ANO
Decomposers in soil, various groups	Functionally important species and biophysical structures	ANO
Functional groups of insects	Functional composition within trophic levels Biological diversity	Extended insect monitoring

5 The IBECA approach in management

The Indicator-Based Ecosystem Condition Assessment (IBECA) approach (Jakobsson et al. 2021) has several characteristics that makes it relevant as a tool for environmental management. Some of these characteristics are shared with other systems for assessing the condition of ecosystems, such as the EU Water Framework Directive (WFD; EC 2019) and the UN framework for ecosystem accounting (SEEA EA; UN et al. 2021), and more generally the IPBES framework as used in the IPBES assessments (Diaz et al. 2015, IPBES 2019). Below, we briefly describe the relevance of the IBECA approach for environmental management and its relationship to some other environmental assessment systems. This chapter builds upon a report that discusses the range of tools and data sources that are used in the assessment of terrestrial ecosystems. The report also discusses how to set management targets (Nybø et al. 2020),

5.1 The need for specific and quantifiable management targets

The Norwegian Government has set three major goals for its biodiversity policy, as specified in the white paper *Nature for life* (Meld. St. 14 (2015-2016)). The white paper describes biodiversity-related challenges and threats, and the policy instruments the Government will use to deal with them. The white paper identifies three national biodiversity goals:

1. achieving good ecological state in ecosystems,
2. safeguarding threatened species and habitats,
3. maintaining a representative selection of Norwegian nature (i.e., the conservation of areas representing the full range of habitats and ecosystems).

The development and application of methods for assessing ecosystem condition is an important step towards evidence-based policy and management towards goal number one.

The Norwegian research community was asked to develop a conceptual framework for the assessment of ecosystem condition (cf. chapter 1). The results were presented in Nybø & Evju (2017). The next step in the process towards evidence-based ecosystem management is to operationalize and test methods to assess and monitor progress towards goal 1 based on the general framework. The IBECA approach (Jakobsson et al. 2021) is one of two proposed operational methods, whereas the panel-based assessment of ecosystem condition (PAEC) is the other (Jepsen et al. 2020). An important practical application of ecosystem condition frameworks in environmental management is for setting management targets and monitoring the progress towards these targets. According to the government white paper (Meld. St. 14 (2015-2016)), management authorities and society at large are required to set concrete management targets and work to achieve them. Note that for specific areas or functions, these targets may deviate from 'good ecosystem condition' as stated in the white paper, for example in cases where environmental concerns are weighed against other usages or societal needs. These general management objectives are formulated in the Norwegian Nature Diversity Act of 2009: "*The objective is to maintain the diversity of habitat types within their natural range and the species diversity and ecological processes that are characteristic of each habitat type. The objective is also to maintain ecosystem structure, functioning and productivity t<u>o the extent this is considered to be reasonable</u>.*" (our underscore).

Thus, the concrete management targets for Norwegian ecosystems and habitat types in terms of the ecological condition to be achieved are not specified in the law or white paper. Instead, these documents set the overall constraints at the national scale, allowing flexibility for how these targets are to be set in specific cases and for specific areas, including how they can be weighed against other societal needs. It follows from this that evidence-based environmental management and monitoring of progress towards both general policy goals and specific targets for specific species, habitats or areas will require that the ecological condition framework can be translated into specific and quantifiable measures or indicators of the ecological condition for the relevant species, habitat, or areas. Further, this general approach requires a flexibility in the methodology to allow targets (whether the specific targets set represents ‘good’ ecological condition or not, depending on political and societal considerations) to be set and assessed, and progress to be monitored at relevant spatial and temporal scales. Our project team was asked to reflect on how the IBECA methodology can be used to achieve these policy and management needs.

Below we describe factors that are important to facilitate the implementation and utility of the IBECA approach for society (chapt. 5.2). In chapter 5.3 we discuss how concrete targets may be set with this method as a starting point. In chapter 5.4 we describe the relationships to some international systems for assessing and reporting on ecosystem condition, particularly the WFD and the SEEA EA ecosystem accounting framework. The link to the SEEA EA framework is particularly important due to the upcoming national discussion on land degradation neutrality, restoration and compensation of habitats, local management plans and the importance of habitats for climate mitigation.

5.2 Society’s confidence in ecosystem assessments

Assessments of ecosystem condition are intended to be used by the authorities in support of evidence-based decision-making in the environmental sector at large, for example regarding effective measures to maintain healthy ecosystems, interventions to improve ecosystem condition, or decisions on priorities of nature vs. other societal needs. The relevant management decisions are broad-ranging, and may involve changes in economic incentives, in legislation and regulations, in spatial planning, as well as specific decisions regarding local management, conservation and restoration measures. As such, these decisions directly and indirectly affect society across a wide range of private and public sectors and interests. These societal interlinkages will likely increase in the future, as environmental policy is ‘mainstreamed’ into more societal sectors, driven by developments in national and international climate, biodiversity, and environmental policy. To ensure effective government and societal support of the environmental policy at large, it is critical that the full range of societal actors affected can have confidence in the integrity of the decision-making process. Ecosystem condition assessments are a core part of the evidence on which decisions regarding nature management and spatial planning are based, and it is therefore critical that these assessments and the resulting knowledge are seen as relevant and trustworthy by the society. This chapter highlights how IBECA fulfils a number of prerequisites for society’s confidence in the credibility and usefulness of ecosystem assessments.

The results of ecosystem assessments should be reliable and credible
To be useful for management authorities, a system for assessment of ecosystem condition should provide data and knowledge that are both reliable and credible. This will make it easier for various actors to agree on a common knowledge base (i.e., all actors accepting the same facts) behind complex and often contested policy and management decisions. Reliable and credible assessment results should be based on the best available knowledge and data, they should be associated with specified measures of precision and accuracy, and there should be transparency of underlying data, methods, and assumptions.

- *Best available knowledge and data*: A foundation for reliable results is using the best available knowledge about the ecosystem, its structure and functions, and its natural dynamics and most important anthropogenic drivers of change. This will allow identification of the most relevant characteristics of the ecosystem and the most appropriate indicators to represent these characteristics. In developing the IBECA methodology, we first identified and assessed the full range of monitoring and other environmental data relevant for each of the seven characteristics of ecosystems identified in the Norwegian ecological condition framework (Nybø & Evju 2017). We then collated scientific knowledge on the relevance of these data for ecological condition from the scientific literature, data, general ecological principles, ecological mapping and monitoring frameworks, and finally, in cases or for aspects where no ‘hard evidence’ existed, from expert knowledge. This ecological knowledge base (data and scientific knowledge) was interrogated to produce a number of relevant quantitative indicators for each of the seven characteristics of ecosystems. Next, the knowledge base was used, and augmented as needed, to determine empirically reference state and limits for ‘good’ ecological condition for each indicator. Finally, we explored methods for combining and interpreting the indicators. The IBECA methodological approach is thus developed to obtain, combine, interpret, and assess data and knowledge on ecosystem state and condition in a quantitative and reproducible way, as described and discussed extensively in Jakobsson et al. (2020, 2021). In the two empirical reports summarised in chapters 3 and 4, we also assess to what extent the results align with the current knowledge on forest and mountain ecosystems in Norway and Scandinavia.

- *Easy to update with new knowledge:* As the two reports summarised in chapters 3 and 4 clearly show, the current knowledge and data on ecosystem condition in Norway is limited. We lack adequate indicators for some of the seven characteristics of ecosystems, and many organism groups and functions are severely underrepresented. This points to pressing needs for augmenting both monitoring and the scientific knowledge in the future (for examples, see Töpper & Jakobsson (2021)). It is therefore important that ecosystem condition assessment methods are set up to allow implementation of methodological developments (new indicators, new knowledge of ecological dose-response functions, new reference limits, etc) as new scientific knowledge and data become available. The IBECA approach is designed to facilitate a wide range of such upgrades and adjustments by being explicitly quantitative, empirical, and script-based. Specifically, all the underlying data, scientific knowledge, process understanding, hypotheses and relationships are explicitly formulated and integrated numerically through R-scripts. In this context, we would like to point out that while a broad knowledge base, ranging from data via scientific knowledge to expert judgements, is incorporated in the IBECA, our approach is to ‘front load’ the entire knowledge base into the assessment by explicitly formulating it mathematically and statistically in a script-based environment. An attractive feature of this approach is that ‘post hoc’ expert interpretation is not needed (in IBECA this aspect is already built into the approach, in a reproducible way) and so new knowledge can be incorporated continuously by adjusting the underlying data, indicator calculations, assumptions via adjusting the R scripts for the analyses. An attractive feature of IBECA is that this approach, which is based on the general principle that the full knowledge base is formulated analytically, is that when new knowledge on reference values or limits for good ecosystem condition becomes available, entire time-series can be updated backwards in time.

- *The IBECA approach does not rely on long time series of data.* The IBECA approach has a great advantage in that it can incorporate indicators and characteristics for which long data series are lacking. IBECA explicitly incorporates a range of potential data sources for setting reference levels for ecological condition, e.g., indicator reference levels derived from reference areas, levels developed from models based on ecological theory, or levels based on expert judgement (see Jakobsson et al. (2020) for a detailed discussion). These reference levels are quantitatively defined (and they can, as described above, be tested, challenged, and updated with new knowledge), and the ecological condition value for each indicator or characteristic is then determined by comparing current values to the reference according to the response function and limits selected for that specific indicator (see Jakobsson et al. 2020). This implies that ecological condition can be assessed on the basis of current data, and new data can immediately be put to use, without the need to first build up long-term monitoring series for the indicators. In general, long-term data series are obviously extremely valuable for documenting variability or trends in indicator values, as a basis for robust assessments of change in ecological condition. However, given the current lack of data of relevance for many aspects of ecological condition of Norwegian nature, as exemplified in chapters 3 and 4, this explicit flexibility of IBECA implies that it can exploit all the available evidence and is not limited to existing or future long-term data series. Another advantage of being able to use new data immediately, and not waiting for 10–20 years of monitoring time series, is that management measures should be implemented as soon as possible, to be able to halt ecosystem degradation in time.

- *Quantitative estimates of indicator and condition values, with specified uncertainty*: Quantitative condition estimates give a clear, reproducible and transparent impression of the extent to which the ecosystem condition deviates from the reference condition. Importantly, the IBECA explicitly incorporates and visualises uncertainty associated with all aspect of the knowledge synthesis, including data collection, indicator estimates. and the analytical methods for deriving condition estimates. By providing such uncertainty estimates and explicitly including them in the estimation process, the IBECA openly presents a realistic picture of the accuracy and precision of each indicator as well as the overall condition assessment. In the IBECA approach, we have thus explicitly included uncertainty for indicator value estimates and aggregated these into the condition estimates. Some data types (like map data without specified uncertainty) present challenges for uncertainty estimates, and improved ways to handle such data should be part of the future development.

- *Transparency of underlying data, methods, and assumptions*: The availability and transparency of the underlying data and methods are critical to reliable and credible ecosystem condition assessments. Hence data and assumptions can be checked independently. In our application of the IBECA approach, we make all sources to data, R-scripts and all assumptions of the method available on public digital platforms (e.g., https://ninanor.github.io/IBECA/faktaark.html, for mountains, in Norwegian). An important part of our transparency and quality control policy is to publish the methods and approaches in international peer-reviewed journals, to ensure and document independent quality control of our work and benchmark against international methodological development and standards. Towards this end, we have published a methodological paper describing the general IBECA approach (Jakobsson et al. 2021) and a separate paper discussing the challenges around setting reference values and limits (Jakobsson et al. 2020). Both papers have already been well cited, including in international ecological state and condition benchmarking exercises (Czúcz et al. 2021, Maes et al. 2020). Transparency further relies on all underlying data, knowledge and methods being available and understandable. Some data used in our assessments for forests and mountains are proprietary and can only be made available by the data owners (cf. the indicator documentation in Appendices 1 and 2). Making these data and the associated data documentation publicly available is a policy question that the Norwegian environmental authorities are addressing.

- *Reproducible results - less dependence on 'black box' expert knowledge*: The ultimate test of a reliable and credible method is that the results may be widely reproduced and understood, given the same data and assumptions as in the original assessment. Hence, the method should be able to give the same results, irrespective of experts doing the assessment. The method should also allow changes in assumptions and data in view of new and improved knowledge in the future (cf. the second bullet above). When quantitative knowledge is lacking, expert knowledge may be used for assumptions related to individual indicators, that is for setting reference values or limit values for good ecosystem condition. In the IBECA approach, we work towards the goal of reproducibility from several fronts. First, we are designing the IBECA to be fully reproducible in the data management and analyses stages (e.g., data, data and methodological documentation is openly available on github, and will be augmented with future developments). Second, the assessment tool is fully script-based, implying that all the underlying assumptions and relationships (whether based on data, ecological theory or expert knowledge) are translated into mathematical or statistical language, making our formulation and combination of all data and relationships and the various outputs (figures, tables, numbers, credibility intervals) fully reproducible. Third, when expert knowledge is used it is applied prior to analyses of the ecosystem condition. Thus, there are no expert judgement *post hoc* analyses where individual researchers may influence the conclusion based on their specific knowledge. Use of *post hoc* expert knowledge may make the final conclusions about the ecosystem condition dependent on the specific experts participating in the assessment. Thus, the IBECA outputs allow inspection of all outcomes, from overall assessments of ecological condition via the seven characteristics, all the underlying indicators, and down to the raw data, along with all the computations needed to arrive at each outcome value and associated uncertainty. Thus, the approach is designed in such a way that as much as possible of the process, including use and content of the expert knowledge, is 'front-loaded' into the explicitly modelled parts of the analysis and hence openly available for inspection and quality control. It follows from this, that reassessments based on the same data will be fully reproducible, and that any adjustments due to changes in expert judgements, data, scientific knowledge, or assumptions will also be reproducible.

- *Methodological challenges*: There are some recognised methodological challenges associated with assessments of ecological condition, which apply to IBECA as well. These particularly relate to (1) the setting of reference values and limit values for good ecological condition for the indicators, (2) the specification of the scaling function relating measured indicator values to the ecosystem condition, and (3) the aggregation of scaled indicators into indices for ecosystem condition. The problem of setting of reference and limit values applies to each indicator separately and for this task various approaches have been suggested and discussed in the literature; see Jakobsson et al. (2020) for a recent review of the topic from an IBECA point-of-view. The need to aggregate indicators into condition indices for ecosystem characteristics, pressures, and the overall ecosystem introduces the issue of how much weight single indicators or ecosystem characteristics receive in the overall index. IBECA avoids different weights for indicators by aggregating indicators independently for each index, but for comparative reasons also applies hierarchical aggregation which avoids different implicit weights for ecosystem characteristics (see Töpper & Jakobsson 2021 for details). The overall scaling function applied to relate the original indicator data to the index scale is dependent on the availability of knowledge on and quantitative understanding of the relationship between ecosystem condition and relevant drivers of condition change. In the EU Water Framework Directive (Direktoratsgruppen vanndirektivet 2018) the response of the ecosystem to eutrophication or acidification has been in focus. In freshwater systems, a thorough understanding of dose-response relationship allows scaling into five condition classes, which represents a coarse non-linear scaling function. In terrestrial ecosystems, knowledge of such relationships between ecosystem condition and important drivers like land use or climate change is mostly lacking. In IBECA, we acknowledge these methodological challenges. As a first approximation we have in most cases used simple linear relationships for the scaling function in setting the limit value for good ecosystem condition. However, we fully anticipate that new data and knowledge will make it possible to set reference and limit values with greater confidence and refine the scaling functions and aggregation mechanism for the indicators. IBECA's accessible and transparent assumptions and calculations should make it simple to incorporate new knowledge and update the method.

The results should be comparable in time and space and at various spatial resolutions
To optimise the utility of the assessments of ecological condition for guidance on management decisions, the results from assessments for different regions and at different times should be comparable. Comparable results across regions will make it possible to prioritize actions and interventions regionally or nationally, and to differentiate management measures to fit the local ecological conditions. Comparable results at different times will enable quantitatively reliable assessments of whether management interventions or conservation measures are effective, and

whether and at what rate the ecological condition is approaching the target. Approaches that can be adapted to and applied at various geographical scales will be useful both at the national policy level and in local practical management.

- *Comparable results in time and space*: For results to be comparable at different locations and times, they need to be based on the same data, assumptions and methods. This includes using the same concept for the reference condition, i.e., establishing the same standard for comparison. By scaling all indicators to the same scale (e.g., between 0 and 1), based on the same general understanding of the reference condition for all regions, the results from the IBECA approach are comparable in space and time. Keep in mind that the reference condition (intact ecosystems) and indicator reference level, may differ within Norway. For example, we have set specific references for total biomass and carnivore population sizes adjusted to local conditions as these indicators have natural lower levels in northern Norway compared to southern Norway. Then scaled values reflect the condition of these indicators corresponding to the region we assess. By using spatially representative national monitoring or other spatially extensive or representative data, the underlying data for indicators will also be fully comparable across regions. We note that the general IBECA approach is compatible with downscaling for future assessment ecosystem condition on a local scale (see below), but it is important to use standardized mapping and/ or monitoring protocols to enable quantitative and explicit comparison of results among areas.

- *Geographically explicit and scalable method*: Assessments of ecological condition can provide relevant and comparable results at different spatial scales if the data, assumptions and method itself applies at all relevant scales. However, the spatial resolution of the underlying data for several indicators has so far limited the possibilities for downscaling. In the assessments of ecosystem condition of forests and mountains, the data for some of the indicators are available at sub-kilometre scales, whereas other indicators rely on data with coarse-scale regional resolution. Hence, we have limited the downscaling in these assessments to coarse geographical regions. Various remote-sensing data and new modelling approaches underway in several ongoing research projects funded by the Norwegian Research Council 'Arealer under press' calls may provide relevant underlying data for several different types of indicators and thus allow more extensive downscaling of ecosystem condition assessments in the future. The IBECA approach applies at all spatial scales and can be downscaled for use if relevant data are available in, e.g., local spatial planning.

The result should be understandable to environmental managers and the public. Policy makers and environmental managers are rarely scientific specialists on ecosystems or condition assessment methods. It is also important for democracy and the public trust in government that the basis for decisions and priorities in society are presented in a way that can be appreciated by the public. Hence, the results and the underlying methods of ecosystem condition assessments should be transparent (cf. above), but the main findings and any caveats should also be communicated in a way that is understandable for the users. This entails that the principles of the assessment approach are clear, logical, and, preferably, similar in content and principle to other related methods that are already known to the users. It must also be possible to communicate the method and the results in terms that are familiar to the users. Finally, the results should preferably also be linked to aspects that users care about, like possible causal factors, thereby allowing attribution of changes to factors that drive environmental deterioration and prioritizing the kind of management measures that may be most relevant to remedy a possible degraded condition.

- *Relation to familiar assessment methods*: The EU Water Framework Directive (WFD) has been implemented in Norway since 2006 and is familiar to many environmental managers. The IBECA approach builds on many of the same principles as the WFD (cf. chap. 5.4 below). It applies the same basic comparison to a reference condition, it uses rescaling of condition indicators to a common scale between 0 and 1 to allow comparing and combining different indicators, and for the same reason it also uses the same value for a rescaled limit value for good ecosystem condition (0.6). The unscaled indicator values may, of course, vary between indicators in linear as well as non-linear fashions. The limit of 0.6 applies also after a (non-linear) rescaling and therefore does not require or imply that 60% of the reference value for indicators is always or even often the limit for good ecological condition. See Jakobsson et al. (2020) for an in-depth discussion of scaling functions, reference limits, and other scaling-related issues. The Norwegian Nature Index (Jakobsson & Pedersen 2020) has been operational since 2010 and is familiar to many Norwegian environmental managers. It also shares the same concept of the reference condition and the scaling and aggregation of indicators as IBECA.

- *Quantitative condition measure linked to human drivers*: A quantitative measure (with uncertainty) of the ecosystem condition gives managers a clear indication of how far the current condition is from the reference condition as well as from the stated target for a specific system. Linking the various ecosystem condition indicators to specific drivers, like land use, climate change or alien species, as possible causes for deviation from the reference condition, provides additional guidance for choice of management measures. The IBECA approach provides a quantitative measure for overall ecosystem condition, as well as aggregated scaled indicator values for the main categories of human drivers and a discussion of the specific drivers that may be the most relevant causes for a degraded ecosystem condition.

5.3 Ecosystem extent and condition in management targets and ecosystem accounting

"*Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs*" (Brundtland 1987). Sustainable development is founded on three pillars: economic, social and environmental sustainability. The United Nations set more concrete goals based on these three pillars (UN 2020) and this has led to new efforts on how to reach the 17 sustainable development goals for society at large. EU's green deal, their biodiversity strategy towards 2030 and the EU taxonomy on sustainable investments have set focus on ecosystems and the role of biodiversity in sustainable development of the economy and to combat the climate crisis (European Commission 2020a, European Commission 2021a, b). In Norway as in many other countries, the recognition that a healthy, functioning nature is a foundation for a sustainable society was promoted by nature-oriented NGOs from the 1960s onwards and is now increasingly recognised in society at large to the extent that most political parties have ambitious policies for nature conservation. At the same time, environmental deterioration continues to the extent that Norway did not reach any of the Aichi 2020 targets (Sabima et al. 2020). Accordingly, there is a need for concrete actions to be implemented in politics, industry and civil society to ensure that we as a society are able to take the necessary steps to maintain our ecosystems and their biodiversity, functions, structure and productivity in order to deliver ecosystem goods and services now and for future generations (Meld. St. 14 (2015-2016)).

The IBECA approach as a purely ecology-oriented assessment tool is well designed to inform environmental management and planning authorities on the condition of ecosystems, their functional characteristics and the potential underlying drivers of reduced condition. Thus, management is provided with a scientifically coherent, data-driven knowledge base for developing and putting into place targets and measures for improving the condition of ecosystems or for mitigating negative effects, where necessary to support the generation of ecosystem services.

Our project team was asked to consider how management targets may be set, using the IBECA method (cf. Nybø et al. 2020). We note that ecosystem services are delivered by the entire landscape and not just by areas designated for environmental protection. Naturally, areas without protection have varying ecological condition, but these areas are still pivotal in nature management since protected areas alone usually are not sufficient to safeguard for instance biodiversity (Geldmann et al. 2013). To ensure the supply of ecosystem services in quantities needed to support human societies, management authorities thus need to see ecosystem condition and ecosystem area in connection. Trade-offs between ecological, societal and economic needs render good ecosystem condition for all areas an unrealistic goal. Some ecosystem services may be prioritised for certain areas at the expense of other services from these areas. Where management targets are set lower than good ecological condition, trade-offs between the prioritised services and the maintenance of the ecosystem's structure and functions should be explicitly considered. There may still be some lower bounds for ecosystem condition, beyond which the ecosystem's fundamental properties and stability may be irreversibly changed. In the EU Water Framework Directive, e.g., a lower ecosystem condition is accepted for some water bodies to accommodate important ecosystem services such as hydropower production. Such water bodies should then satisfy criteria for good ecosystem potential, rather than good ecosystem condition.

Consequently, decision makers need to assess to which extent deviations from good condition can be accepted for areas that are to meet alternative societal goals, and they may consider mitigating the loss of ecological qualities in one area by improving ecosystem condition in another. Hence, it is desirable to know the spatial extent of ecosystems in varying condition, i.e., the distribution of ecosystem areas across levels of ecosystem condition (**Figure 5.1a**). This is important as (i) the average measured ecosystem condition can remain stable while ecosystem area may be lost or gained (**Figure 5.1b**), and (ii) ecosystem condition may change (as different areas improve or degrade) while the total area remains constant (**Figure 5.1c**).

Both aspects, the extent of ecosystems and the condition they are in, define the quantity and quality of ecosystem services provided to society. Therefore, decision making in land management should be informed by spatially explicit assessments of ecological condition, as in principle envisioned by the UN framework for ecosystem accounting SEEA EA (UN et al. 2021). The IBECA approach is compatible with this requirement, as it relies on the aggregation of spatially representative indicators. What is needed for a management-relevant assessment to be spatially explicit is a set of indicators with a spatial resolution of underlying data fine enough to allow an estimation of ecosystem condition for all spatial units at relevant scales. Currently, the availability

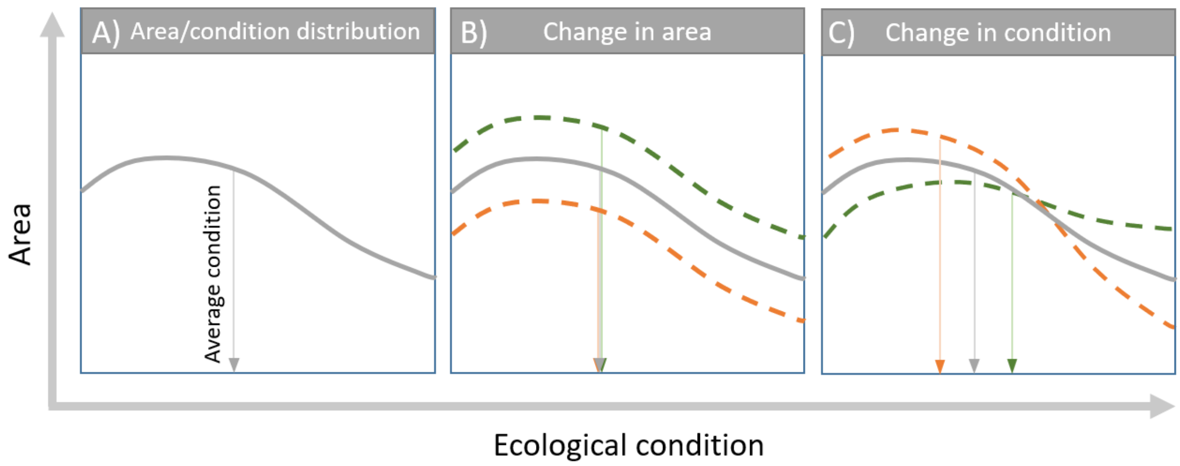

Figure 5.1 *The graphs show the distribution of area across a gradient from low to high ecological condition in a hypothetical ecosystem, i.e., how much area is in a certain ecological condition. Green and orange dotted lines represent changes in the area distribution in relation to a starting situation (grey line). The area under the curve represents the area of the ecosystem. Arrows pointing to the x-axis indicate the average ecosystem condition of the respective distributions. Panel B illustrates a change in the area of the ecosystem, where the average ecosystem condition of the area is constant. Panel C illustrates changes in ecosystem condition along the condition gradient, and on average, while the area of the ecosystem stays constant.*

of such indicators is the limiting factor for spatially explicit assessments with IBECA. However, promising avenues to mitigate this problem may be found in continuing development of environmental monitoring (both field campaign-driven and by remote sensing), combined with spatially explicit model-based indicator development that will allow production of fine-grained maps of individuals indicators as well as of ecological condition at large, as exemplified by the ECoMAP project, https://betweenthefjords.w.uib.no/ecomap/.

5.4 How IBECA corresponds to international frameworks

Here we describe frameworks that are relevant for assessing the ecosystem condition in Norwegian terrestrial and limnic ecosystems.

The IBECA approach is a quantitative method that aims to inform management authorities of the need for potential management measures. The method is based on the DPSIR (Drivers-Pressures-State-Impact-Response) framework (EEA 1999) which is used by the Norwegian Authorities and the European Environment Agency to structure information on the environment. The concepts of 'ecosystem condition' and 'direct drivers' in IBECA correspond to State (S) and Impact (I) (deviations from the reference condition) and Pressure (P) in the DPSIR framework.

The IBECA approach has been developed with conceptual and methodological ties to the EU Water Framework Directive (WFD) (European Commission 2000b), which applies to Norway through the EEA agreement. The IBECA approach adopts the WFD's scaling principles where indicators are scaled to values ranging from 0 to 1 (i.e., lowest to best ecosystem condition, respectively). These scaled indicator values may then be aggregated to quantitative indices. Following the requirement from the government when commissioning the empirical methodologies for assessing ecological condition, the IBECA allows discrimination between two levels, good and degraded condition, where this distinction is based on setting a limit value for a quantitative variable. Accordingly, the limit for good ecological condition is set at a scaled value of 0.6, corresponding to the WFD's distinction between the levels 'high' and 'good' versus 'moderate', 'poor' and 'bad' condition. As in the WFD, all assessments have some uncertainty. If expensive or controversial measures are to be taken, extra investigations may be carried out when the condition is assessed to be close to this limit. All management levels in Norway, including municipalities, water regions and national authorities, along with stakeholders are included in developing management plans that will be used to achieve management targets set according to the national legislation of the WFD. In the WFD, the management target is an ecosystem in 'at least good condition'. In Norway's national biodiversity action plan (Meld. St. 14 (2015-2016), management targets for the condition of terrestrial and marine ecosystems shall be set by policymakers or management authorities and 'may deviate from good condition'. These policy goals necessitate the division into quantitative steps of the IBECA and WFD ecological condition scales. In the overall ecosystem assessment, IBECA differs from the WFD by using averages of indicators to assess the overall ecosystem condition, similarly to the SEEA EA, whereas the WFD uses the 'one-out, all-out' principle.

The IBECA approach also has commonalities with the UN framework for ecosystem accounting (SEEA EA) (UN et al. 2021), which has been developed with Norwegian support and with invited input from IBECA developers. The UN framework on ecosystem accounting was adopted as a statistical standard in March 2021 (UN et al. 2021). The standard includes biophysical reporting on ecosystem extent, condition and ecosystem services, as well as quantification of ecosystem services in monetary terms. Indicators and ecosystem characteristics of the IBECA approach was compared to the SEEA EA framework by Jakobsson et al. (2021). The IBECA approach for assessing ecosystem condition is in line with the SEEA EA framework, with some minor adjustments on ecosystem characteristics (categories of indicators). We note that the quantitative and scalable nature if the IBECA approach, especially when combined with downscaled mapped and modelled indicators, will allow for exciting opportunities for developing general ecosystem accounting tools that explicitly incorporate both the area and condition of ecosystems and various ecosystem functions and services (see **Figure 5.1**).

IBECA is also in accordance with the IPBES conceptual framework (Diaz et al. 2015) in that it provides information on the state of 'nature', including key aspects of the state and condition of biodiversity and ecosystems as recognized in the IPBES framework. Further, IBECA attributes changes in the various aspects of nature to 'drivers', which in IBECA are quantified and classified according to the five major classes of direct drivers in the IPBES framework (climate change, land-use change, pollution, over-harvesting, alien species). As such the IBECA approach is well suited as an empirical assessment tool for these components of the IPBES assessment, and it will provide a useful tool in a future national-scale IPBES-like assessment for Norway. We note, however, that IBECA lacks consideration of other key components of the more holistic approaches of IPBES assessments, notably consideration of nature's benefits to people and good quality of life, the role of indirect drivers of change, and management and policy options. These aspects, while critically important, were explicitly excluded in the Norwegian ecosystem condition framework as given in the mandate from the Government (Nybø & Evju 2017) and the associated methodologies (IBECA, PAEC). The underlying idea of the Norwegian approach is that by isolating the 'science' of ecosystems from 'politics' we can arrive at a shared and common knowledge base about our environment on which policies can be built and priorities made. While this approach is widely applied internationally and has broad support, as illustrated by the related frameworks above and other national assessments, it lacks explicit linkages and consideration of policy options and to human lives and livelihoods. Experiences from IPBES assessments regionally and globally illustrate how such more holistic and integrated assessments can be made without being policy prescriptive, and IBECA provides a good starting point for such an exercise at the national scale.

Finally, and more generally, following up on the policy aspects above, several research initiatives explore how to create downscaled indicators for the IBECA approach to support local land management are under way (cf. chapt. 5.2). To achieve indicators with fine enough geographical resolution for local assessments of ecosystem condition, modelling, remote sensing and data mining techniques are explored within projects financed by the Norwegian Research Council e.g. ECOMAP and ECOGAP. These will directly feed into the development of IBECA as a tool for down-scaled ecosystem condition monitoring and for ecosystem accounting.

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Appendix 1: Technical documentation of forest indicators

Indicator	**NDVI**
Completion of the protocol	Tessa Bargmann (NINA)
Date filled out/ reviewed	20.04.2021
Data source	MOD13Q1 V6 Terra Vegetation Indices 16-Day Global 250m
Ownership and permissions	Public, MODIS data and products acquired via NASA's Land Processes Distributed Active Archive Centre (LP DAAC) have no limitations for use, sale or redistribution.
Description of raw data	The MOD13Q1 V6-product provides a vegetation index (VI) value per pixel. MODIS NDVI is calculated from atmospherically corrected bi-directional surface reflectances that have been masked for water, clouds, heavy aerosols and cloud shadows. The algorithm chooses the best available pixel-value from a 16-day period (see "Frequency of data collection" below). The criteria used are low clouds, low view angle, and the highest NDVI value. NDVI ranges between –1 and 1 and is calculated as NDVI = (NIR-Red) / (NIR+Red), where NIR is near-infrared light and Red is visible red light. See https://lpdaac.usgs.gov/products/mod13q1v006/
Description of data collection method and data structure	NASA's Terra satellite carries MODIS (Moderate-resolution Imaging Spectroradiometer) and passes over the earth every 1-2 days. Data are global with a 250 m resolution.
Description of the indicator	The indicator is the deviation of the current NDVI value per MODIS pixel from the reference value of hat pixel. This is a two-sided indicator where values both lower and higher than the reference value may indicate degraded ecosystem condition.
Spatial representation/coverage	Global coverage.
Geographical delimitation	Total coverage of Norway.
Measurement unit	Values between -1 and 1, where -1 indicates water/no vegetation and 1 maximum green vegetation density.
Time period covered	18 February 2000 – present (the Terra satellite's instruments are expected to stop data collection in spring 2026).
Frequency of data collection	The MODIS sensor collects data every 1-2 days, but this data product chooses the best available pixel value from a 16-day period (i.e., 16-day cycle).
Additional description of data properties, if necessary	The spectral reflectance of vegetation across different bands measured by the MODIS sensor serves as an indicator of vegetation presence and its condition, or "health". NDVI is a combination of two of these bands (near infrared and visible red light) which enhances the contrast between vegetation (high reflectance) and non-vegetation (low reflectance), and quantifies plant characteristics such as density, biomass, plant photosynthetic activity, and stress. (Pettorelli et al 2005)
Significance of the indicator in the ecosystem and ecological consequences of reduced indicator value (including references)	The indicator represents the density of green vegetation, i.e., plant biomass involved in active photosynthesis, as this varies through the season and between years. Higher NDVI values than the reference value may indicate denser green vegetation due to effects of climate change, land use or eutrophication, whereas lower values may be due to drought, logging/deforestation, fires etc.
Attribution to ecosystem characteristics	Primary production
- *justification*	NDVI represents green biomass which correlates with primary production.
Correlations (collinearities) with other assessed indicators	Ellenberg N may be affected by increased productivity.
Natural effects on the indicator	Climate/weather, seasonal variation, pests, fires

Anthropogenic effects on the indicator (including references)	Forestry (clear-cutting, planting), climate change, nitrogen deposition
Approach for determining reference value(s)	Reference areas. Two-sided indicator. The Potential Natural Vegetation (PNV; https://peerj.com/articles/5457/) concept is used and applied to the NDVI indicator. Protected areas across Norway are used to define a reference NDVI state, and data for NDVI (response) and climatic + edaphic (explanatory) variables in reference areas are used to train a Random Forest regression model. This model is used to predict potential NDVI (pNDVI) outside of protected areas. The reference condition is then defined via the difference between the pNDVI and the observed NDVI (dNDVI). See https://github.com/NINAnor/pNDVI-nature-index for more details on data inputs.
Quantification of reference value(s)	The reference value is equivalent to the median dNDVI in protected areas of the region of interest (county or municipality).
Approach for determining the limit value for good ecological condition	Two-sided indicator Statistical distribution
Quantification of the limit value for good ecological condition	Upper and lower limit values for good ecological condition are reported as the 0.025 and 0.975 quantiles (i.e., 95% confidence interval) in the reference distribution of dNDVI values of the region of interest (county or municipality).
Quantification of minimum and/or maximum values	Minimum/maximum values are defined by the minimum and maximum values for dNDVI nationally.
References	Pettorelli, N., Vik, J.O., Mysterud, A., Gaillard, J.-M., Tucker, C.J. & Stenseth, N.C. 2005. Using the satellite derived NDVI to assess ecological responses to environmental change. Trends in Ecology and Evolution 20: 503–510.
Indicator	**Ellenberg N**
Completion of the protocol	Joachim Töpper (NINA)
Date filled out/ reviewed	29.03.2019/23.03.2019/20.04.2021
Data source	Geographically representative nature monitoring (ANO). British Ellenberg N values.
Ownership and permissions	ANO is owned by the Norwegian Environment Agency. The British Ellenberg values are published in Hill et al. (1999) and can be used freely (authors must be cited).
Description of raw data	ANO: The species composition of vascular plants is registered as presence and cover (%) of all vascular plants per 1 m^2 quadrat in the centre of an ANO-point. Ellenberg N: the nitrogen affinity per species on a scale of 1 (least nitrophile) to 9 (most nitrophile).
Description of data collection method and data structure	Vertically projected total cover of all vascular plants, registered by visual estimation per species. Observations/measurements are done for every 1 m^2 quadrat in the centre of every ANO-point, with 18 ANO-points per ANO-site and 1000 ANO-sites in total (for all main ecosystem types, see Tingstad et al. 2019).
Description of the indicator	The indicator is the vegetation mean Ellenberg score for the affinity of vascular plant species for nitrogen, weighted with the frequency of each species. This is a two-sided indicator where values both lower and higher than the reference value may indicate deviation from good ecological condition.
Spatial representation/coverage	ANO's data collection is done at 1000 sites (covers all ecosystems) per cycle, randomly selected from SSB's national 500 x 500 m^2 grid; sites that are inaccessible or which do not contain natural elements are discarded and replaced (see Tingstad et al. 2019 for details). As of 2020, data from 2 ANO-seasons in the first cycle are available, i.e., 1742 forest-points in 189 sites across the whole country (out of 4447 points in 256 sites in total). Based on the assumption that 1/3 of Norway is covered by forest, it is expected that there will be roughly 6000 forest points after a full cycle is completed (1000 sites). In principle all

	ecosystem types are covered, but sites far away from roads may be underrepresented.
Geographical delimitation	Mainland Norway
Measurement unit	Weighted average value of the indicator value for nitrogen (Ellenberg N) based on presence and abundance of all vascular plants in the 1 m^2 ANO-quadrat (see Nybø et al. 2018, Töpper et al. 2018 for details).
Time period covered	Species composition data of vascular species in the 1 m^2 quadrats has been available since the start-up of ANO (2019), currently 2019, 2020.
Frequency of data collection	Data collection for ANO is done in a five-year cycle (Tingstad et al. 2019).
Additional description of data properties, if necessary	ANO data are associated with NiN-registrations with mapping units at a scale of 1:5000. The Ellenberg value of each species is an estimate of its realised ecological niche based on the species' dose-response curves associated with nitrogen content in soil. Ellenberg values are taken from Hill et al. (1999, 2007).
Significance of the indicator in the ecosystem and ecological consequences of reduced indicator value (including references)	Changes in the indicator value indicate a change in dominance and/or a succession to more nitrogen poor or nitrogen rich plant communities than are normal for forests in the reference condition.
Attribution to ecosystem characteristics	Primary production Abiotic factors
- *justification*	The indicator is directly linked to the amount of nitrogen in the soil but can also be an indication of productivity.
Correlations (collinearities) with other assessed indicators	May be correlated with NDVI (productivity).
Natural effects on the indicator	Natural variation in local complex environmental variables such as drought sensitivity and lime content.
Anthropogenic effects on the indicator (including references)	Climate change, nitrogen addition, forest management (planting/densification, clear-cutting).
Approach for determining reference value(s)	Reference communities: The generalised species data lists for basic nature types included in the mapping units used in the description system 'Nature in Norway' (NiN) (Halvorsen et al. 2015) are the basis for the calculation of reference- and limit values. See Nybø et al. (2018) and Töpper et al. (2018) for details. Generalised species lists for the basic nature types in NiN. The lists describe the expected species composition and abundance in each nature type (1:5000 mapping units in NiN) in the reference state. See Halvorsen et al. (2015) for details. A weighted average indicator value for Ellenberg N was calculated for each of the generalised species lists by multiplying each species' abundance with its indicator value, adding these values and then dividing by the sum of the amounts. Bootstrapping was used to calculate the potential uncertainty in generalised species lists: each species list was resampled 10 000 times, and in each round, 1/3 of the species in the species list was randomly sampled. Dominant key species in the ecosystem, i.e., species with abundance values ≥ 6 on a scale from 1-6 were included in each selection. The average indicator value for each bootstrap was calculated, and a density distribution across indicator values was produced as a reference distribution. See Töpper et al. 2018 for more details. The following changes were made to the methodology: Re-sampling 1/3 of the species in the species list instead of 2/3, based on species richness documented in ANO. Using mandatory species with abundance value ≥ 6 instead of ≥ 4 in every sample. The reference distribution is unique to each mapping unit at a scale of 1:5000 in T4 non-wetland forest and T30 riparian forest.
Quantification of reference value(s)	The reference value is reported as the median of the reference distribution.
Approach for determining the limit value for good ecological condition	Two-sided indicator Statistical distribution

Quantification of the limit value for good ecological condition	Upper and lower limit values for good ecological condition are reported as the 0.025 and 0.975 quantiles in the reference distribution (i.e., 95% confidence interval).
Quantification of minimum and/or maximum values	Minimum/maximum values are defined by the minimum and maximum values on the Ellenberg N scale (1 and 9, respectively).
References	Ellenberg, H., Weber, H.E., Düll, R., Wirth, V., Werner, W. & Paulissen, D. 1992. Zeigerwerte von Pflanzen in Mit-teleuropa. Scripta Geobotanica XVII, Göttingen. Halvorsen, R., Bryn, A., Erikstad, L. & Lindgaard, A. 2015. Natur i Norge - NiN. Versjon 2.0.0. Artsdatabanken, Trondheim. Hill, M.O., Mountford, J.O. & et. al. 1999. Ellenberg's indicator values for British plants. ECOFACT Volume 2 technical annex. Institute of Terrestrial Ecology, Huntingdon. Hill, M. O., et al. (2007). "BRYOATT: Attributes of British and Irish mosses, liverworts and hornworts." NERC Centre for Ecology and Hydrology, Huntington, UK. Nybø, S., Evju, M., Framstad, E., Lyngstad, A., Pedersen, C., Sickel, H., Sverdrup-Thygeson, A., Töpper, J., Vandvik, V., Velle, L.G. & Aarrestad, P.A. 2018. Operasjonalisering av fagsystemet for økologisk tilstand for terrestriske økosystemer. Forslag til referanse- og grenseverdier for indikatorer som er klare eller nesten klare til bruk. NINA Rapport 1536. Norsk institutt for naturforskning. Tingstad, L., Evju, M., Sickel, H. & Töpper, J. 2019. Utvikling av arealrepresentativ nasjonal naturovervåking (ANO). Forslag til gjennomføring, protokoller og kostnadsvurderinger med utgangspunkt i erfaringer fra uttesting i Trøndelag. NINA Rapport 1642. Norsk institutt for naturforskning. Töpper, J., Velle, L.G. & Vandvik, V. 2018. Utvikling av metodikk for økologisk tilstandsvurdering basert på indikatorverdier etter Ellenberg og Grime (revidert utgave). NINA Rapport 1529b. Norsk institutt for naturforskning.
Indicator	**Ellenberg F**
Completion of the protocol	Joachim Töpper (NINA)
Date filled out/ reviewed	29.03.2019/23.03.2019/20.04.2021
Data source	Geographically representative nature monitoring (ANO). British Ellenberg F values.
Ownership and permissions	ANO is owned by the Norwegian Environment Agency. The British Ellenberg values are published in Hill et al. (1999) and can be used freely (authors must be cited).
Description of raw data	ANO: The species composition of vascular plants is registered as presence and cover (%) of all vascular plants per 1 m^2 quadrat in the centre of an ANO-point. Ellenberg F: each species affinity to moisture on a scale of 1 (least moisture demanding) to 9 (most moisture demanding).
Description of data collection method and data structure	Vertically projected total cover of all vascular plants, registered by visual estimation per species. Observations/measurements are done for every 1 m^2 quadrat in the centre of every ANO-point, with 18 ANO-points per ANO-site and 1000 ANO-sites in total (for all main ecosystem types, see Tingstad et al. 2019).
Description of the indicator	The indicator is the vegetation mean Ellenberg score for the affinity of vascular plant species for moisture, weighted with the frequency of each species. This is a two-sided indicator where values both lower and higher than the reference value may indicate deviation from good ecological condition.
Spatial representation/coverage	ANO's data collection is done at 1000 sites (covers all ecosystems) per cycle, randomly selected from SSB's national 500 x 500 m^2 grid; sites that are inaccessible or which do not contain natural elements are discarded and replaced (see Tingstad et al. 2019 for details). As of 2020, data from 2 ANO-seasons in the first cycle are available, i.e., 1742 forest-points in 189 sites across the whole country (out of 4447 points in 256 sites in total). Based on the assumption that 1/3 of Norway is

	covered by forest, it is expected that there will be roughly 6000 forest points after a full cycle is completed (1000 sites). In principle all ecosystem types are covered, but sites far away from roads may be underrepresented.
Geographical delimitation	Mainland Norway
Measurement unit	Weighted average value of the indicator value for moisture (Ellenberg F) based on presence and abundance of all vascular plants in the 1 m^2 ANO-quadrat (see Nybø et al. 2018, Töpper et al. 2018 for details).
Time period covered	Species composition data of vascular species in the 1 m^2 quadrats has been available since the start-up of ANO (2019), currently 2019, 2020.
Frequency of data collection	Data collection for ANO is done in a five-year cycle (Tingstad et al. 2019).
Additional description of data properties, if necessary	ANO data are associated with NiN-registrations with mapping units at a scale of 1:5000. The Ellenberg value of each species is an estimate of its realised ecological niche based on the species' dose-response curves associated with soil moisture. Ellenberg values are taken from Hill et al. (1999, 2007).
Significance of the indicator in the ecosystem and ecological consequences of reduced indicator value (including references)	Changes in the indicator value indicate a change in dominance and/or a succession to drier or wetter plant communities than are normal for forests in the reference condition.
Attribution to ecosystem characteristics	Abiotic factors
- *justification*	The indicator is directly linked to soil moisture.
Correlations (collinearities) with other assessed indicators	No relevant correlations.
Natural effects on the indicator	Natural variation in local complex environmental variables such as drought sensitivity and lime content.
Anthropogenic effects on the indicator (including references)	Climate change, ditching, forest management (planting/densification, clear-cutting).
Approach for determining reference value(s)	Reference communities: The generalised species data lists for basic nature types included in the mapping units used in the description system 'Nature in Norway' (NiN) (Halvorsen et al. 2015) are the basis for the calculation of reference- and limit values. See Nybø et al. (2018) and Töpper et al. (2018) for details. Generalised species lists for the basic nature types in NiN. The lists describe the expected species composition and abundance in each nature type (1:5000 mapping units in NiN) in the reference state. See Halvorsen et al. (2015) for details. A weighted average indicator value for Ellenberg F was calculated for each of the generalised species lists by multiplying each species' abundance with its indicator value, adding these values and then dividing by the sum of the amounts. Bootstrapping was used to calculate the potential uncertainty in generalised species lists: each species list was resampled 10 000 times, and in each round, 1/3 of the species in the species list was randomly sampled. Dominant key species in the ecosystem, i.e., species with abundance values ≥ 6 on a scale from 1-6 were included in each selection. The average indicator value for each bootstrap was calculated, and a density distribution across indicator values was produced as a reference distribution. See Töpper et al. 2018 for more details. The following changes were made to the methodology: Re-sampling 1/3 of the species in the species list instead of 2/3, based on species richness documented in ANO. Using mandatory species with abundance value ≥ 6 instead of ≥ 4 in every sample. The reference distribution is unique to each mapping unit at a scale of 1:5000 in T4 non-wetland forest and T30 riparian forest.
Quantification of reference value(s)	The reference value is reported as the median of the reference distribution.

Approach for determining the limit value for good ecological condition	Two-sided indicator Statistical distribution
Quantification of the limit value for good ecological condition	Upper and lower limit values for good ecological condition are reported as the 0.025 and 0.975 quantiles in the reference distribution (i.e., 95% confidence interval).
Quantification of minimum and/or maximum values	Minimum/maximum values are defined by the minimum and maximum values on the Ellenberg F scale (1 and 9, respectively).
References	Ellenberg, H., Weber, H.E., Düll, R., Wirth, V., Werner, W. & Paulissen, D. 1992. Zeigerwerte von Pflanzen in Mit-teleuropa. Scripta Geobotanica XVII, Göttingen. Halvorsen, R., Bryn, A., Erikstad, L. & Lindgaard, A. 2015. Natur i Norge - NiN. Versjon 2.0.0. Artsdatabanken, Trondheim. Hill, M.O., Mountford, J.O. & et. al. 1999. Ellenberg's indicator values for British plants. ECOFACT Volume 2 technical annex. Institute of Terrestrial Ecology, Huntingdon. Hill, M. O., et al. (2007). "BRYOATT: Attributes of British and Irish mosses, liverworts and hornworts." NERC Centre for Ecology and Hydrology, Huntington, UK. Nybø, S., Evju, M., Framstad, E., Lyngstad, A., Pedersen, C., Sickel, H., Sverdrup-Thygeson, A., Töpper, J., Vandvik, V., Velle, L.G. & Aarrestad, P.A. 2018. Operasjonalisering av fagsystemet for økologisk tilstand for terrestriske økosystemer. Forslag til referanse- og grenseverdier for indikatorer som er klare eller nesten klare til bruk. NINA Rapport 1536. Norsk institutt for naturforskning. Tingstad, L., Evju, M., Sickel, H. & Töpper, J. 2019. Utvikling av arealrepresentativ nasjonal naturovervåking (ANO). Forslag til gjennomføring, protokoller og kostnadsvurderinger med utgangspunkt i erfaringer fra uttesting i Trøndelag. NINA Rapport 1642. Norsk institutt for naturforskning. Töpper, J., Velle, L.G. & Vandvik, V. 2018. Utvikling av metodikk for økologisk tilstandsvurdering basert på indikatorverdier etter Ellenberg og Grime (revidert utgave). NINA Rapport 1529b. Norsk institutt for naturforskning.
Indicator	**Absence of alien species**
Completion of the protocol	Joachim Töpper (NINA)
Date filled out/ reviewed	29.03.2019/23.05.2019/20.04.2021
Data source	Geographically representative nature monitoring (ANO) (Tingstad et al. 2019)
Ownership and permissions	ANO is owned by the Norwegian Environment Agency
Description of raw data	The total cover (%) in 250 m^2 ANO-points of alien vascular plants in the very high risk (SE), high risk (HI) and potentially high risk (PH) categories, following the Norwegian Biodiversity Information Centre (Artsdatabanken 2018).
Description of data collection method and data structure	Vertically projected total cover of all alien vascular plants, registered by visual estimation of all alien species together. Observations/measurements are done for every 250 m^2-ANO point, with 18 ANO-points per ANO-site and 1000 ANO-sites in total (covers all main ecosystem types, not only mountains, see Tingstad et al. 2019).
Description of the indicator	The indicator is the proportion of the area without such alien species (i.e., 100% - total cover (%) of alien species).
Spatial representation/coverage	ANO's data collection is done at 1000 sites (covers all ecosystems) per 5-year cycle, randomly selected from SSB's national 500 x 500 m^2 grid; sites that are inaccessible or which do not contain natural elements are discarded and are replaced (see Tingstad et al. 2019 for details). As of 2020, data from 2 ANO-seasons in the first cycle are available, i.e., 1742 forest points in 189 sites across the country (out of 4447 points in 256 sites in total). Based on the assumption that 1/3 of Norway is covered by mountains, it is expected that there will be roughly 6000 mountain points after a full cycle is completed (1000 sites). In principle all

	ecosystem types are covered, but sites far away from roads may be underrepresented.
Geographical delimitation	Mainland Norway
Measurement unit	Proportion (%) of area without alien species cover, calculated as 100% minus total cover (%) of alien species (see Nybø et al. 2018 for details).
Time period covered	2019-2020
Frequency of data collection	Every five years for each ANO-site.
Additional description of data properties, if necessary	ANO data are associated with mapping of units at scale 1:5000 in the nature description system 'Natur i Norge' (Nature in Norway, NiN, also called the EcoSyst framework) (Halvorsen et al. 2016, 2020).
Significance of the indicator in the ecosystem and ecological consequences of reduced indicator value (including references)	Alien species are a threat to native ecosystems, from the conscious introduction of non-native tree species in forestry, through dispersal from parks/gardens and other voluntary or involuntary introductions.
Attribution to ecosystem characteristics	Functionally important species and structures.
- *justification*	Absence of alien species is an important functional quality of ecosystems.
Correlations (collinearities) with other assessed indicators	No relevant correlations.
Natural effects on the indicator	Naturalised alien species may disperse into forests because of climate change.
Anthropogenic effects on the indicator (including references)	Introduction of alien species, anthropogenic climate change, land use, pollution.
Approach for determining reference value(s)	Absolute biophysical boundaries.
Quantification of reference value(s)	The reference value is given as the complete absence of alien species, i.e., 100% of the area without alien species.
Approach for determining the limit value for good ecological condition	Expert knowledge. One-sided indicator.
Quantification of the limit value for good ecological condition	The limit value is given as 95% of the area without alien species.
Quantification of minimum and/or maximum values	The minimum value is defined as the lowest possible value, i.e., 0% of the area without alien species.
References	Artsdatabanken 2018. Fremmedartslista 2018. Accessed 22.11.2021. https://www.artsdatabanken.no/fremmedartslista2018 Halvorsen, R., Bryn, A. & Erikstad, L. 2016. NiNs systemkjerne – teori, prinsipper og inndelingskriterier. Natur i Norge, Artikkel 1 (versjon 2.0.0) Halvorsen, R., Skarpaas, O., Bryn, A., Bratli, H., Erikstad, L., Simensen, T. & Lieungh, E. 2020. Towards a systematics of ecodiversity: The EcoSyst framework. Global Ecology and Biogeography 29: 1887–1906. Hendrichsen, D.K., Sandvik, H., Töpper, J.P., Olsen, S.L., Hilmo, O., Magnussen, K., Navrud, S., Fleisje, E.M., & Åström, S. 2020. Spredningsveier for fremmede arter i Norge. Kunnskapssta-tus per 2019. NINA Rapport 1735.Nybø, S., Evju, M., Framstad, E., Lyngstad, A., Pedersen, C., Sickel, H., Sverdrup-Thygeson, A., Töpper, J., Vandvik, V., Velle, L.G. & Aarrestad, P.A. 2018. Operasjonalisering av fagsystem for økologisk tilstand for terrestriske økosystemer. Forslag til referanse- og grenseverdier for indikatorer som er klare eller nesten klare til bruk. NINA Rapport 1536. Tingstad, L., Evju, M., Sickel, H., & Töpper, J. 2019. Utvikling av nasjonal arealrepresentativ naturovervåking (ANO). Forslag til gjennomføring, protokoller og kostnadsvurderinger med utgangspunkt i erfaringer fra uttesting i Trøndelag. NINA Rapport 1642.

Indicator	**Bilberry cover**
Completion of the protocol	Erik Framstad (NINA), Simon Jakobsson (NINA)
Date filled out/ reviewed	01.06.2019/20.04.2021
Data source	National Forest Inventory – bilberry cover
Ownership and permissions	The National Forest Inventory (NIBIO); permission is required for data extraction
Description of raw data	Percent cover of blueberries (*Vaccinium myrtillus*) is recorded in the National Forest Inventory plots, based on cover in four small 0,5x0,5 m sites (starting with the 10th inventory).
Description of data collection method and data structure	National Forest Inventory field instructions 2018 (Viken 2018). Observations/ measurements are done for every inventory plot; each plot is 250 m^2.
Description of the indicator	The indicator is the percentage cover of bilberries, estimated as an area-weighted average of observations per inventory plot.
Spatial representation/coverage	Data collection for the National Forest Inventory takes place on sites laid out in a regular grid of 3x3 km that covers all forests below the coniferous treeline, with a grid of 9x9 above the coniferous treeline and 1.5x1.5 km in protected areas with forests. In principle, the location of the sites is secret, and the effect of forest management is therefore assumed to be comparable to other forested areas. The whole population is covered. The sample sites are randomly selected. Sample sites represent 0,003 % of forested areas.
Geographical delimitation	Forest land throughout Norway, according to the definition applied by FAO and National Forest Inventory (Tomter & Dalen 2018).
Measurement unit	Percentage cover of bilberry plants
Time period covered	The National Forest Inventory has recorded bilberry cover since 2008, but only data starting at the 10th inventory (2010-2014) are used for the evaluation of ecological condition.
Frequency of data collection	Data collection is done in a five-year cycle (i.e., data used for the assessment of ecological condition are compiled per five-year period).
Additional description of data properties, if necessary	The abundance of bilberry plants is considered important for many forest species (small rodents, forest birds, deer), and the total abundance of leaves and berry production per unit area are probably important. The registration of bilberry cover is a direct representation of the indicator and will be closely correlated with leaf abundance and blueberries per unit area. Registration methodology and frequency, as well as choice of sample sites is considered to be reliable. Challenges can be associated with (1) possible data compilation across areas that are too small, such that the number of sample sites is too small to make precise estimates, and (2) possible breaches in the assumption of representative forest management in the National Forest Inventory plots.
Significance of the indicator in the ecosystem and ecological consequences of reduced indicator value (including references)	Bilberry is a key species in boreal forests, functioning as food in summer and winter for a wide range of species and influencing the structure of the field layer.
Attribution to ecosystem characteristics	Functionally important species and biophysical structures
- justification	Bilberry is a key species in boreal forests (cf. above)
Correlations (collinearities) with other assessed indicators	No relevant correlations.
Natural effects on the indicator	climate, pests
Anthropogenic effects on the indicator (including references)	Forestry, especially early felling and dense planting, forest management type (clear-cutting, whole-tree harvesting); climate change; nitrogen addition
Approach for determining reference value(s)	Reference areas

	The reference value is assessed in the same way as the nature index, i.e., as a discretionary assessment based on recorded values for bilberry cover in selected National Forest Assessment sample sites with natural forest characteristics (Nilsen et al. 2010). The reference values are differentiated for varying forest productivity in the different counties. This could be assessed in more detail using data on forest productivity and tree-type dominance but has not yet been done. See details in chapter 6.1 in Nybø et al. (2018).
Quantification of reference value(s)	The reference values reported for the indicators in the Norwegian Nature Index are used for the assessment of ecological condition (www.naturindeks.no), and vary between 2,5 and 12,5 % between counties and county divisions.
Approach for determining the limit value for good ecological condition	Empirically supported expert knowledge. One-sided indicator. It is assumed that there is a relatively linear relationship between bilberry cover and its importance for species diversity. A lower limit for good condition can therefore be set to a relative value of 60% of the reference value.
Quantification of the limit value for good ecological condition	The limit value is calculated as 0,6* the reference value, i.e., between 1,5 and 7,5 % of the forest area, depending on the geographical region (cf. above).
Quantification of minimum and/or maximum values	The minimum value is defined as the total absence of the indicator (0% bilberry cover).
References	Nilsen, J.-E.Ø., Moum, S.O. &Astrup, R. 2010. Indirekte indikatorer – Landsskogtakseringen. Chapt. 5.9 in Nybø, S. (ed.) Datagrunnlag for Naturindeksen 2010. DN-utredning 4-2010. Nybø, S., Evju, M., Framstad, E., Lyngstad, A., Pedersen, C., Sickel, H., Sverdrup-Thygeson, A., Töpper, J., Vandvik, V., Velle, L.G. & Aarrestad, P.A. 2018. Operasjonalisering av fagsystemet for økologisk tilstand for terrestriske økosystemer. Forslag til referanse- og grenseverdier for indikatorer som er klare eller nesten klare til bruk. NINA Rapport 1536. Norsk institutt for naturforskning. Viken, K.O. 2018. Landsskogtakseringens feltinstruks – 2018. NIBIO BOK 4(6)2018.
Indicator	**Rowan-aspen-goat willow**
Completion of the protocol	Erik Framstad (NINA), Simon Jakobsson (NINA)
Date filled out/ reviewed	01.06.2019/20.04.2021
Data source	National Forest Inventory – volume of rowan, aspen and willow (*Sorbus aucuparia, Populus tremula, Salix caprea*)
Ownership and permissions	The National Forest Inventory (NIBIO); permission is required for data extraction
Description of raw data	Total volume per ha of rowan, aspen and willow ≥10cm dbh (diameter at chest height) on productive forest land, recorded on the National Forest Inventory plots (starting at the 7th inventory, 1994-1998).
Description of data collection method and data structure	National Forest Inventory field instructions 2018 (Viken 2018). Observations/ measurements are done for every inventory plot; each plot is 250 m^2.
Description of the indicator	The indicator is the volume (m^3/ha) of trees > 10 cm dbh for rowan, aspen and willow on productive forest land, estimated as an area-weighted average of observations.
Spatial representation/coverage	Data collection for the National Forest Inventory takes place on sites laid out in a regular grid of 3x3 km that covers all forests below the coniferous treeline, with a grid of 9x9 above the coniferous treeline and 1.5x1.5 km in protected areas with forests. In principle, the location of the sites is secret, and the effect of forest management is therefore assumed to be comparable to other forested areas. The whole population is covered. The sample sites are randomly selected. Sample sites represent 0,003 % of forested areas.
Geographical delimitation	Forest land throughout Norway, according to the definition applied by FAO and National Forest Inventory (Tomter & Dalen 2018).

Measurement unit	Volume (m3/ha) of trees ≥10cm dbh of rowan, aspen and goat willow on productive forest land
Time period covered	Data starting at the 7th inventory (1994-1998).
Frequency of data collection	Data collection is done in a five-year cycle (i.e., data used for the assessment of ecological condition are compiled per five-year period).
Additional description of data properties, if necessary	Rowan, aspen and willow are considered important for species diversity in boreal forests, and larger trees of these species are particular important. Measuring the volume of trees >10 cm on productive land is considered the best way to capture the significance of these tree species for species diversity. The registration in the National Forest Assessment is a direct representation of the indicator. Also see Storaunet & Framstad (2018). Registration methodology and frequency, as well as choice of sample sites is considered to be reliable. Challenges can be associated with (1) possible data compilation across areas that are too small, such that the number of sample sites is too small to make precise estimates, and (2) possible breaches in the assumption of representative forest management in the National Forest Assessment's study sites.
Significance of the indicator in the ecosystem and ecological consequences of reduced indicator value (including references)	Rowan, aspen and willow are considered important for species diversity in boreal forests, both as food and habitat, and larger trees of these species are particular important.
Attribution to ecosystem characteristics	Functionally important species and biophysical structures
- *justification*	Rowan, aspen and willow are considered important for species diversity in boreal forests (cf. above)
Correlations (collinearities) with other assessed indicators	No relevant correlations.
Natural effects on the indicator	Natural disturbances: forest fires, landslides, floods, windthrow
Anthropogenic effects on the indicator (including references)	Forestry, especially early felling and dense planting, forest management type (clear-cutting); forest fire management; reduction in traditional management activities/ grazing
Approach for determining reference value(s)	Reference areas The reference condition is based on the recorded values in productive forests on the National Forest Inventory sample sites which are considered to have the greatest degree of natural forest characteristics for the different regions. An expert assessment of natural forest dynamics and how they will affect the relevant tree species has also been done, since the sites are not randomly distributed in geographical space. Overall, this indicates that the average reference value for these tree species is approximately 7 m^3/ha in productive forests throughout the country, but the reference value is defined regionally due to different natural conditions in different regions. See details in chapter 6.2 in Nybø et al. (2018).
Quantification of reference value(s)	The reference values reported for the indicators in the Norwegian Nature Index are used for the assessment of ecological condition (www.naturindeks.no), and vary between 3 and 10 m^3 per ha between counties.
Approach for determining the limit value for good ecological condition	Empirically supported expert knowledge. One-sided indicator. It is assumed that there is a relatively linear relationship between volume of rowan, aspen and willow >10 cm dbh on productive land, and its importance for species diversity. A lower limit for good condition can therefore be set to a relative value of 60% of the reference value. Also see chapter 6.2 in Nybø et al. (2018).
Quantification of the limit value for good ecological condition	The limit value is calculated as 0,6* the reference value, i.e., between 1,8 and 6,0 m^3/ha, depending on the geographical region.
Quantification of minimum and/or maximum values	The minimum value is defined as the total absence of the indicator (0 m^3/ha).

References	Nybø, S., Evju, M., Framstad, E., Lyngstad, A., Pedersen, C., Sickel, H., Sverdrup-Thygeson, A., Töpper, J., Vandvik, V., Velle, L.G. & Aarrestad, P.A. 2018. Operasjonalisering av fagsystemet for økologisk tilstand for terrestriske økosystemer. Forslag til referanse- og grenseverdier for indikatorer som er klare eller nesten klare til bruk. NINA Rapport 1536. Norsk institutt for naturforskning. Storaunet, K.O. & Framstad, E. 2018. Nye indikatorer fra Landsskogtakseringen. Gammel skog, rogn-osp-selje (ROS) og eik. Notat til Naturindeksen, nov. 2018. Viken, K.O. 2018. Landsskogtakseringens feltinstruks – 2018. NIBIO BOK 4(6)2018.
Indicator	**Dead wood total**
Completion of the protocol	Erik Framstad (NINA), Simon Jakobsson (NINA)
Date filled out/ reviewed	15.01.2019/31.05.2019/20.04.2021
Data source	National Forest Inventory – total volume of dead wood
Ownership and permissions	The National Forest Assessment (NIBIO); permission is required for data extraction
Description of raw data	Volume (m^3/ha) of fallen and standing dead wood (≥ 10 cm diameter) of all tree species and decay stages, based on measurements per inventory plot in the National Forest Inventory (for inventory cycles 7, 10, 11).
Description of data collection method and data structure	National Forest Inventory field instructions 2018 (Viken 2018). Observations/ measurements are done for every inventory plot; each plot is 250 m^2.
Description of the indicator	The indicator is estimated as an area-weighted average of observations of the volume (m^3/ha) of standing and fallen dead wood ≥ 10 cm in diameter per plot
Spatial representation/coverage	Data collection for the National Forest Inventory takes place on plots laid out in a regular grid of 3x3 km that covers all forests below the coniferous treeline, with a grid of 9x9 above the coniferous treeline and 1.5x1.5 km in protected areas with forests. In principle, the location of the sites is secret, and the effect of forest management is therefore assumed to be comparable to other forested areas. The whole population is covered. The sample sites are randomly selected. Sample sites represent 0,003 % of forested areas.
Geographical delimitation	Forest land throughout Norway, according to the definition applied by FAO and National Forest Inventory (Tomter & Dalen 2018).
Measurement unit	Volume (m^3/ha) of fallen and standing dead wood (≥ 10 cm diameter) of all tree species and decay stages
Time period covered	Data for the volume of dead wood using the current registration method are only available starting at the 10th inventory (2010-2014), but previous estimates (using a different method) are available for the 7th inventory (1994-1998).
Frequency of data collection	Data collection is done in a five-year cycle (i.e., data used for the assessment of ecological condition are compiled per five-year period).
Additional description of data properties, if necessary	The volume of dead wood is an important ecological variable in forests, both as a reflection of forest dynamics and as a resource for many species. Registrations in the National Forest Assessment represent the volume of dead wood in an equivalent way to various studies of the importance of dead wood for species diversity. Registration methodology and frequency, as well as choice of sample sites is considered to be reliable. Challenges can be associated with (1) possible data compilation across areas that are too small, such that the number of sample sites is too small to make precise estimates, and (2) possible breaches in the assumption of representative forest management in the National Forest Assessment's study sites.

Significance of the indicator in the ecosystem and ecological consequences of reduced indicator value (including references)	Dead wood is a key functional structure on forests, with great significance as habitat and substrate for a large number of fungi, invertebrates and other species.
Attribution to ecosystem characteristics	Functionally important species and biophysical structures
- justification	Dead wood is a key functional structure in forests due to its importance as habitat for many species.
Correlations (collinearities) with other assessed indicators	Strong correlation with coarse woody debris.
Natural effects on the indicator	Forest fires, windthrow, floods, landslides, insect infestations, rot, age
Anthropogenic effects on the indicator (including references)	Forestry, especially early felling, thinning, forest management-type (stand management, dimension felling, whole-tree harvesting); forest-fire management
Approach for determining reference value(s)	Empirically supported expert knowledge: Data + ecosystem dynamics models Combination of observational data, literature (Siitonen 2001, Nilsson et al. 2002, Ranius et al. 2004, Jonsson & Siitonen 2012, Storaunet & Rolstad 2015) and modelling (with elements of expert assessments): Published empirical and modelled values for quantity of dead wood in old-growth forests with different productivity/ in different bioclimatic zones (Siitonen 2001, Nilsson et al. 2002, Ranius et al. 2004, Jonsson & Siitonen 2012). This is linked to a model for the age distribution of trees in forests characterized by natural disturbance processes and succession (Pennanen 2002), as well as a simple model for accumulation of different types of dead wood through the forest's successional ages. See details in chapter 6.5 in Nybø et al. (2018).
Quantification of reference value(s)	The reference value is calculated as the average of all age classes in assumed natural forest for the productivity classes high, medium and low (details in chapter 6.5 in Nybø et al. 2018). In each region, the reference value must be linked to the distribution of areas with different productivities (cf. data from the National Forest Assessment in Granhus et al. 2012).
Approach for determining the limit value for good ecological condition	Empirically supported expert knowledge: Data + ecosystem dynamics models. One-sided indicator. It is assumed that there is a relatively linear relationship between dead wood and its importance for species diversity associated with dead wood, down to a possible lower limit for dead wood. A few studies have tried to provide such a threshold value, where the number of individuals or species associated with dead wood decreases more quickly than the volume of dead wood (cf. Müller & Bütler 2010, Junninen & Komonen 2011). This can be considered a boundary between moderate and poor condition. On a 5-part scale from reference state (1) to completely reduced state (0), this corresponds to a relative value of 0,4. A lower limit for good condition can thus be set to a relative value of 0,6.
Quantification of the limit value for good ecological condition	The limit value is calculated as 0,6*the reference value.
Quantification of minimum and/or maximum values	The minimum value is defined as the total absence of the indicator (0 m^3/ha).
References	Granhus, A., Hylen, G. & Nilsen, J.-E.Ø. 2012. Skogen i Norge. Statistikk over skogforhold og skogressurser i Norge registrert i perioden 2005-2009. Ressursoversikt fra Skog og landskap 03/2012. Jonsson, B.G. & Siitonen, J. 2012. Natural forest dynamics. pp: 275-301 in Stokland, J.N., Siitonen, J. & Jonsson, B.G. (eds) Biodiversity in dead wood. Cambridge University Press. Junninen, K. & Komonen, A. 2011. Conservation ecology of boreal polypores: A review. Biological Conservation 144: 11-20. Müller, J. & Bütler, R. 2010.A review of habitat thresholds for dead wood: A baseline for management recommendations in European forests. European Journal of Forest Research 129: 981-992. Nilsson, S.G., Niklasson, M., Hedin, J., Aronsson, G., Gutowski, J.M., Linder, P., Ljungberg, H., Mikusinksi, G. & Ranius, T. 2002.

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Indicator	**Coarse woody debris**
Completion of the protocol	Erik Framstad (NINA), Simon Jakobsson (NINA)
Date filled out/ reviewed	31.05.2019/30.04.2021
Data source	National Forest Inventory – volume of dead wood >30 cm
Ownership and permissions	The National Forest Inventory (NIBIO); permission is required for data extraction
Description of raw data	Volume (m^3/ha) of fallen and standing dead wood (≥ 30 cm diameter) of all tree-types and decay stages, based on measurements per plot of the National Forest Inventory (for inventories 7, 10, 11).
Description of data collection method and data structure	National Forest Inventory field instructions 2018 (Viken 2018). Observations/ measurements are done for every inventory plot; each plot is 250 m^2.
Description of the indicator	The indicator is estimated as an area-weighted average of observations of the volume (m^3/ha) of standing and fallen dead wood ≥ 30 cm in diameter per plot.
Spatial representation/coverage	Data collection for the National Forest Assessment takes place on sites laid out in a regular grid of 3x3 km that covers all forests below the coniferous treeline, with a grid of 9x9 above the coniferous treeline and 1.5x1.5 km in protected areas with forests. In principle, the location of the sites is secret, and the effect of forest management is therefore assumed to be comparable to other forested areas. The whole population is covered. The sample sites are randomly selected. Sample sites represent 0,003 % of forested areas.
Geographical delimitation	Forest land throughout Norway, according to the definition applied by FAO and National Forest Inventory (Tomter & Dalen 2018).
Measurement unit	Volume (m^3/ha) of fallen and standing dead wood (≥ 30 cm diameter) of all tree species and decay stages
Time period covered	Data for the volume of dead wood using the current registration method are only available starting at the 10th inventory (2010-2014), but previous estimates (using a different method) are available for the 7th inventory (1994-1998).
Frequency of data collection	Data collection is done in a five-year cycle (i.e., data used for the assessment of ecological condition are compiled per five-year period).

Additional description of data properties, if necessary	The volume of dead wood is an important ecological variable in forests, both as a reflection of forest dynamics and as a resource for many species. Coarse woody debris is especially important as a long-lasting substrate which provides a varied range of opportunities for life. Registrations in the National Forest Assessment represent the volume of dead wood in an equivalent way to various studies of the importance of dead wood for species diversity. However, the separation criterion for coarse woody debris may vary between studies. Registration methodology and frequency, as well as choice of sample sites is considered to be reliable. Challenges can be associated with (1) possible data compilation across areas that are too small, such that the number of sample sites is too small to make precise estimates, and (2) possible breaches in the assumption of representative forest management in the National Forest Assessment's study sites.
Significance of the indicator in the ecosystem and ecological consequences of reduced indicator value (including references)	Coarse woody debris is an especially important functional structure on forests since it tends to go through a longer succession until complete decay, and thus presents a long-lasting habitat with particular significance for specialised forest species of fungi, invertebrates etc associated with old forests.
Attribution to ecosystem characteristics	Functionally important species and biophysical structures
- justification	Coarse woody debris is a key functional structure in forests due to its importance as habitat for specialised forest species.
Correlations (collinearities) with other assessed indicators	Strong correlation with dead wood total.
Natural effects on the indicator	Forest fire, windthrow, flood, landslides, insect infestation, rot, age
Anthropogenic effects on the indicator (including references)	Forestry, especially early felling, thinning, forest management type (clear-cutting, dimension felling, whole-tree harvesting); forest fire management
Approach for determining reference value(s)	Empirically supported expert knowledge: Data + ecosystem dynamics models Combination of observational data, literature (Siitonen 2001, Nilsson et al. 2002, Ranius et al. 2004, Jonsson & Siitonen 2012, Storaunet & Rolstad 2015) and modelling (with elements of expert assessments). Various studies (cf. references above) suggest that the proportion of coarse woody debris in natural forests is about 40% of the total volume of dead wood. Published empirical and modelled values for quantity of dead wood in old-growth forests with different productivity/ in different bioclimatic zones (Siitonen 2001, Nilsson et al. 2002, Ranius et al. 2004, Jonsson & Siitonen 2012, Storaunet & Rolstad 2015). This is linked to a model for the age distribution of trees in forests characterized by natural disturbance processes and succession (Pennanen 2002), as well as a simple model for accumulation of different types of dead wood through the forest's successional ages. See details in chapters 6.5 and 6.6 in Nybø et al. (2018).
Quantification of reference value(s)	The reference value is calculated as the average of all age classes in assumed natural forest for the productivity classes high, medium and low (details in chapter 6.5 in Nybø et al. 2018). In each region, the reference value must be linked to the distribution of areas with different productivities (cf. data from the National Forest Assessment in Granhus et al. 2012). The reference value for the volume of coarse woody debris is 40% of the reference value of the total volume of dead wood.
Approach for determining the limit value for good ecological condition	Empirically supported expert knowledge. One-sided indicator. It is assumed that there is a relatively linear relationship between dead wood and its importance for species diversity associated with dead wood, down to a possible lower limit for dead wood. A few studies have tried to provide such a threshold value, where the number of individuals or species associated with dead wood decreases more quickly than the volume of dead wood (cf. Müller & Bütler 2010, Junninen & Komonen 2011). This can be considered a boundary between moderate and poor

	condition. On a 5-part scale from reference state (1) to completely reduced state (0), this corresponds to a relative value of 0,4. A lower limit for good condition can thus be set to a relative value of 0,6. Also see chapter 6.5-6.6 in Nybø et al. (2018).
Quantification of the limit value for good ecological condition	The limit value is calculated as 0,6*the reference value, corresponding to 40% of the limit value for the indicator dead wood total (cf. above).
Quantification of minimum and/or maximum values	The minimum value is defined as the total absence of the indicator (0 m^3/ha).
References	See *Dead wood total* above
Indicator	**Biologically old forest**
Completion of the protocol	Erik Framstad (NINA), Simon Jakobsson (NINA)
Date filled out/ reviewed	15.01.2019/31.05.2019/20.04.2021
Data source	National Forest Inventory – biologically old forest
Ownership and permissions	The National Forest Inventory (NIBIO); permission is required for data extraction.
Description of raw data	Proportion of forest area older than a specified stand age for forests dominated by spruce, pine or deciduous trees, in areas with low, medium and high forest productivity (cf. table in chapter 6.7 in Nybø et al. 2018), based on measurements of stand age, forest productivity and dominant tree-type per inventory plot in the National Forest Inventory (starting at the 8th Inventory).
Description of data collection method and data structure	National Forest Inventory field instructions 2018 (Viken 2018). Observations/measurements are done for every inventory plot; each plot is 250 m^2.
Description of the indicator	The indicator is the proportion of inventory plots that satisfy the criteria for old-growth forest (cf. above) estimated as an area-weighted average of observations.
Spatial representation/coverage	Data collection for the National Forest Assessment takes place on sites laid out in a regular grid of 3x3 km that covers all forests below the coniferous treeline, with a grid of 9x9 above the coniferous treeline and 1.5x1.5 km in protected areas with forests. In principle, the location of the sites is secret, and the effect of forest management is therefore assumed to be comparable to other forested areas. The whole population is covered. The sample sites are randomly selected. Sample sites represent 0,003 % of forested areas.
Geographical delimitation	Forest land throughout Norway, according to the definition applied by FAO and National Forest Inventory (Tomter & Dalen 2018).
Measurement unit	Proportion of inventory plots that satisfy the criteria for biologically old forest (cf. above).
Time period covered	Data for the proportion of old-growth forest area can be calculated based on data starting at the 8th assessment (2000-2004).
Frequency of data collection	Data collection is done in a five-year cycle (i.e., data used for the assessment of ecological condition are compiled per five-year period).
Additional description of data properties, if necessary	Old-growth forests have a large variation in tree age, size, and horizontal and vertical diversity, with a significant proportion of old and often large trees, as well as a large quantity of and variation in dead wood. This means that this forest type has great significance as a habitat for a large, diverse and often specialised group of species. The criteria for old-growth forest do not specifically capture the aspects of this forest type which are important to species diversity, but they consider that the development of these aspects varies with tree species, forest productivity and age. Registration methodology and frequency, as well as choice of sample sites is considered to be reliable. Challenges can be associated with (1) possible data compilation across areas that are too small, such that the number of sample sites is too small to make precise estimates, and (2) possible breaches in the

	assumption of representative forest management in the National Forest Assessment's study sites.
Significance of the indicator in the ecosystem and ecological consequences of reduced indicator value (including references)	Biologically old forests represent remnants of old forest of particular importance to species associated with old forests; such forests tend to be in short supply in the current forest landscape dominated by industrial forestry.
Attribution to ecosystem characteristics	Functionally important species and biophysical structures Landscape ecological patterns
- justification	Biologically old forests represent remnants of old forest of particular importance to species associated with old forests
Correlations (collinearities) with other assessed indicators	Some correlation with dead wood indicators may be expected.
Natural effects on the indicator	Forest fire, windthrow, floods, landslides, insect infestations, rot
Anthropogenic effects on the indicator (including references)	Forestry, especially early felling, forest management type (clear-cutting, whole-tree harvesting)
Approach for determining reference value(s)	Empirically supported expert knowledge: Data + ecosystem dynamics models Age criteria for old-growth forest range from around >80 years (highly productive deciduous forest) to >155 years (unproductive pine forest). Simulations of age distributions in boreal forests under different natural fire regimes indicate that the proportion of forested area where the oldest cohort is older than 150 years is between 57-72% (cf. Pennanen 2002). This could indicate that the proportion of old-forest area in the reference condition following our criteria for this forest type is markedly higher than 60%. See details in chapter 6.7 in Nybø et al. (2018).
Quantification of reference value(s)	The reference value is calculated as 60% of the forest area, which should be considered a conservative estimate (cf. above and chapter 6.7 in Nybø et al. 2018).
Approach for determining the limit value for good ecological condition	Empirically supported expert knowledge. One-sided indicator. It is assumed that there is a relatively linear relationship between the proportion of old-growth forest area and its importance for species diversity associated with this forest type. A lower limit for good condition can therefore be set to a relative value of 60% of the reference value, i.e., 36% of the forest area. Also see chapter 6.7 in Nybø et al. (2018).
Quantification of the limit value for good ecological condition	The limit value is calculated as 0,6* the reference value.
Quantification of minimum and/or maximum values	The minimum value is defined as the total absence of the indicator (0% old-growth forest).
References	Nybø, S., Evju, M., Framstad, E., Lyngstad, A., Pedersen, C., Sickel, H., Sverdrup-Thygeson, A., Töpper, J., Vandvik, V., Velle, L.G. & Aarrestad, P.A. 2018. Operasjonalisering av fagsystemet for økologisk tilstand for terrestriske økosystemer. Forslag til referanse- og grenseverdier for indikatorer som er klare eller nesten klare til bruk. NINA Rapport 1536. Norsk institutt for naturforskning. Pennanen, J. 2002. Forest age distribution under mixed-severity fire regimes – a simulation-based analysis for middle boreal Fennoscandia. Silva Fennica 36: 213-231. Tomter, S.M. & Dalen, S.L. (eds) 2018. Bærekraftig skogbruk i Norge. Norsk institutt for bioøkonomi. Viken, K.O. 2018. Landsskogtakseringens feltinstruks – 2018. NIBIO BOK 4(6)2018.
Indicator	**Large cervids**
Completion of the protocol	Simon Jakobsson (NINA)
Date filled out/ reviewed	28.03.2019/20.04.2021
Data source	Norwegian Nature Index 2020
Ownership and permissions	NINA and the Norwegian Environment Agency through the Norwegian Nature Index; permission is required for data extraction.

Description of raw data	The indicator is based on population estimates of elk (*Alces alces*) and red deer (*Cervus elaphus*) used in the Nature Index. Indicator values and reference values are reported to the Norwegian Nature Index 2020 database by those responsible for the indicator. Based on data from Hjorteviltregisteret (https://www.hjorteviltregisteret.no/). Values represent population levels for elk and red deer as they are presented in the Norwegian Nature Index.
Description of data collection method and data structure	https://www.hjorteviltregisteret.no/ and www.naturindeks.no Data are available per county but are aggregated to regional level in the Nature Index (cf. Jakobsson & Pedersen 2020) and here.
Description of the indicator	The indicator is a composite index ('elk equivalents') for the abundance of elk and red deer, adjusted for their metabolic weights. Elk-equivalents, converted from index values (0-1) and reference values (corresponding to 1), via the number of individuals, for each indicator species. Elk-equivalents are based on the estimated metabolic weight ($E=W^{0,75}$, E = metabolic weight and W = body weight; Kleiber 1961) of the population (elk: 80,9 kg; red deer: 31,6 kg; see Nybø et al. 2018). Elk: 1 elk-equivalent = 1 elk. Red deer: 1 elk-equivalent = 0,39 red deer. For details, see Nybø et al. (2018)
Spatial representation/coverage	Data are not based on a statistical selection. The data for these deer species are relatively comprehensive, including hunting statistics from the whole country. All available observation and monitoring data form the basis for estimation of population levels and are associated with various research activities, as well as reporting to the Norwegian Nature Index 2020. For more information, see www.naturindeks.no
Geographical delimitation	Virtually all areas with current populations of elk and/or red deer.
Measurement unit	Relative units of 'elk equivalents' per km^2.
Time period covered	1990, 2000, 2010, 2014, 2019
Frequency of data collection	In practice, every 5 years since 2010.
Additional description of data properties, if necessary	This indicator is mainly affected by human regulation of the population level, and changes made to landscape structure by forestry. Elk and red deer are important herbivores in forests and greatly impact vegetation cover by consuming large volumes of vegetation in specific parts of the forest, where particularly deciduous trees and bushes are heavily grazed upon during the winter. Elk and red deer are also important prey animals for large predators, and carcasses are of great importance to several smaller predators and scavengers. Road traffic also causes high mortality rates among these deer species. Severe, snowy winters and local shortages in fodder also contribute significantly to these populations. In a natural state, large predators will regulate both population size and composition to a larger extent than is currently the case. This joint-indicator for large deer species in forests considers that the ecological effect of elk is larger than the ecological effect of red deer and is thus calculated using the equation for the relationship between energy requirement and body weight (see above; Kleiber 1961) to calculate "elk-equivalents". The data for this indicator are not based on a statistical selection, but are mostly based on the near-complete coverage of harvest data. In addition, a large amount of scientific knowledge is available for the other variables included in the calculations of population levels.
Significance of the indicator in the ecosystem and ecological consequences of reduced indicator value (including references)	The large cervids are dominating herbivores in forests, with considerable effects on the distribution and growth of several deciduous tree species and important prey for large carnivores and various scavengers.
Attribution to ecosystem characteristics	Distribution of biomass between trophic levels
- *justification*	Key herbivores in major vertebrate food chains.
Correlations (collinearities) with other assessed indicators	No relevant correlations
Natural effects on the indicator	Predators, climate/ weather.

Anthropogenic effects on the indicator (including references)	Harvest, predator management, forestry (particularly access to deciduous trees and bushes), traffic.
Approach for determining reference value(s)	Empirically supported expert knowledge: Demography + habitat availability models. One-sided indicator. Reference values for elk and red deer in the Norwegian Nature Index 2020 are estimated as the number of individuals per km^2 under the climatic treeline for each county. These reference values are calculated based on the amount of suitable area and potential density per species given natural populations of large predators.
Quantification of reference value(s)	The reference values reported for the indicators in the Norwegian Nature Index are used for the assessment of ecological condition (www.naturindeks.no).
Approach for determining the limit value for good ecological condition	Expert knowledge: Assumed linear relationship. Two-sided indicator. It is assumed that there is a relatively linear relationship between the population level of deer species and the significance of their ecological impact, down to a possible lower limit for the population. The simplified approach described in Nybø et al. (2018; chapter 3.2 and 6.3) is used such that the lower limit for good condition is set to a relative value of 0,6 of the reference value for the number of elk-equivalents/km^2. An upper limit value is used to take into account that populations of elk and red deer that are too large can have harmful effects on trees and other vegetation. Currently, the indicator is treated as a one-sided indicator: If the indicator estimate is lower than the reference value, the indicator is scaled towards the lower limit value, whereas indicator estimates higher than the reference value are scaled towards the upper limit value. Although the indicator in principle is two-sided, only one estimate is used in the assessment of ecological condition (cf. the indicators Ellenberg F, Ellenberg N and NDVI). Alternative approaches for this two-way indicator should be considered, especially in light of possible updated data (cf. Nybø et al. 2018, Framstad et al. 2021).
Quantification of the limit value for good ecological condition	The lower limit is calculated as 0,6* the reference value, and the upper limit is calculated as 1,4* the reference value.
Quantification of minimum and/or maximum values	The minimum value is defined as index value 0, which corresponds to total absence of the included indicator species. The maximum value is defined as index value 2. Any future adjustments of this indicator (cf. above) should also reconsider these minimum and maximum values.
References	Framstad, E., Berglund, H., Jacobsen, R.M., Jakobsson, S., Ohlson, M., Sverdrup-Thygeson, A. & Töpper, J. 2021. Vurdering av økologisk tilstand for skog i Norge i 2020. NINA Rapport 2000. Jakobsson, S. & Pedersen, B. (Eds) 2020. The Nature Index for Norway 2020. State and trends for Norwegian biodiversity. NINA Report 1886. Norwegian Institute for Nature Research. Kleiber, M. 1961. The fire of life: an introduction to animal energetics. Wiley, New York. Nybø, S., Evju, M., Framstad, E., Lyngstad, A., Pedersen, C., Sickel, H., Sverdrup-Thygeson, A., Töpper, J., Vandvik, V., Velle, L.G. & Aarrestad, P.A. 2018. Operasjonalisering av fagsystemet for økologisk tilstand for terrestriske økosystemer. Forslag til referanse- og grenseverdier for indikatorer som er klare eller nesten klare til bruk. NINA Rapport 1536. Norsk institutt for naturforskning.
Indicator	**Large carnivores**
Completion of the protocol	Simon Jakobsson (NINA)
Date filled out/ reviewed	28.03.2019/20.04.2021
Data source	Norwegian Nature Index 2020
Ownership and permissions	NINA and the Norwegian Environment Agency through the Norwegian Nature Index; permission is required for data extraction.
Description of raw data	The indicator is based on population estimates of lynx (*Lynx lynx*), brown bear (*Ursus arctos*) and wolves (*Canis lupus*) used in the Nature Index. Indicator values and reference values are reported to the

	Norwegian Nature Index 2020 database by those responsible for the indicator. Based on data from Rovdata (https://rovdata.no/). Values represent population levels for wolf, brown bear and lynx, as they are presented in the Norwegian Nature Index. The number of lynx is estimated as the number of family groups, whereas the number of brown bears and wolves are estimated as the number of individuals.
Description of data collection method and data structure	https://rovdata.no/ and www.naturindeks.no Lynx: Track and visual observations of family groups classified as "Documented" or "Assumed certain" in Rovbase from 1 October to 28 February, number of family groups estimated using distance criteria (Brøseth & Tovmo 2013). Data before 2014 are not directly comparable with data 2014-. For details, see Mattisson et al. (2020) and https://rovdata.no/. Bear: DNA analysis (Tobiassen et al. 2011) of excrement and hair samples of suspected bear-origin, as well as tissue samples from dead bears. For details, see Fløystad et al. (2020) and https://rovdata.no/. Wolf: Combination of tracking on snow, DNA analysis, GPS tracking, wildlife cameras, dead wolves. When the population size is calculated, wolf territory located across the national border is divided (50%) between Sweden and Norway. For details, see Wabakken et al. (2020), https://rovdata.no/ and www.naturvardsverket.se. Data are available per county (wolf, bear) or predator-region (lynx; previously also per county), but are aggregated per region in the Nature Index (cf. Jakobsson & Pedersen 2020) and here.
Description of the indicator	The indicator is a composite index (‘lynx equivalents’) for the abundance of lynx, brown bear and wolves, adjusted for their metabolic weights. Lynx-equivalents, converted from index values (0-1) and reference values (corresponding to 1), via the number of individuals, for each indicator species. Lynx-equivalents are based on the estimated average weight of the population (wolf: 38 kg; lynx: 18 kg; bear: 136 kg; Bjærvall & Ullstrøm 1997) and relationship between body weight and energy requirement: $E = W^{0,75}$, where E = metabolic weight and W = body weight (kg) (Kleiber 1961). Lynx: 1 lynx-equivalent = 1 lynx; converted from family groups, where 1 family group is estimated at 5.95 individuals. Brown bear: 1 lynx-equivalent = 1,48 bears. To factor in that bears have a diet that consists of approximately 75% plant matter and 25% meat, the metabolic weight is adjusted by a factor of 0,325 (25 + 7,5%), as the energy transfer from one trophic level to a higher trophic level is approximately 10%. Wolf: 1 lynx-equivalent = 1,75 wolves. For details, see Nybø et al. (2018).
Spatial representation/coverage	Data are not based on a statistical selection. The data for these predators are relatively comprehensive, including monitoring and other observations across the country. All available observation and monitoring data form the basis for estimation of population levels and are associated with Rovdata’s research activities as well as reporting to the Norwegian Nature Index 2020. For more information, see www.naturindeks.no
Geographical delimitation	All of Norway
Measurement unit	Relative units of total abundance in ‘lynx equivalents’.
Time period covered	1990, 2000, 2010, 2014, 2019
Frequency of data collection	In practice, every fifth year since 2010.
Additional description of data properties, if necessary	Large predators represent an important part of a well-functioning natural forest ecosystem by contributing to the regulation of deer populations, which, in turn reduces the grazing pressure. In its natural condition, the population levels of large predators will partly be dependent on access to prey, which, in turn is dependent on the production of fodder for deer and other herbivores. This food chain is particularly important for wolves and lynx, which are carnivores, whereas bears have a more versatile diet that also includes a significant amount of plant matter and invertebrates.

	An indicator based on the total number of large predators can sum up the approximated or estimated number of individuals per species. However, differences in body size and ecology will have an impact on nutritional needs and how these species affect the rest of the ecosystem.
Significance of the indicator in the ecosystem and ecological consequences of reduced indicator value (including references)	Large predators represent an important part of a well-functioning natural forest ecosystem by contributing to the regulation of deer populations, which, in turn reduces the grazing pressure. In the natural condition large predators may have an important role in regulation of food web dynamics.
Attribution to ecosystem characteristics	Distribution of biomass between trophic levels
- justification	Key predators in natural ecosystems
Correlations (collinearities) with other assessed indicators	No relevant correlations
Natural effects on the indicator	Access to prey (+ nutritional status/ productivity), intra-specific social interactions
Anthropogenic effects on the indicator (including references)	Hunting/harvest, indirect effects on prey
Approach for determining reference value(s)	Empirically supported expert knowledge: Demography + habitat availability models. One-sided indicator. Reference values for predators in the Norwegian Nature Index 2020 are estimated as the number of family groups per predator-region (lynx), and total number of individuals in the country (bear) or per county (wolf), in a Norway with intact nature and limited human impacts. These reference values are calculated from the amount of suitable area and potential density per species based on Lande et al. (2003), Støen et al. (2006) and J. Swenson (pers. comm.). The total reference value for the indicator, converted to lynx equivalents, is calculated using the same approximation as for the indicator values (see above).
Quantification of reference value(s)	The reference values reported for the indicators in the Norwegian Nature Index are used for the assessment of ecological condition (www.naturindeks.no).
Approach for determining the limit value for good ecological condition	Expert knowledge: Assumed linear relationship. One-sided indicator. It is assumed that there is a relatively linear relationship between the population level of predators and the significance of their ecological impact, down to a possible lower limit for the population. The simplified approach described in Nybø et al. (2018; chapter 3.2 and 6.4) is used such that the lower limit for good condition is set to a relative value of 0,6 of the reference value for the number of lynx-equivalents.
Quantification of the limit value for good ecological condition	The limit value is calculated as 0,6* the reference value, i.e., 60% of the reference value.
Quantification of minimum and/or maximum values	The minimum value is defined as index value 0, which corresponds to total absence of all the included indicator species in the indicator.
References	Bjärvall, A. & Ullström, S. 1997. Pattedyr. Alle Europas arter i tekst og bilde J. W. Cappelens Forlag Brøseth, H. & Tovmo, M. 2013. Antall familiegrupper, bestandsestimat og bestandsutvikling for gaupe i Norge i 2013. NINA Rapport 960.Fløystad, I., Brøseth, H., Bakke, B. B., Eiken, H. G., Hagen, S. B. 2020. Populasjonsovervåking av brunbjørn. DNA-analyse av prøver innsamlet i Norge i 2019. NINA Rapport 1808. Norsk institutt for naturforskning.Jakobsson, S. & Pedersen, B. (Eds) 2020. The Nature Index for Norway 2020. State and trends for Norwegian biodiversity. NINA Report 1886. Norwegian Institute for Nature Research. Jakobsson, S. & Pedersen, B. (red.) 2020. The Nature Index for Norway 2020. State and trends for Norwegian biodiversity. NINA Report 1886. Kleiber, M. 1961. The fire of life: an introduction to animal energetics. Wiley, New York. Lande, U.S., Linnell, J.D.C., Herfindal, I., Salvatori, V., Brøseth, H., Andersen, R., Odden, J., Andrén, H., Karls-son, J., Willebrand, T., Persson, J., Landa, A., May, R., Dahle, B. & Swenson, J. 2003.

	Potensielle leveområ-der for store rovdyr i Skandinavia: GIS-analyser på et økoregionalt nivå. Utredninger i forbindelse med ny rovviltmelding. NINA Fagrapport 64. Mattisson, J., Brøseth, H. & Nilsen, E.B. 2020. Antall familiegrupper, bestandsestimat og bestandsutvikling for gaupe i Norge i 2020. NINA Rapport 1846. Nybø, S., Evju, M., Framstad, E., Lyngstad, A., Pedersen, C., Sickel, H., Sverdrup-Thygeson, A., Töpper, J., Vandvik, V., Velle, L.G. & Aarrestad, P.A. 2018. Operasjonalisering av fagsystemet for økologisk tilstand for terrestriske økosystemer. Forslag til referanse- og grenseverdier for indikatorer som er klare eller nesten klare til bruk. NINA Rapport 1536. Norsk institutt for naturforskning Støen, O.-G., Zedrosser, A., Sæbø, S. & Swenson, J.E. 2006. Inversely density-dependent natal dispersal in brown bears Ursus arctos. Oecologia 148:356-364. Tobiassen C., Brøseth H., Bergsvåg M., Aarnes S.G., Bakke B.B., Hagen S., Eiken H.G. 2011. Populasjonsover-våking av brunbjørn 2009-2012: DNA analyse av prøver samlet i Norge i 2010. Bioforsk rapport 49: 1 Wabakken, P., Svensson, L., Maartmann, E., Nordli, K., Flagstad, Ø. & Åkesson, M. 2020. Bestandsovervåking av ulv vinteren 2019-2020. Inventering av varg vintern 2019-2020. Bestandsstatus for store rovdyr i Skandi-navia. Beståndsstatus för stora rovdjur i Skandinavien 1-2020. 55 s.
Indicator	**Nature index for forests**
Completion of the protocol	Simon Jakobsson (NINA)
Date filled out/ reviewed	20.04.2021
Data source	Norwegian Nature Index 2020
Ownership and permissions	NINA and the Norwegian Environment Agency through the Norwegian Nature Index; permission is required for data extraction.
Description of raw data	Indicator values and reference values are reported to the Norwegian Nature Index 2020 database by those responsible for the indicator. Based on either monitoring data, modelling, or expert assessments.
Description of data collection method and data structure	www.naturindeks.no and Jakobsson & Pedersen (2020). Observations for indicators are made on different levels (municipal – national scale). Standard calculations of the Norwegian Nature Index are done per region (the same regional divisions as in the assessment of ecological condition per 2021).
Description of the indicator	The indicator is an index with values between 0 and 1, estimated as a weighted average of more than 80 individual indicators. See Jakobsson & Pedersen (2020) and www.naturindeks.no for details.
Spatial representation/coverage	Varies between indicators. Calculations take differences in area representativeness into account. For more information, see www.naturindeks.no
Geographical delimitation	All of Norway, although the geographical representation of underlying data varies with the included indicators.
Measurement unit	Scaled index value between 0 and 1
Time period covered	1990, 2000, 2010, 2014, 2019
Frequency of data collection	In practice, every fifth year since 2010.
Additional description of data properties, if necessary	The nature index measures the state of biological diversity in seven main ecosystems: forests, mountains, wetlands, semi-natural areas, freshwater, coastal waters and oceans. The condition index is based on a selection of indicator species associated with one or more of the main ecosystems. Challenges are associated with a lack of indicator coverage and resolution of data in some areas and ecosystems.

Significance of the indicator in the ecosystem and ecological consequences of reduced indicator value (including references)	The indicator aggregates the relative abundances for a large number of species and indirect indicators of biodiversity and, hence, provides a robust overall measure of condition for biodiversity.
Attribution to ecosystem characteristics	Biological diversity
- justification	Aggregates abundance information for a large number of species and indirect measures of biodiversity.
Correlations (collinearities) with other assessed indicators	Some separate condition indicators are also included in the nature index for forests but these are rather few and show limited correlation to the overall nature index.
Natural effects on the indicator	See www.naturindeks.no
Anthropogenic effects on the indicator (including references)	See www.naturindeks.no For an evaluation of ecological condition in forest (see Framstad et al. 2021) the indicator is linked to the effects of climate and land use, as these factors have the greatest effect on the value of the Nature Index (cf. Jakobsson & Pedersen 2020).
Approach for determining reference value(s)	Varies. Indicator reference values in the Norwegian Nature Index relate to the same conceptual ecosystem reference condition ('intact nature') as in the System for assessment of ecological condition. See www.naturindeks.no for more information.
Quantification of reference value(s)	The reference values reported for the indicators in the Norwegian Nature Index are used for the assessment of ecological condition (www.naturindeks.no).
Approach for determining the limit value for good ecological condition	Expert knowledge: Assumed linear relationship. One-sided indicator.
Quantification of the limit value for good ecological condition	The limit value is calculated as 0,6* the reference value, i.e., index value 0,6.
Quantification of minimum and/or maximum values	The minimum value is defined as index value 0, which corresponds to the total absence of species-based indicators in the Norwegian Nature Index.
References	Framstad, E., Berglund, H., Jacobsen, R.M., Jakobsson, S., Ohlson, M., Sverdrup-Thygeson, A. & Töpper, J. 2021. Vurdering av økologisk tilstand for skog i Norge i 2020. NINA Rapport 2000. Jakobsson, S. & Pedersen, B. (Eds) 2020. The Nature Index for Norway 2020. State and trends for Norwegian biodiversity. NINA Report 1886. Norwegian Institute for Nature Research.
Indicator	**Area without technical infrastructure**
Completion of the protocol	Simon Jakobsson (NINA)
Date filled out/ reviewed	28.03.2019/01.06.2019/20.04.20
Data source	The 'Inngrepsfri Natur i Norge'('Infrastructure-free areas') dataset by the Norwegian Environment Agency can be downloaded via Geonorge's map catalogue.
Ownership and permissions	Owner: The Norwegian Environment Agency. License: Norwegian licence for public data (NLOD) 2.0
Description of raw data	Vector map. The dataset shows which areas in Norway are not affected by significant technical infrastructure. Infrastructure-free nature is defined as areas which are at least one kilometre away from major technical infrastructure such as roads, large powerlines, railways, and technical interventions in waterways etc (buildings are not included).
Description of data collection method and data structure	Modelled, nationwide data based on base maps such as N50. https://kartkatalog.miljodirektoratet.no/Dataset/Details/100 Observations/ measurements are made per registration site; each site is 250 m^2.
Description of the indicator	The indicator is the proportion of the area at least 1 km away from major technical infrastructure
Spatial representation/coverage	Complete coverage

Geographical delimitation	Complete coverage for Norway
Measurement unit	Proportion of area at least 1 km away from major infrastructure
Time period covered	1988, 1998, 2003, 2008, 2013, 2018
Frequency of data collection	Currently updated every 5 years.
Additional description of data properties, if necessary	The dataset does not provide uncertainty related to the delimitations of polygons.
Significance of the indicator in the ecosystem and ecological consequences of reduced indicator value (including references)	Infrastructure-free areas are areas with little anthropogenic activity and where highly mobile species have greater freedom of movement. A reduction in this area indicates a larger human footprint, and human infrastructure can affect movement patterns of mobile species such as reindeer.
Attribution to ecosystem characteristics	Landscape ecological patterns
- *justification*	The indicator quantifies how much of the area that is distant from human infrastructure. In principle, areas without infrastructure reflect a more natural condition than areas with infrastructure. However, the value of these infrastructure-free areas for biodiversity will also be dependent on other factors which affect environmental condition.
Correlations (collinearities) with other assessed indicators	No relevant correlations
Natural effects on the indicator	The indicator is unaffected by natural variation.
Anthropogenic effects on the indicator (including references)	The indicator is affected by infrastructure development.
Approach for determining reference value(s)	Absolute biophysical boundaries. A reference state, defined as intact nature, entails a complete absence of modern infrastructure such as roads, railways, power lines, buildings etc.
Quantification of reference value(s)	The reference value of the indicator assumes that the entire area (100%) of the ecosystem is <1 km from infrastructure.
Approach for determining the limit value for good ecological condition	Empirically supported expert knowledge. One-sided indicator. Larger contiguous natural areas are important as habitats and migration corridors for species, especially those that are adapted to large areas that are in or close to their natural state, as well as species that are particularly vulnerable to edge effects or other disturbances. Intact nature is also important for nature's ability to adapt to climate change, e.g., infrastructure creates additional barriers for the movement of species to areas with more suitable climates. However, the importance of intact nature for biodiversity will also depend on other impacts on the ecosystem. How much the proportion of intact nature can be reduced before there are negative effects on ecological condition depends on several factors, e.g., how large the area is in the first place, how the loss of intact nature is distributed, and the natural degree of fragmentation for the relevant ecosystem in the region. Various studies indicate that fragmentation that reduces the original area down to 20-40% will have a greater negative effect on affected species than a reduction in habitat alone would suggest. If we assume that this represents a boundary between moderate and poor condition, and that the relationship between the indicator and ecological condition is linear down to this boundary, the limit value for good condition can be set to 60% of the reference value. Also see the reasoning in chapter 3.2 and 4.1 in Nybø et al. 2018.
Quantification of the limit value for good ecological condition	The limit value is calculated as 0,6* the reference value, i.e., 60%.
Quantification of minimum and/or maximum values	The minimum value is defined as the total absence of intact nature (0%).
References	https://www.miljodirektoratet.no/ansvarsomrader/overvaking-arealplanlegging/naturkartlegging/Inngrepsfrie-naturomrader/ Nybø, S., Evju, M., Framstad, E., Lyngstad, A., Pedersen, C., Sickel, H., Sverdrup-Thygeson, A., Töpper, J., Vandvik, V., Velle, L.G. &

	Aarrestad, P.A. 2018. Operasjonalisering av fagsystemet for økologisk tilstand for terrestriske økosystemer. Forslag til referanse- og grenseverdier for indikatorer som er klare eller nesten klare til bruk. NINA Rapport 1536. Norsk institutt for naturforskning

Appendix 2: Technical documentation of mountain indicators

Indicator	**NDVI trend**
Completion of the protocol	Joachim Töpper
Date filled out/ reviewed	09.12.2021
Data source	MOD13Q1 V6 Terra Vegetation Indices 16-Day Global 250m
Ownership and permissions	Public, MODIS data and products acquired via NASA's Land Processes Distributed Active Archive Centre (LP DAAC) have no limitations for use, sale or redistribution.
Description of raw data	The MOD13Q1 V6-product provides a vegetation index (VI) value per pixel. MODIS NDVI is calculated from atmospherically corrected bi-directional surface reflectances that have been masked for water, clouds, heavy aerosols and cloud shadows. The algorithm chooses the best available pixel-value from a 16-day period (see "Frequency of data collection" below). The criteria used are low clouds, low view angle, and the highest NDVI value. NDVI ranges between –1 and 1 and is calculated as NDVI = (NIR-Red) / (NIR+Red), where NIR is near-infrared light and Red is visible red light. See https://lpdaac.usgs.gov/products/mod13q1v006/
Description of data collection method and data structure	NASA's Terra satellite carries MODIS (Moderate-resolution Imaging Spectroradiometer) and passes over the earth every 1-2 days. Data are global with a 250 m resolution.
Description of the indicator	The indicator is the slope of a regression of mean NDVI values per MODIS pixel for June-September against year 2000–2019¸ based on a random selection of 25,000 MODIS pixels covering mountains. This is a two-sided indicator where values both lower and higher than the reference value may indicate degraded ecosystem condition.
Spatial representation/coverage	Global coverage at 250 m resolution
Geographical delimitation	Total coverage of Norway
Measurement unit	Slope of NDVI per pixel versus time for the period 2000-2019.
Time period covered	2000-2019
Frequency of data collection	The MODIS sensor collects data every 1-2 days, but this data product chooses the best available pixel value in a 16-day period (i.e., a 16-day cycle).
Additional description of data properties, if necessary	The spectral reflectance of vegetation over the different bands measured by the MODIS-sensor acts an indicator of the vegetation and its condition, or "health". NDVI is a combination of two of these bands (near infrared and visible red light) which improves the contrast between vegetation (high reflectance) and non-vegetation (low reflectance), and quantifies plant properties such as density, biomass, photosynthetic activity and stress.
Significance of the indicator in the ecosystem and ecological consequences of reduced indicator value (including references)	NDVI provides a direct signal of "greenness" and thus the quantity of chlorophyll. An increase or reduction in NDVI indicates an increase or reduction in primary production.
Attribution to ecosystem characteristics	Primary production. Distribution of biomass between trophic levels.
- justification	NDVI is directly relevant to both factors.
Correlations (collinearities) with other assessed indicators	Ellenberg N may be affected by increased productivity.
Natural effects on the indicator	Local environmental variation.
Anthropogenic effects on the indicator (including references)	Climate change (increased temperature results in increased NDVI, drought may decrease it). Land use (degradation or overgrazing lowers NDVI). Pollution (nitrogen deposition may increase NDVI).

Approach for determining reference value(s)	Absolute biophysical boundaries.
Quantification of reference value(s)	Reference value set at 0, i.e., no systematic change in NDVI over time.
Approach for determining the limit value for good ecological condition	Statistical distribution, two-way indicator. Distribution of slopes in regression models of NDVI versus randomised time for every pixel.
Quantification of the limit value for good ecological condition	Upper and lower limit values are given as 0.025 and 0.975 quantiles in the reference distribution (i.e., 95% confidence interval for a two-way indicator).
Quantification of minimum and/or maximum values	Minimum/maximum values are defined based on minimum and maximum values of the reference distribution.
References	Pettorelli, N., Vik, J.O., Mysterud, A., Gaillard, J.-M., Tucker, C.J. & Stenseth, N.C. 2005. Using the satellite derived NDVI to assess ecological responses to environmental change. Trends in Ecology and Evolution 20: 503–510.
Indicator	**Reindeer**
Completion of the protocol	Anders L. Kolstad
Date filled out/ reviewed	10.12.2021
Data source	Kjørstad et al. (2017) for the current population of wild reindeer and reinbase.no for domestic reindeer. The Terrain Ruggedness Index is calculated from the Norwegian Mapping Authority's (Kartverket) 10 m DEM.
Ownership and permissions	Reinbase.no and published public data.
Description of raw data	Population estimates are given as total numbers per defined reindeer area (with georeferenced maps). The Terrain Ruggedness Index is calculated from the 10 m DEM according to Riley et al. (1999).
Description of data collection method and data structure	The population estimates come from slightly different sources, including direct counts and estimates for wild reindeer and reported figures for domestic reindeer.
Description of the indicator	The indicator is given as the density of wild or domestic reindeer for all defined reindeer areas based on the total populations within these areas and the size of the areas.
Spatial representation/coverage	Complete coverage
Geographical delimitation	The whole mountain area
Measurement unit	Reindeer per square kilometre
Time period covered	The last 5 years.
Frequency of data collection	Annually for domestic reindeer. Sporadically for wild reindeer.
Additional description of data properties, if necessary	
Significance of the indicator in the ecosystem and ecological consequences of reduced indicator value (including references)	Reindeer are the largest grazing animals in the mountains and therefore play a key role in grazing effects on the vegetation. Reindeer are also important prey for top predators and a food source for scavengers.
Attribution to ecosystem characteristics	Distribution of biomass between trophic levels Functional composition within trophic levels Functionally important species and biophysical structures
- justification	See above.
Correlations (collinearities) with other assessed indicators	No strong correlations.
Natural effects on the indicator	The population level of reindeer in the reference condition can vary greatly due to weather conditions in winter and spring.
Anthropogenic effects on the indicator (including references)	Reindeer are affected by hunting, predator regulation, fragmentation and habitat degradation. The introduction of the prion disease Chronic wasting disease (CWD) can potentially have a major impact on the species.

Approach for determining reference value(s)	The reference value is an estimated density of wild reindeer for all mountain areas under the reference condition. This reference density is based on the empirical relationship between the density of the management targets for the wild reindeer populations (Kjørstad et al. 2017) and the variation in the terrain in wild reindeer areas (measured by the Terrain Ruggedness Index (TRI), Riley et al. 1999), given by the formula Reference density = 1.0759 * EXP (-0.001 * TRI). This relationship is assumed to apply to all mountain areas, including domestic reindeer areas and mountain areas currently without reindeer. The total reference population for wild reindeer can be calculated given the area of the mountain areas and the areas' average TRI values. In addition, we have assumed that natural populations of large predators will lead to a somewhat lower density in the reference condition than is specified for the management targets given in Kjørstad et al. (2017). The reference density given by the formula above is therefore reduced by 25%.
Quantification of reference value(s)	See above.
Approach for determining the limit value for good ecological condition	This is a two-sided indicator, where both low and high reindeer populations can indicate a deviation from the reference condition. Lower and upper limit values have therefore been determined for the indicator, given as 60% and 200% of the reference value, respectively. An asymmetric scaling function is based on the assumption that lower densities have greater effects on the ecosystem than higher densities.
Quantification of the limit value for good ecological condition	The lower limit value has been set to 60% of the reference value, while the upper limit value has been set to 200% of the reference value.
Quantification of minimum and/or maximum values	The minimum value has been set to 0 and the maximum value has been set to 10 times the reference value.
References	Kjørstad, M., Bøthun, S.W., Gundersen, V., Holand, Ø., Madslien, K., Mysterud, A., Myren, I.N., Punsvik, T., Røed, K.H., Strand, O., Tveraa, T., Tømmervik, T., Ytrehus, B. & Veiberg, V. (red.) 2017. Miljøkvalitetsnorm for villrein. Forslag fra en ekspertgruppe. NINA Rapport 1400. Riley, S.J., DeGloria, S.D. & Elliot, R.1999. A terrain ruggedness index that quantifies topographic heterogeneity, Intermountain Journal of Sciences 5: 23–27. www.reinbase.no
Indicator	**Small rodents**
Completion of the protocol	Anders L. Kolstad
Date filled out/ reviewed	08.12.2021
Data source	Data have been obtained from the Nature Index, based on multiple data sources, e.g., the terrestrial nature monitoring program (TOV).
Ownership and permissions	Variable (see above). Data from TOV are owned by the Norwegian Environment Agency.
Description of raw data	Trapping data of small rodents from selected monitoring sites, including the TOV sites, Finse, and published data series in Ehrich et al. (2020), supplemented with other quantitative and qualitative information about the occurrence of small rodent population peaks in mountain areas. Data and qualitative information are aggregated for groups of counties to represent regional data.
Description of data collection method and data structure	See above.
Description of the indicator	The indicator is the average abundance for population peaks in the small rodent community (mainly of lemmings and root voles) in mountain areas over the last 10-year period (currently 2010-2019).
Spatial representation/coverage	The data come from actual catch data from a limited number of small (about 1 km^2) study sites. These are distributed in mountain areas (mainly in the low alpine zone) across the country.
Geographical delimitation	Set to be valid for the entire mountain area but excluding coastal mountains in the west and north.

Measurement unit	Average population peaks per 10 years, as catch per 100 trapping nights.
Time period covered	1990-2019
Frequency of data collection	Annually, with five years between each compilation in the Nature Index.
Additional description of data properties, if necessary	The data are specified for zones/regions which do not match those used in ecological condition.
Significance of the indicator in the ecosystem and ecological consequences of reduced indicator value (including references)	Small rodents are a very important functional group with large effects on vegetation and other animal species. Population fluctuations of small rodents drive coinciding fluctuations in predator populations such as stoats, weasels, arctic foxes and rough-legged buzzards, and to some extent populations of alternative prey species.
Attribution to ecosystem characteristics	Distribution of biomass between trophic levels Functional composition within trophic levels Functionally important species and biophysical structures
- *justification*	Small rodents represent one group of important herbivores in the mountains and are part of important food chains. Small rodents are a functionally important group that drives population dynamics of several other species.
Correlations (collinearities) with other assessed indicators	Small rodents is one of 28 indicators in the ecosystem condition indicator *nature index for mountains (modified)*.
Natural effects on the indicator	Small rodents are mainly influenced by natural variation in weather, climate, plant nutritional quality and predation pressure.
Anthropogenic effects on the indicator (including references)	Small rodents are negatively affected by climate change, particularly the increasing frequency of unstable winters with variable extent and quality of snow cover.
Approach for determining reference value(s)	The reference value is based on an idealised population variation with an empirical basis in long-term studies and observations from Finse and other mountain areas.
Quantification of reference value(s)	The reference value varies between 10 regions.
Approach for determining the limit value for good ecological condition	The limit value is set at 60% of the reference value.
Quantification of the limit value for good ecological condition	
Quantification of minimum and/or maximum values	The minimum value is set to zero.
References	Ehrich, D., Schmidt, N.M., Gauthier, G., et al. 2020. Documenting lemming population change in the Arctic: Can we detect trends? Ambio 49: 786–800. https://doi.org/10.1007/s13280-019-01198-7 Framstad, E. & Eide, N.E. 2021. Smågnagere. NINA Rapport 1972: 90-98.
Indicator	**Willow grouse**
Completion of the protocol	Anders L. Kolstad
Date filled out/ reviewed	08.12.2021
Data source	Hønsefuglportalen (https://honsefugl.nina.no/innsyn) – a website for information on census results for game birds (Tetraonidae, mainly willow grouse and ptarmigan)
Ownership and permissions	Hønsefuglportalen is owned by the Norwegian Institute for Nature Research.
Description of raw data	The dataset is based on transect sampling in willow grouse habitat in August. As of 2020, there are 181 assessment areas in 75 municipalities (Nilsen & Rød-Eriksen 2020).
Description of data collection method and data structure	See above.
Description of the indicator	The indicator is the density of adult birds per km^2 in August, as a mean for the last 5 years

Spatial representation/coverage	Nation-wide, but there are few assessment areas in western and southern Norway.
Geographical delimitation	Set to be valid for all mountain areas.
Measurement unit	Average density of adult individuals over the last five years.
Time period covered	2010-2020
Frequency of data collection	Annually
Additional description of data properties, if necessary	The data are population estimates (posterior distribution) from a model similar to the one in Nilsen & Rød-Eriksen (2020) but with a regional division which corresponds to the one used here.
Significance of the indicator in the ecosystem and ecological consequences of reduced indicator value (including references)	Willow grouse are important herbivores and prey in the mountains and around the forest boundary.
Attribution to ecosystem characteristics	Distribution of biomass between trophic levels Functional composition within trophic levels
- *justification*	Willow grouse are one of several herbivores which are part of important food chains in the mountains.
Correlations (collinearities) with other assessed indicators	Willow grouse is one of 28 indicators in the ecosystem condition indicator *nature index for mountains (modified)*. Fluctuations in the population sizes of willow grouse have previously been shown to be associated with fluctuations in small rodent populations, where years with peak small rodent populations resulted in greater survival in grouse populations.
Natural effects on the indicator	Willow grouse are affected by several natural factors which result in population fluctuations in both the short and long term.
Anthropogenic effects on the indicator (including references)	Willow grouse are primarily affected by hunting, but also by climate change.
Approach for determining reference value(s)	Expert evaluation
Quantification of reference value(s)	The reference density is set to 36 birds per km^2 in all suitable willow grouse habitat.
Approach for determining the limit value for good ecological condition	The limit value is set to 60% of the reference value.
Quantification of the limit value for good ecological condition	
Quantification of minimum and/or maximum values	The minimum value is set to zero.
References	Nilsen, E.B. & Rød-Eriksen, L. 2020. Trends in the size of the Norwegian willow ptarmigan population 2009-2020: Analyses based on data in Hønsefuglportalen. NINA Report 1869.
Indicator	**Ptarmigan**
Completion of the protocol	Anders L. Kolstad
Date filled out/ reviewed	08.12.2021
Data source	TOV-E (https://tov-e.nina.no/Fugl/Default.aspx) – nation-wide, spatially representative monitoring of breeding birds
Ownership and permissions	TOV-E is owned by the Norwegian Environment Agency
Description of raw data	The data come from transect sampling in fixed quadrats in the mountains in the breeding season; for all ecosystems, a total of just under 500 quadrats are stratified randomly selected from a systematic grid of Norway (Kålås et al. 2021).
Description of data collection method and data structure	See above.
Description of the indicator	The indicator is a relative abundance index where annual values are scaled to the abundance in 2010, as a mean for the last 5 years
Spatial representation/coverage	Spatially representative due to a systematic data collection design.

Geographical delimitation	Set to be valid for all mountainous areas.
Measurement unit	Relative population abundance scaled towards the index year 2010.
Time period covered	2010-2020
Frequency of data collection	Annually
Additional description of data properties, if necessary	The relative population change is estimated using TRIM-analysis.
Significance of the indicator in the ecosystem and ecological consequences of reduced indicator value (including references)	Ptarmigan is an important herbivore and prey in the mountains.
Attribution to ecosystem characteristics	Distribution of biomass between trophic levels Functional composition within trophic levels
- justification	Ptarmigans are one of several herbivores which are part of important food chains in the mountains.
Correlations (collinearities) with other assessed indicators	Ptarmigans are one of 28 indicators in the ecosystem condition indicator *nature index for mountains (modified)*. Fluctuations of ptarmigan populations have previously been shown to be associated with fluctuations in small rodent populations, where years of peak small rodent populations resulted in greater survival in ptarmigan populations.
Natural effects on the indicator	Ptarmigans are affected by several natural factors which result in population fluctuations in both the short and long term.
Anthropogenic effects on the indicator (including references)	Ptarmigans are sensitive to changes in climatic factors such as temperature, precipitation and timing of snowmelt. The species is also affected by hunting.
Approach for determining reference value(s)	Expert evaluation
Quantification of reference value(s)	The reference value is taken from the Nature Index where it is specified as 8 breeding individuals per km^2 of suitable ptarmigan habitat (see https://www.naturindeks.no/Indicators/fjellrype). To convert the relative population abundance into scaled indicator values we multiplied the relative scores with the value that the indicator had in the Nature Index in 2010, which was the index year in the TRIM analysis. The scaled indicators were truncated above the value 1.
Approach for determining the limit value for good ecological condition	The limit value is set at 60% of the reference value.
Quantification of the limit value for good ecological condition	See above.
Quantification of minimum and/or maximum values	The minimum value is set to zero.
References	Kålås, J.A., Øien, J.I., Stokke, B.G. & Vang, R. 2021. Ekstensiv overvåking av hekkebestander av fugl – TOV-E. I Framstad, E. (red.) Terrestrisk naturovervåking i 2020: Markvegetasjon, epifytter, smågnagere og fugl. Sammenfatning av resultater. NINA Rapport 1972: 121–132.
Indicator	**Arctic fox**
Completion of the protocol	Anders L. Kolstad
Date filled out/ reviewed	08.12.2021
Data source	Monitoring programme for Arctic fox (Eide et al. 2020).
Ownership and permissions	The national monitoring programme for Arctic fox is financed by the Norwegian Environment Agency and is reported to Rovbase (https://www.rovbase.no/).
Description of raw data	The number of reproductive individuals of Arctic fox in mountain areas of each municipality is based on estimates from a closed catch-release model with data on unique individuals in the national Arctic fox monitoring programme (2010-2019). Expert evaluation of observation and historic data before 2010.

Description of data collection method and data structure	Visits to known den locations, combined with DNA-analyses and population modelling. See Eide et al. 2020.
Description of the indicator	The indicator is a 3-year running mean for the number of reproductive individuals of Arctic fox in each municipality.
Spatial representation/coverage	The data cover all mountain areas with historic occurrence of Arctic fox.
Geographical delimitation	All mountain areas (with occurrence of Arctic fox since 1950). Suitable habitat: low alpine and mid-alpine zones.
Measurement unit	Average number of reproductive individuals over the last three years.
Time period covered	2010-2019. Expert evaluation for 1950, observation-based for 1990, 2000, 2010.
Frequency of data collection	Annually after 2010
Additional description of data properties, if necessary	
Significance of the indicator in the ecosystem and ecological consequences of reduced indicator value (including references)	Arctic foxes are alpine meso-predators, and a reduced population will result in a reduced predation pressure, particularly on small rodents.
Attribution to ecosystem characteristics	Distribution of biomass between trophic levels Functional composition within trophic levels
- *justification*	Fewer Arctic foxes can often be explained by increased competition from red fox, which is in the same trophic group. The arctic fox represents a characteristic element in the food chain for mammals in the mountains.
Correlations (collinearities) with other assessed indicators	Arctic fox is one of the 28 indicators for the ecosystem condition indicator *nature index for mountains (modified).* Reproduction in Arctic foxes are closely related to small rodent (especially lemming) population peaks.
Natural effects on the indicator	Arctic foxes are affected by natural fluctuations in the small rodent populations and the availability of carrion (probably reindeer in particular) which can be a sporadic resource.
Anthropogenic effects on the indicator (including references)	Arctic foxes are affected by hunting for their fur which occurred in the past. They are also affected by climate change, particularly where it has a negative effect on small rodents. Land use change occurring as a result of cabin construction also has a negative effect.
Approach for determining reference value(s)	Estimated occurrence in 1950 is set at 10% of the reference condition.
Quantification of reference value(s)	Variable between municipalities.
Approach for determining the limit value for good ecological condition	The limit value is set at 60% of the reference value.
Quantification of the limit value for good ecological condition	
Quantification of minimum and/or maximum values	The minimum value is set to zero.
References	Eide, N.E., Ulvund, K., Kleven, O., Landa, A. & Flagstad, Ø. 2020. Fjellrev i Norge 2020. Resultater fra det nasjonale overvåkingsprogrammet for fjellrev. NINA Rapport 1913.
Indicator	**Wolverine**
Completion of the protocol	Anders L. Kolstad
Date filled out/ reviewed	08.12.2021
Data source	Rovdata (https://rovdata.no/) – the official website for information on large predators. Data are downloaded from the Nature Index.
Ownership and permissions	Rovdata.
Description of raw data	The dataset contains the number of individuals of wolverine in the large predator regions of Norway. The values for 2014 and 2019 are model-based estimates from Bischof et al. (2019). The values for 1990, 2000 and 2010 are expert assessments in the form of predictions derived from a regression model of the number of annual reproductions and the

	number of individuals in the large predator regions. The estimate of the number of reproductions in 1990 is based on an assessment of the number of reproductions reported annually by the county governor's environmental protection departments between 1990-1994. For 2000 and 2010, the number of reproductions is taken from the annual status reports from the national monitoring program for large predators (www.rovdata.no). The uncertainty in the indicator values for these years takes the uncertainty in the original estimates in the parameters of the regression model and in the predictions of the model into account.
Description of data collection method and data structure	See above
Description of the indicator	The indicator is the estimated number of individuals per mountain region.
Spatial representation/coverage	The data covers all wolverine habitats.
Geographical delimitation	All mountain regions.
Measurement unit	Number of individuals.
Time period covered	1990-2019
Frequency of data collection	Data in the Nature Index are currently updated every 5 years.
Additional description of data properties, if necessary	
Significance of the indicator in the ecosystem and ecological consequences of reduced indicator value (including references)	The wolverine is a predator and a scavenger. A reduced wolverine population will affect populations of their prey, particularly reindeer, both in terms of their population number and changes in their behaviour. In addition, more carrion will be available for other animals such as red fox, golden eagle, and crows.
Attribution to ecosystem characteristics	Distribution of biomass between trophic levels Functional composition within trophic levels
- *justification*	Wolverines are one of two important top-predators in the mountains today. Wolverines are part of several important food chains in the mountains.
Correlations (collinearities) with other assessed indicators	Wolverines are also one of 28 indicators for the ecosystem condition indicator *nature index for mountains (modified)*.
Natural effects on the indicator	Wolverines are affected by natural fluctuations in their prey, particularly reindeer.
Anthropogenic effects on the indicator (including references)	Wolverines are mainly affected by population regulation (removal of litters or adults).
Approach for determining reference value(s)	The reference condition for wolverines is calculated from the amount of suitable habitat in the different counties and the potential density of reproductive units (Lande et al. 2003).
Quantification of reference value(s)	See above.
Approach for determining the limit value for good ecological condition	The limit value is set at 60% of the reference value.
Quantification of the limit value for good ecological condition	
Quantification of minimum and/or maximum values	The minimum value is set at zero.
References	Bischof, R., Milleret, C., Dupont, P., Chipperfield, J., Brøseth, H., & Kindberg, J. 2019. RovQuant: Estimating density, abundance and population dynamics of bears, wolverines, and wolves in Scandinavia. MINA fagrapport 63. Lande, U.S., Linnell, J.D.C., Herfindal, I., Salvatori, V., Brøseth, H., Andersen, A., Odden, J., Andrén, H., Karlsson, J., Willebrand, T., Persson, J., Landa, A., May, R., Dahle, B. & Swenson, J. 2003. Utredninger i forbindelse med ny rovviltmelding. Potensielle leveområder for store rovdyr i Skandinavia: GIS-analyser på et økoregionalt nivå. NINA Fagrapport 064.

Indicator	**Golden eagle**
Completion of the protocol	Anders L. Kolstad
Date filled out/ reviewed	08.12.2021
Data source	Model for the calculation of the number of territories based on data from Rovdata (https://rovdata.no/) (Mattisson et al. 2020).
Ownership and permissions	Rovdata owns the raw data. Population estimates are published in Mattisson et al. (2020).
Description of raw data	Golden eagle territories have been registered for several years and documented in Rovdata. Some of these territories have also been monitored to see if they are inhabited. These data have been used to run models to estimate how many of the total number of territories are inhabited.
Description of data collection method and data structure	Data collection from nesting sites is carried out by SNO and amateurs. Monitoring is coordinated by SNO and is divided into one intensive and one extensive programme. See https://rovdata.no/Kongeørn.aspx
Description of the indicator	The indicator is the estimated number of occupied territories for the period 2015-2019.
Spatial representation/coverage	The extensive monitoring programme of breeding populations of golden eagle is designed to cover all of Norway but is not able to cover all breeding territories.
Geographical delimitation	All of Norway minus a few areas in SE (Akershus, Østfold, Oslo)
Measurement unit	Number of territories.
Time period covered	2015-2019
Frequency of data collection	The modelling has been done for two time periods at 5-year intervals. Only the last time period is included here.
Additional description of data properties, if necessary	-
Significance of the indicator in the ecosystem and ecological consequences of reduced indicator value (including references)	The golden eagle is a top predator in the mountains and will kill medium-sized mammals and birds (incl. grouse). Golden eagles are also opportunistic scavengers and profit from large numbers of reindeer.
Attribution to ecosystem characteristics	Distribution of biomass between trophic levels Functional composition within trophic levels
- *justification*	Golden eagles are part of several important food chains in the mountains.
Correlations (collinearities) with other assessed indicators	Golden eagles are one of 28 indicators for the ecosystem condition indicator *nature index for mountains (modified)*.
Natural effects on the indicator	Golden eagles are affected by natural fluctuations in their food supply.
Anthropogenic effects on the indicator (including references)	Golden eagles are negatively affected by development and infrastructure, as well as associated anthropogenic activities in the mountains.
Approach for determining reference value(s)	The reference condition is the same as in the Nature Index where the current population is set at 90% of the reference value. This is based on expert assessments. There are different reference values for northern Norway and southern Norway (south of Nordland).
Quantification of reference value(s)	See above.
Approach for determining the limit value for good ecological condition	The limit value is set at 60% of the reference value.
Quantification of the limit value for good ecological condition	
Quantification of minimum and/or maximum values	The minimum value is set to zero.
References	Mattisson, J., Nilsen, E. & Brøseth, H. 2020. Estimering av antall hekkende par kongeørn basert på kjent forekomst i Norge for perioden 2015–2019. NINA Rapport 1858.

Indicator	**Absence of alien species**
Completion of the protocol	Joachim Töpper
Date filled out/ reviewed	09.12.2021
Data source	Geographically representative nature monitoring (ANO) (Tingstad et al. 2019)
Ownership and permissions	ANO is owned by the Norwegian Environment Agency
Description of raw data	The total cover (%) in 250 m^2 ANO-points of alien vascular plants in the very high risk (SE), high risk (HI) and potentially high risk (PH) categories, following the Norwegian Biodiversity Information Centre (Artsdatabanken 2018).
Description of data collection method and data structure	Vertically projected total cover of all alien vascular plants, registered by visual estimation of all alien species together. Observations/measurements are done for every 250 m^2-ANO point, with 18 ANO-points per ANO-site and 1000 ANO-sites in total (covers all main ecosystem types, not only mountains, see Tingstad et al. 2019).
Description of the indicator	The indicator is the proportion of the area without such alien species (i.e., 100% - total cover (%) of alien species).
Spatial representation/coverage	ANO's data collection is done at 1000 sites (covers all ecosystems) per 5-year cycle, randomly selected from SSB's national 500 x 500 m^2 grid; sites that are inaccessible or which do not contain natural elements are discarded and are replaced (see Tingstad et al. 2019 for details). As of 2021, data from 3 ANO-seasons in the first cycle are available, i.e., 2412 mountain points in 206 sites across the country (out of 8856 points in 507 sites). Based on the assumption that 1/3 of Norway is covered by mountains, it is expected that there will be roughly 5000 mountain points after a full cycle is completed (1000 sites). In principle all ecosystem types are covered, but sites far away from roads may be underrepresented.
Geographical delimitation	Mainland Norway
Measurement unit	Proportion (%) of area without alien species cover, calculated as 100% minus total cover (%) of alien species (see Nybø et al. 2018 for details).
Time period covered	2019-2021
Frequency of data collection	Every five years for each ANO-site.
Additional description of data properties, if necessary	ANO data are associated with mapping of units at scale 1:5000 in the nature description system 'Natur i Norge' (Nature in Norway, NiN, also called the EcoSyst framework) (Halvorsen et al. 2016, 2020).
Significance of the indicator in the ecosystem and ecological consequences of reduced indicator value (including references)	Alien species are a threat to native ecosystems. This is not currently a problem in the mountains but may become so in the future.
Attribution to ecosystem characteristics	Functionally important species and structures.
- justification	Absence of alien species is an important functional quality of ecosystems.
Correlations (collinearities) with other assessed indicators	No relevant correlations.
Natural effects on the indicator	Naturalised alien species which are dispersed to the mountains because of climate change.
Anthropogenic effects on the indicator (including references)	Introduction of alien species.
Approach for determining reference value(s)	Absolute biophysical boundaries.
Quantification of reference value(s)	The reference value is given as the complete absence of alien species, i.e., 100% of the area without alien species.
Approach for determining the limit value for good ecological condition	Expert knowledge. One-sided indicator.

Quantification of the limit value for good ecological condition	The limit value is given as 95% of the area without alien species.
Quantification of minimum and/or maximum values	The minimum value is defined as the lowest possible value, i.e., 0% of the area without alien species.
References	Artsdatabanken 2018. Fremmedartslista 2018. Accessed 22.11.2021. https://www.artsdatabanken.no/fremmedartslista2018 Halvorsen, R., Bryn, A. & Erikstad, L. 2016. NiNs systemkjerne – teori, prinsipper og inndelingskriterier. Natur i Norge, Artikkel 1 (versjon 2.0.0) Halvorsen, R., Skarpaas, O., Bryn, A., Bratli, H., Erikstad, L., Simensen, T. & Lieungh, E. 2020. Towards a systematics of ecodiversity: The EcoSyst framework. Global Ecology and Biogeography 29: 1887–1906. Nybø, S., Evju, M., Framstad, E., Lyngstad, A., Pedersen, C., Sickel, H., Sverdrup-Thygeson, A., Töpper, J., Vandvik, V., Velle, L.G. & Aarrestad, P.A. 2018. Operasjonalisering av fagsystem for økologisk tilstand for terrestriske økosystemer. Forslag til referanse- og grenseverdier for indikatorer som er klare eller nesten klare til bruk. NINA Rapport 1536. Tingstad, L., Evju, M., Sickel, H., & Töpper, J. 2019. Utvikling av nasjonal arealrepresentativ naturovervåking (ANO). Forslag til gjennomføring, protokoller og kostnadsvurderinger med utgangspunkt i erfaringer fra uttesting i Trøndelag. NINA Rapport 1642.
Indicator	**Area without technical infrastructure**
Completion of the protocol	Anders L. Kolstad
Date filled out/ reviewed	09.12.2021
Data source	The 'Inngrepsfri Natur i Norge'('Infrastructure-free areas') dataset by the Norwegian Environment Agency can be downloaded via Geonorge's map catalogue.
Ownership and permissions	Owner: The Norwegian Environment Agency. License: Norwegian licence for public data (NLOD) 2.0
Description of raw data	Vector map. The dataset shows which areas in Norway are not affected by significant technical infrastructure. Infrastructure-free nature is defined as areas which are at least one kilometre away from major technical infrastructure such as roads, large powerlines, railways, and technical interventions in waterways etc (buildings are not included).
Description of data collection method and data structure	Modelled, nationwide data based on base maps such as N50.
Description of the indicator	The indicator is the proportion of the area at least 1 km away from major technical infrastructure
Spatial representation/coverage	Complete coverage
Geographical delimitation	Complete coverage for Norway
Measurement unit	Area units
Time period covered	1988, 2008, 2013, 2018
Frequency of data collection	Currently updated every 5 years.
Additional description of data properties, if necessary	The dataset does not provide uncertainty related to the delimitations of polygons.
Significance of the indicator in the ecosystem and ecological consequences of reduced indicator value (including references)	Infrastructure-free areas are areas with little anthropogenic activity and where highly mobile species have greater freedom of movement. A reduction in this area indicates a larger human footprint, and human infrastructure can affect movement patterns of mobile species such as reindeer.
Attribution to ecosystem characteristics	Landscape ecological patterns
- justification	The indicator quantifies how much of the area that is distant from human infrastructure. In principle, areas without infrastructure reflect a more natural condition than areas with infrastructure. However, the value of

	these infrastructure-free areas for biodiversity will also be dependent on other factors which affect environmental condition.
Correlations (collinearities) with other assessed indicators	The indicator is relatively closely correlated with the indicator *connectivity of mountain area*.
Natural effects on the indicator	The indicator is unaffected by natural variation.
Anthropogenic effects on the indicator (including references)	The indicator is affected by infrastructure development.
Approach for determining reference value(s)	The reference value is set to 1 (no interventions/infrastructure-free)
Quantification of reference value(s)	
Approach for determining the limit value for good ecological condition	The limit value is set to 60% of the reference value.
Quantification of the limit value for good ecological condition	
Quantification of minimum and/or maximum values	The minimum value is set to zero.
References	Inngrepsfrie naturområder i Norge - Miljødirektoratet (miljodirektoratet.no)
Indicator	**Connectivity of mountain area**
Completion of the protocol	Anders L. Kolstad
Date filled out/ reviewed	10.12.2021
Data source	N50 base map
Ownership and permissions	Norwegian Mapping Authority (Kartverket). Licence: Creative Commons BY 4.0 (CC BY 4.0)
Description of raw data	From the map catalogue: themes included in the product are land cover type, administrative regions, built-up areas, altitude, restricted areas, infrastructure, and place names. N50 map data covers mainland Norway and is limited to national borders to neighbouring countries, and territorial borders in the sea. The product is cartographically corrected for visualisation at a 1:50 000 scale.
Description of data collection method and data structure	Responsibilities for updating the existing dataset are divided among several organisations.
Description of the indicator	The indicator is the mean distance from the centre of mountain patches to the boundary of the nearest forest patch or technical infrastructure (including buildings).
Spatial representation/coverage	Complete coverage
Geographical delimitation	The whole mountain area.
Measurement unit	Metres
Time period covered	Current map data (since the last map update).
Frequency of data collection	Unknown.
Additional description of data properties, if necessary	
Significance of the indicator in the ecosystem and ecological consequences of reduced indicator value (including references)	The indicator reflects changes in the connectedness of separate mountain areas as a result of the development of human infrastructure (roads, powerlines, cropland, built-up areas etc.). Footpaths are not included as human infrastructure. The indicator is calculated as the average distance from the centre of every encompassed mountain area to the nearest infrastructure or forested area. The indicators therefore also represent the reduction of core areas and the corresponding increase in edges resulting from infrastructure.
Attribution to ecosystem characteristics	Landscape ecological patterns
- *justification*	Connectivity affects dispersal and mobility of species in the landscape.

Correlations (collinearities) with other assessed indicators	High correlation with the indicator *area without technical infrastructure*.
Natural effects on the indicator	The indicator is unaffected by natural variation.
Anthropogenic effects on the indicator (including references)	Connectivity is reduced when human infrastructure is built in the mountains. This can facilitate the spread and invasion of boreal species and reduce the mobility of alpine species.
Approach for determining reference value(s)	The reference value is the average distance from the mountain patches to the nearest forest patch, where the mountain patches are not divided by or influenced by infrastructure.
Quantification of reference value(s)	See above.
Approach for determining the limit value for good ecological condition	The limit value is set at 60% of the reference value.
Quantification of the limit value for good ecological condition	
Quantification of minimum and/or maximum values	The minimum value is set at zero (all mountainous areas are gone).
References	https://kartkatalog.geonorge.no/metadata/n50-kartdata/ea192681-d039-42ec-b1bc-f3ce04c189ac
Indicator	**Nature index for mountains (modified) (Mountain index)**
Completion of the protocol	Anders L. Kolstad
Date filled out/ reviewed	09.12.2021
Data source	The data comes from several sources but is filtered through the Nature Index.
Ownership and permissions	The Nature Index is owned by the Norwegian Environment Agency, but the data series used to calculate the indicators have different owners.
Description of raw data	The raw data are very varied, but the data retrieved from the Nature Index are standardised, i.e., scaled between zero and a reference value.
Description of data collection method and data structure	Varies among the underlying data (see above).
Description of the indicator	The indicator is the aggregated scaled value [0,1] for a modified version of the Nature Index 2020 for forests, based on 28 underlying indicators which are weighted by the proportion of the total area covered by the data for each indicator.
Spatial representation/coverage	Collectively covers the whole mountain area.
Geographical delimitation	All mountains. The different indicators in the mountain index have different coverage but are weighted to account for this.
Measurement unit	Varies, The most common measurement units for the indicators are population estimates and densities.
Time period covered	1990-2019
Frequency of data collection	Currently updated every 5 years,
Additional description of data properties, if necessary	
Significance of the indicator in the ecosystem and ecological consequences of reduced indicator value (including references)	The nature index represents the condition of the areas as reflected by a set of underlying indicators. As the indicator value decreases, the condition of the mountain area worsens. Since most of the indicators in the mountain index refer to species, this often means that the abundance of the species has decreased.
Attribution to ecosystem characteristics	Biological diversity
- *justification*	Given the number of underlying indicators, several species groups are represented even if species diversity as such is not represented.
Correlations (collinearities) with other assessed indicators	The indicator overlaps somewhat with other indicators included in both the Mountain Index and as separate indicators for ecosystem condition.

	This is the case for reindeer, small rodents, willow grouse, ptarmigan, golden eagle, arctic fox and wolverine (several of these are represented in another way in the Mountain Index).
Natural effects on the indicator	Due to the breadth of the indicator, the Mountain Index is influenced very little by natural fluctuations in the environment.
Anthropogenic effects on the indicator (including references)	The Mountain Index is particularly affected by climate change, hunting and land use. The effects of pollution and alien species are probably limited.
Approach for determining reference value(s)	The reference values are set for each of the 28 indicators in the Mountain index. Details can be found on https://www.naturindeks.no/.
Quantification of reference value(s)	See above.
Approach for determining the limit value for good ecological condition	The limit value is set at 60% of the reference value.
Quantification of the limit value for good ecological condition	
Quantification of minimum and/or maximum values	The minimum value is set to zero.
References	Berge, S.E. & Pedersen, B. 2021. Nature index system documentation. Mathematical framework, database, web-portals, scripts and API. NINA Report 1990.
Indicator	**Ellenberg N**
Completion of the protocol	Joachim Töpper
Date filled out/ reviewed	09.12.2021
Data source	Geographically representative nature monitoring (ANO). British Ellenberg N values.
Ownership and permissions	ANO is owned by the Norwegian Environment Agency. The British Ellenberg values are published in Hill et al. (1999) and can be used freely (authors must be cited).
Description of raw data	ANO: The species composition of vascular plants is registered as presence and cover (%) of all vascular plants per 1 m^2 quadrat in the centre of an ANO-point. Ellenberg N: the nitrogen affinity per species on a scale of 1 (least nitrophile) to 9 (most nitrophile).
Description of data collection method and data structure	Vertically projected total cover of all vascular plants, registered by visual estimation per species. Observations/measurements are done for every 1 m^2 quadrat in the centre of every ANO-point, with 18 ANO-points per ANO-site and 1000 ANO-sites in total (for all main ecosystem types, see Tingstad et al. 2019).
Description of the indicator	The indicator is the vegetation mean Ellenberg score for the affinity of vascular plant species for nitrogen, weighted with the frequency of each species. This is a two-sided indicator where values both lower and higher than the reference value may indicate deviation from good ecological condition.
Spatial representation/coverage	ANO's data collection is done at 1000 sites (covers all ecosystems) per cycle, randomly selected from SSB's national 500 x 500 m^2 grid; sites that are inaccessible or which do not contain natural elements are discarded and replaced (see Tingstad et al. 2019 for details). As of 2021, data from 3 ANO-seasons in the first cycle are available, i.e., 2412 mountain points in 206 sites across the country (out of 8856 points in 507 sites). Based on the assumption that 1/3 of Norway is covered by mountains, it is expected that there will be roughly 5000 mountain points after a full cycle is completed (1000 sites). In principle all ecosystem types are covered, but sites far away from roads may be underrepresented.
Geographical delimitation	Mainland Norway
Measurement unit	The weighted average of the vegetation's indicator value for nitrogen (Ellenberg N) based on the occurrence and cover of all vascular plants in a 1 m^2-ANO quadrat (see Nybø et al. 2018 and Töpper et al. 2018 for

	details), for each minor type in the major types T3, T7, T14, T22 of the nature description system 'Natur i Norge' (Nature in Norway, NiN, also called the EcoSyst framework) (Halvorsen et al. 2016, 2020).
Time period covered	2019-2021
Frequency of data collection	Every five years in each ANO-site.
Additional description of data properties, if necessary	ANO data are associated with NiN mapping units at scale 1:5000. For more information on Ellenberg N see Hill et al. (1999).
Significance of the indicator in the ecosystem and ecological consequences of reduced indicator value (including references)	Changes in the indicator value indicate a change in dominance and/or a succession to more nitrogen poor or nitrogen rich plant communities than are normal for the mountains in the reference condition.
Attribution to ecosystem characteristics	Abiotic factors.
- justification	The indicator is directly linked to the amount of nitrogen in the soil but can also be an indication of productivity.
Correlations (collinearities) with other assessed indicators	May be correlated with NDVI (productivity).
Natural effects on the indicator	Local phenomena such as presence of carrion can significantly increase nitrogen availability and consequently affect the plant community.
Anthropogenic effects on the indicator (including references)	Pollution (nitrogen deposition, acid rain) and climate change where (i) increased precipitation and runoff can lead to leaching of nitrogen from the soil and (ii) increased temperature results in increased productivity which may influence the community weighted average of Ellenberg N if the dominance structure in the plant community is altered.
Approach for determining reference value(s)	Reference community. Generalised species lists for minor types included in the NiN mapping units (Halvorsen et al. 2016) are the basis of reference and limit value calculations. See Nybø et al. (2018) and Töpper et al. (2018) for details. Generalised species lists for the minor types in NiN describe the expected species composition and cover in each nature type (1:5000 mapping units in NiN) in the reference condition. See Halvorsen et al. (2016, 2020) for details. A weighted average indicator value for Ellenberg N was calculated for each of the generalised species lists by multiplying the cover of every individual species by the species' indicator value, adding these values, and then dividing this by the sum of species cover. Bootstrapping was used to calculate the potential uncertainty in the generalised species lists: every species list was re-sampled 10,000 times, and 1/3 of the species in the species list were randomly sampled in each iteration. The ecosystem's dominant key species, i.e., species cover ≥ 6 on a scale of 1-6, were used in each selection. The average indicator value was calculated for every bootstrap, and a density distribution of the indicator values was made to be used as a reference distribution. See Töpper et al. 2018 for details. The following changes were made to the methods specified by Töpper et al. (2018): a re-sampling of 1/3 rather than 2/3 of the species number, based on the species richness documented in ANO from species with a cover score ≥ 4 as compulsory in each sample to species a cover score ≥ 6. The reference distribution is unique for every mapping unit at scale 1:5000 for the major types T3 (mountain heath, leeside, tundra), T7 (snow bed), T14 (ridge) and T22 (mountain grass heath and tundra).
Quantification of reference value(s)	The reference value is given as the median of the reference distribution.
Approach for determining the limit value for good ecological condition	Statistical distribution, two-sided indicator.
Quantification of the limit value for good ecological condition	The upper and lower limit values are given as 0.025 and 0.975 quantiles in the reference distribution (i.e., 95% confidence interval for a two-sided indicator).
Quantification of minimum and/or maximum values	The minimum and maximum values are defined based on the minimum and maximum values of the Ellenberg scale (1 and 9, respectively).

References	Halvorsen, R., Bryn, A., & Erikstad, L. 2016. NiNs systemkjerne – teori, prinsipper og inndelingskriterier. Natur i Norge, Artikkel 1 (versjon 2.0.0) Halvorsen, R., Skarpaas, O., Bryn, A., Bratli, H., Erikstad, L., Simensen, T. & Lieungh, E. 2020. Towards a systematics of ecodiversity: The EcoSyst framework. Global Ecology and Biogeography 29: 1887–1906. Hill, M.O., Mountford, J.O., Roy, D.B., & Bunce, R.G.H. 1999. Ellenberg's Indicator Values for British Plants. Institute of Terrestrial Ecology, Huntingdon, UK. Nybø, S., Evju, M., Framstad, E., Lyngstad, A., Pedersen, C., Sickel, H., Sverdrup-Thygeson, A., Töpper, J., Vandvik, V., Velle, L.G. & Aarrestad, P.A. 2018. Operasjonalisering av fagsystem for økologisk tilstand for terrestriske økosystemer. Forslag til referanse- og grenseverdier for indikatorer som er klare eller nesten klare til bruk. NINA Rapport 1536. Tingstad, L., Evju, M., Sickel, H., & Töpper, J. 2019. Utvikling av nasjonal arealrepresentativ naturovervåking (ANO). Forslag til gjennomføring, protokoller og kostnadsvurderinger med utgangspunkt i erfaringer fra uttesting i Trøndelag. NINA Rapport 1642. Töpper, J.P., Velle, L.G., & Vandvik, V. 2018. Utvikling av metodikk for økologisk tilstandsvurdering basert på indikatorverdier etter Ellenberg og Grime. NINA Rapport 1529.
Indicator	**Ellenberg L**
Completion of the protocol	Joachim Töpper
Date filled out/ reviewed	09.12.2021
Data source	Geographically representative nature monitoring (ANO). British Ellenberg L values.
Ownership and permissions	ANO is owned by the Norwegian Environment Agency. The British Ellenberg values are published in Hill et al. (1999) and can be used freely (authors must be cited).
Description of raw data	ANO: The species composition of vascular plants is registered as presence and cover (%) of all vascular plants per 1 m^2 quadrat in the centre of an ANO-point. Ellenberg L: light affinity per species on a scale of 1 (lowest light requirement) to 9 (highest light requirement).
Description of data collection method and data structure	Vertically projected total cover of all vascular plants, registered by visual estimation per species. Observations/measurements are done for every 1 m^2 quadrat in the centre of every ANO-point, with 18 ANO-points per ANO-site and 1000 ANO-sites in total (covers all main ecosystem types, not only mountains, see Tingstad et al. 2019).
Description of the indicator	The indicator is the vegetation mean Ellenberg score for the affinity of vascular plant species for light, weighted with the frequency of each species. This is a two-sided indicator where values both lower and higher than the reference value may indicate deviation from good ecological condition.
Spatial representation/coverage	ANO's data collection is done at 1000 sites (covers all ecosystems) per cycle, randomly selected from SSB's national 500 x 500 m^2 grid; sites that are inaccessible or which do not contain natural elements are discarded and replaced (see Tingstad et al. 2019 for details). As of 2021, data from 3 ANO-seasons in the first cycle are available, i.e., 2412 mountain points in 206 sites across the country (out of 8856 points in 507 sites). Based on the assumption that 1/3 of Norway is covered by mountains, it is expected that there will be roughly 5000 mountain points after a full cycle is completed (1000 sites). In principle all ecosystem types are covered, but sites far away from roads may be underrepresented.
Geographical delimitation	Mainland Norway
Measurement unit	The weighted average of the vegetation's indicator value for light (Ellenberg L) based on the occurrence and cover of all vascular plants in a 1 m^2-ANO quadrat (see Nybø et al. 2018 and Töpper et al. 2018 for

	details), for each minor type in the major types T3, T7, T14, T22 of the nature description system 'Natur i Norge' (Nature in Norway, NiN, also called the EcoSyst framework) (Halvorsen et al. 2016, 2020).
Time period covered	2019-2021
Frequency of data collection	Every five years in each ANO-site.
Additional description of data properties, if necessary	ANO data are associated with NiN mapping units at scale 1:5000. For more information on Ellenberg L see Hill et al. 1999.
Significance of the indicator in the ecosystem and ecological consequences of reduced indicator value (including references)	Changes in the indicator value indicate a change in dominance and/or a succession to a plant community with lower or higher light requirement than is normal for the mountains in the reference condition.
Attribution to ecosystem characteristics	Abiotic factors.
- justification	The indicator is directly linked to the amount of available light.
Correlations (collinearities) with other assessed indicators	No relevant correlations.
Natural effects on the indicator	Locally the occurrence of trees can significantly reduce the light availability and thus affect the plant community.
Anthropogenic effects on the indicator (including references)	Land-use: clearing shrubs/trees and grazing/mowing increase light availability, abandonment leads to encroachment. Climate change: increasing temperature results in an increase in shrubs which reduce light availability in the field layer and can affect the community weighted average of Ellenberg L if the dominance structure in the plant community is altered.
Approach for determining reference value(s)	Reference community. Generalised species lists for minor types included in the NiN mapping units (Halvorsen et al. 2016) are the basis of reference and limit value calculations. See Nybø et al. (2018) and Töpper et al. (2018) for details. Generalised species lists for the minor types in NiN. Lists describe the expected species composition and cover in each nature type (1:5000 mapping units in NiN) in the reference condition. See Halvorsen et al. (2016) for details. A weighted average indicator value for Ellenberg L was calculated for each of the generalised species lists by multiplying the cover of every individual species by the species' indicator value, adding these values, and then dividing this by the sum of species cover. Bootstrapping was used to calculate the potential uncertainty in the generalised species lists: every species list was re-sampled 10,000 times, and 1/3 of the species in the species list were randomly sampled in each iteration. The ecosystem's dominant key species, i.e., species cover ≥ 6 on a scale of 1-6, were used in each selection. The average indicator value was calculated for every bootstrap, and a density distribution of the indicator values was made to be used as a reference distribution. See Töpper et al. 2018 for details. The following changes were made to the methods specified by Töpper et al. (2018): a re-sampling of 1/3 rather than 2/3 of the species number, based on the species richness documented in ANO from species with a cover score ≥ 4 as compulsory in each sample to species a cover score ≥ 6. The reference distribution is unique for every mapping unit at scale 1:5000 for the major types T3 (mountain heath, leeside, tundra), T7 (snow bed), T14 (ridge) and T22 (mountain grass heath and tundra).
Quantification of reference value(s)	The reference value is given as the median of the reference distribution.
Approach for determining the limit value for good ecological condition	Statistical distribution, two-sided indicator.
Quantification of the limit value for good ecological condition	The upper and lower limit values are given as 0.025 and 0.975 quantiles in the reference distribution (i.e., 95% confidence interval for a two-sided indicator).
Quantification of minimum and/or maximum values	The minimum and maximum values are defined based on the minimum and maximum values of the Ellenberg scale (1 and 9, respectively).

References	Halvorsen, R., Bryn, A., & Erikstad, L. 2016. NiNs systemkjerne – teori, prinsipper og inndelingskriterier. Natur i Norge, Artikkel 1 (versjon 2.0.0) Halvorsen, R., Skarpaas, O., Bryn, A., Bratli, H., Erikstad, L., Simensen, T. & Lieungh, E. 2020. Towards a systematics of ecodiversity: The EcoSyst framework. Global Ecology and Biogeography 29: 1887–1906. Hill, M.O., Mountford, J.O., Roy, D.B., & Bunce, R.G.H. 1999. Ellenberg's Indicator Values for British Plants. Institute of Terrestrial Ecology, Huntingdon, UK. Nybø, S., Evju, M., Framstad, E., Lyngstad, A., Pedersen, C., Sickel, H., Sverdrup-Thygeson, A., Töpper, J., Vandvik, V., Velle, L.G. & Aarrestad, P.A. 2018. Operasjonalisering av fagsystem for økologisk tilstand for terrestriske økosystemer. Forslag til referanse- og grenseverdier for indikatorer som er klare eller nesten klare til bruk. NINA Rapport 1536. Tingstad, L., Evju, M., Sickel, H., & Töpper, J. 2019. Utvikling av nasjonal arealrepresentativ naturovervåking (ANO). Forslag til gjennomføring, protokoller og kostnadsvurderinger med utgangspunkt i erfaringer fra uttesting i Trøndelag. NINA Rapport 1642. Töpper, J.P., Velle, L.G., & Vandvik, V. 2018. Utvikling av metodikk for økologisk tilstandsvurdering basert på indikatorverdier etter Ellenberg og Grime. NINA Rapport 1529.
Indicator	**Vegetation heat requirement**
Completion of the protocol	Joachim Töpper
Date filled out/ reviewed	09.12.2021
Data source	Geographically representative nature monitoring (ANO). Heat requirement data for Swedish plant species.
Ownership and permissions	ANO is owned by the Norwegian Environment Agency. Heat requirement data are published in Tyler et al. (2021) and can be used freely (authors must be cited).
Description of raw data	ANO: The species composition of vascular plants is registered as presence and cover (%) of all vascular plants per 1 m^2 quadrat in the centre of an ANO-point. Heat requirement: heat values per species on a scale of 1 (lowest heat requirement) to 14 (highest heat requirement).
Description of data collection method and data structure	Vertically projected total cover of all vascular plants, registered by visual estimation per species. Observations/measurements are done for every 1 m^2 quadrat in the centre of every ANO-point, with 18 ANO-points per ANO-site and 1000 ANO-sites in total (covers all main ecosystem types, not only mountains, see Tingstad et al. 2019).
Description of the indicator	The indicator is the cumulative cover of vascular plant species with high heat requirements, relative to the total cover of all vascular plant species.
Spatial representation/coverage	ANO's data collection is done at 1000 sites (covers all ecosystems) per cycle, randomly selected from SSB's national 500 x 500 m^2 grid; sites that are inaccessible or which do not contain natural elements are discarded and replaced (see Tingstad et al. 2019 for details). As of 2021, data from 3 ANO-seasons in the first cycle are available, i.e., 2412 mountain points in 206 sites across the country (out of 8856 points in 507 sites). Based on the assumption that 1/3 of Norway is covered by mountains, it is expected that there will be roughly 5000 mountain points after a full cycle is completed (1000 sites). In principle all ecosystem types are covered, but sites far away from roads may be underrepresented.
Geographical delimitation	Mainland Norway
Measurement unit	Cumulative species cover at a defined heat requirement level and higher, for each minor type in the major types T3, T7, T14, T22 of the nature description system 'Natur i Norge' (Nature in Norway, NiN, also called the EcoSyst framework) (Halvorsen et al. 2016, 2020).
Time period covered	2019-2021

Frequency of data collection	Every five years in each ANO-site.
Additional description of data properties, if necessary	ANO data are associated with NiN mapping units at scale 1:5000. For more information on the heat requirement indicator see Tyler et al. (2021).
Significance of the indicator in the ecosystem and ecological consequences of reduced indicator value (including references)	A reduction in the indicator value is an indication of a change in dominance and/or a succession to a plant community with a higher heat requirement than is normal for the mountains in the reference condition.
Attribution to ecosystem characteristics	Abiotic factors.
- justification	The indicator is directly linked to temperature and temperature changes.
Correlations (collinearities) with other assessed indicators	No relevant correlations.
Natural effects on the indicator	Not relevant, with the exception of local environmental variation.
Anthropogenic effects on the indicator (including references)	Climate change.
Approach for determining reference value(s)	Reference community. Generalised species lists for minor types included in the NiN mapping units (Halvorsen et al. 2016) are the basis of reference and limit value calculations. See Nybø et al. (2018) and Töpper et al. (2018) for details. Generalised species lists for the minor types in NiN describe the expected species composition and cover in each nature type (1:5000 mapping units in NiN) in the reference condition. See Halvorsen et al. (2016) for details. Cumulative species cover at a defined heat requirement level and higher (cumulative from highest to lowest heat requirement) was calculated for each of the generalised species lists. Note that it is the maximum cover that is given by these species lists in NiN, and we therefore use relative cover, i.e., species cover of every species is divided by the total cover of all species. Bootstrapping was used to calculate the potential uncertainty in the generalised species lists: every species list was re-sampled 10,000 times, and 1/2 of the species in the species list were randomly sampled in each iteration. The ecosystem's dominant key species, i.e., species cover ≥ 5 on a scale of 1-6, were used in each selection. The cumulative cover was calculated for every bootstrap, and a density distribution of the indicator values was made to be used as a reference distribution. The reference distribution is unique for every mapping unit at scale 1:5000 for the major types T3 (mountain heath, leeside, tundra), T7 (snow bed), T14 (ridge) and T22 (mountain grass heath and tundra)..
Quantification of reference value(s)	The reference value is given as the median of the reference distribution.
Approach for determining the limit value for good ecological condition	Statistical distribution, one-sided indicator.
Quantification of the limit value for good ecological condition	The limit value is given as the 0.95 quantile in the reference distribution (i.e., 95% confidence interval for a one-sided indicator).
Quantification of minimum and/or maximum values	The maximum value is set to 1 (i.e., the quadrat is completely covered by species at the heat requirement level or higher).
References	Halvorsen, R., Bryn, A., & Erikstad, L. 2016. NiNs systemkjerne – teori, prinsipper og inndelingskriterier. – Natur i Norge, Artikkel 1 (versjon 2.0.0) Halvorsen, R., Skarpaas, O., Bryn, A., Bratli, H., Erikstad, L., Simensen, T. & Lieungh, E. 2020. Towards a systematics of ecodiversity: The EcoSyst framework. Global Ecology and Biogeography 29: 1887–1906. Tingstad, L., Evju, M., Sickel, H., & Töpper, J. 2019. Utvikling av nasjonal arealrepresentativ naturovervåking (ANO). Forslag til gjennomføring, protokoller og kostnadsvurderinger med utgangspunkt i erfaringer fra uttesting i Trøndelag. NINA Rapport 1642. Tyler, T., Herbertsson, L., Olofsson, J., & Olsson, P. A. 2021. Ecological indicator and traits values for Swedish vascular plants. Ecological Indicators, 120. doi:10.1016/j.ecolind.2020.106923

Indicator	**Area of glaciers**
Completion of the protocol	Anders L. Kolstad
Date filled out/ reviewed	10.12.2021
Data source	New glacier atlas for 2018-2019 (pers. com. Liss Marie Andreassen, NVE) and digitised N50 maps for glacial area in 1947-1985 (Winsvold et al. 2014).
Ownership and permissions	Map data are owned by NVE. The glacier atlas for 2018-2019 is to be published in spring 2022 (Andreassen et al. 2022).
Description of raw data	The N50 dataset is a digitised edition of the original N50 maps which were based on an interpretation of aerial photographs from 1947-1985. The glacier atlas is based on Sentinel satellite imagery from 2018-2019.
Description of data collection method and data structure	See above.
Description of the indicator	The indicator is the total area of glaciers and perennial snow fields.
Spatial representation/coverage	Total coverage. The N50 map may be missing smaller glaciers or snow fields which would be visible in the Sentinel imagery. This may have resulted in a slight underestimation of the reference condition.
Geographical delimitation	All of Norway, in practise only mountainous areas.
Measurement unit	Area units.
Time period covered	1947-2019
Frequency of data collection	Varies
Additional description of data properties, if necessary	
Significance of the indicator in the ecosystem and ecological consequences of reduced indicator value (including references)	In addition to being indicators of climate change, glaciers are important structures in the mountains. Meltwater is predictable and provides conditions which are favourable for the development of special vegetation types. Glaciers are habitats for different specialised organisms, such as algae, rotifers, tardigrades, and small insects. Reindeer often use glaciers in the summer to cool off and to avoid insect harassment.
Attribution to ecosystem characteristics	Abiotic factors.
- justification	As a result of changes in glacial area, emphasis has been placed on changes in meltwater.
Correlations (collinearities) with other assessed indicators	The changes in glacier area are likely to be correlated with changes in snow beds – an indicator which is missing in this report.
Natural effects on the indicator	Glaciers are affected by long-term climate change.
Anthropogenic effects on the indicator (including references)	Climate change (Winsvold et al. 2014, Andreassen et al. 2020, 2022)
Approach for determining reference value(s)	The reference condition is set to the area occupied by glaciers in 1947-1985 (Winsvold et al. 2014).
Quantification of reference value(s)	See above.
Approach for determining the limit value for good ecological condition	The limit value is set to 60% of the reference value.
Quantification of the limit value for good ecological condition	
Quantification of minimum and/or maximum values	The minimum value is set at zero.
References	Andreassen, L.M., & Winsvold, S.H. (eds.). 2012. Inventory of Norwegian glaciers. NVE Rapport 38, Norges Vassdrags- og energidirektorat, 236 s. Andreassen, L.M., Elvehøy, H., Kjøllmoen, B. & Belart, J.M.C. 2020. Glacier change in Norway since the 1960s – an overview of mass balance, area, length and surface elevation changes. Journal of Glaciology 66: 313–328.

	Andreassen, L.M., Nagy, T., Kjøllmoen, B. & Leigh, J.R. 2022. A Sentinel-2 based inventory of Norway's glaciers and ice-marginal lakes 2018/2019. Journal of Glaciology (in review). Winsvold, S.H., Andreassen, L.M. & Kienholz, C. 2014. Glacier area and length changes in Norway from repeat inventories. The Cryosphere 8: 1885-1903.
Indicator	**Snow depth**
Completion of the protocol	Anders L. Kolstad
Date filled out/ reviewed	10.12.2021
Data source	Modelled climate data from the Norwegian Meteorological Institute (MET).
Ownership and permissions	MET
Description of raw data	Modelled, interpolated snow depths (mm) per day per square kilometre.
Description of data collection method and data structure	The model is based on observed weather data from stationary weather stations, terrain models etc.
Description of the indicator	The indicator is the deviation in mean snow depth for December-May over the last 5 years from the mean value for the normal period 1961-1990.
Spatial representation/coverage	Total coverage.
Geographical delimitation	Mainland Norway
Measurement unit	mm
Time period covered	1960-2020
Frequency of data collection	Daily
Additional description of data properties, if necessary	
Significance of the indicator in the ecosystem and ecological consequences of reduced indicator value (including references)	A stable snow cover enables life under the snow. A reduction in snow depth results in more difficult conditions for these species, greater temperature fluctuations in the soil, and deeper frost. It can also result in easier access to food for large herbivores, earlier snow melt and less access to meltwater in the spring.
Attribution to ecosystem characteristics	Abiotic factors.
- *justification*	Snow depth is an important abiotic factor for species and ecosystem functions in the mountains.
Correlations (collinearities) with other assessed indicators	Correlates somewhat with snow cover duration.
Natural effects on the indicator	The indicator is unaffected by natural variation in the environment within the given time frame (less than 100 years).
Anthropogenic effects on the indicator (including references)	Climate change
Approach for determining reference value(s)	As the indicator value is defined as the deviation from the corresponding mean value during the previous normal period (1961-1990), the reference value is 0.
Quantification of reference value(s)	See above.
Approach for determining the limit value for good ecological condition	The limit value for good ecological condition is set to two standard deviations for snow depth in the normal period and can be interpreted as a value that would have been considered extreme in that period.
Quantification of the limit value for good ecological condition	
Quantification of minimum and/or maximum values	The minimum value for good ecological condition is set to 5 standard deviations for snow depth in the normal period.
References	http://www.senorge.no/

Indicator	**Snow cover duration**
Completion of the protocol	Anders L. Kolstad
Date filled out/ reviewed	10.12.2021
Data source	Modelled climate data from the Norwegian Meteorological Institute (MET).
Ownership and permissions	MET
Description of raw data	Modelled, interpolated snow depths (mm) and temperature per day per square kilometre.
Description of data collection method and data structure	The model is based on observed weather data from stationary weather stations, terrain models etc.
Description of the indicator	The indicator is the deviation in mean number of days with snow cover for October-June over the last 5 years from the mean value for the normal period 1961-1990.
Spatial representation/coverage	Total coverage.
Geographical delimitation	Mainland Norway
Measurement unit	Days
Time period covered	1960-2020
Frequency of data collection	Daily
Additional description of data properties, if necessary	
Significance of the indicator in the ecosystem and ecological consequences of reduced indicator value (including references)	Snow cover duration defines the duration of winter and simultaneously dictates the time that is available for growth. A shorter snow cover duration results in a longer growing season, lower albedo and higher ground temperatures.
Attribution to ecosystem characteristics	Abiotic factors.
- justification	Snow cover duration is an important abiotic influence on species and ecosystem functions in the mountains which, among other things, dictates important phenological events.
Correlations (collinearities) with other assessed indicators	Correlates somewhat with snow depth.
Natural effects on the indicator	The indicator is unaffected by natural variation in the environment within the given time frame (less than 100 years).
Anthropogenic effects on the indicator (including references)	Climate change
Approach for determining reference value(s)	As the indicator value is defined as the deviation from the corresponding mean value during the previous normal period (1961-1990), the reference value is 0.
Quantification of reference value(s)	See above.
Approach for determining the limit value for good ecological condition	The limit value for good ecological condition is set to two standard deviations for snow cover duration in the normal period and can be interpreted as a value that would have been considered extreme in that period.
Quantification of the limit value for good ecological condition	
Quantification of minimum and/or maximum values	The minimum value for good ecological condition is set to 5 standard deviations for snow cover duration in the normal period.
References	http://www.senorge.no/
Indicator	**Winter rain**
Completion of the protocol	Anders L. Kolstad
Date filled out/ reviewed	10.12.2021
Data source	Modelled climate data from the Norwegian Meteorological Institute (MET).

Ownership and permissions	MET
Description of raw data	Modelled, interpolated precipitation (mm) and temperature per day per square kilometre.
Description of data collection method and data structure	The model is based on observed weather data from stationary weather stations, terrain models etc.
Description of the indicator	The indicator is the deviation of the summed precipitation in January-March for days with mean daily temperature above two degrees Celsius, as a mean for the last 5 years, from the mean value for the normal period 1961-1990.
Spatial representation/coverage	Total coverage.
Geographical delimitation	Mainland Norway
Measurement unit	mm
Time period covered	1960-2020
Frequency of data collection	Daily
Additional description of data properties, if necessary	
Significance of the indicator in the ecosystem and ecological consequences of reduced indicator value (including references)	The reasoning for including this indicator is that precipitation which would have been in the form of snow during the reference period increasingly falls as rain, which has a negative effect on many species. Species living under the snow will be negatively affected if the snow cover is altered by rain or an ice sheet covers the ground. Ice formation may also reduce access to winter food for larger herbivores.
Attribution to ecosystem characteristics	Abiotic factors.
- *justification*	Winter rain is an important abiotic effect on species and ecosystem functions in the mountains.
Correlations (collinearities) with other assessed indicators	No relevant correlations.
Natural effects on the indicator	The indicator is unaffected by natural variation in the environment within the given time frame (less than 100 years).
Anthropogenic effects on the indicator (including references)	Climate change
Approach for determining reference value(s)	As the indicator value is defined as the deviation from the corresponding mean value during the previous normal period (1961-1990), the reference value is 0.
Quantification of reference value(s)	See above.
Approach for determining the limit value for good ecological condition	The limit value for good ecological condition is set to two standard deviations for the amount of winter rain in the normal period, and can be interpreted as a value that would have been considered extreme in that period.
Quantification of the limit value for good ecological condition	
Quantification of minimum and/or maximum values	The minimum value for good ecological condition is set to 5 standard deviations for the amount of winter rain in the normal period.
References	http://www.senorge.no/

The Norwegian Institute for Nature Research, NINA,
is as an independent foundation focusing on environmental research, emphasizing the interaction between human society, natural resources and biodiversity.

NINA was established in 1988. The headquarters are located in Trondheim, with branches in Tromsø, Lillehammer, Bergen and Oslo. In addition, NINA owns and runs the aquatic research station for wild fish at Ims in Rogaland and the arctic fox breeding center at Oppdal.

NINA's activities include research, environmental impact assessments, environmental monitoring, counselling and evaluation. NINA's scientists come from a wide range of disciplinary backgrounds that include biologists, geographers, geneticists, social scientists, sociologists and more. We have a broad-based expertise on the genetic, population, species, ecosystem and landscape level, in terrestrial, freshwater and coastal marine ecosystems.

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