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COVER PICTURE
Semidomestic reindeer (*Rangifer tarandus tarandus*). Photo: Manuel Ballesteros, NINA.
Nordic Monkshood bumblebee (lushatthumle, *Bombus consobrinus*) on Northern Monkshood (tyrihjelm, *Aconitum septentrionale*). Photo: Jutta Kapfer, NIBIO.
Sitka spruce forest (sitkagran, *Picea sitchensis*). Photo: Olga Hilmo, NINA.
Arctic fox (*Vulpes lagopus*) with cub at the breeding den. Photo: Automatic camera trap, NINA/SNO.

KEYWORDS
Norway, Ecosystem assessment, Ecosystem condition, Ecosystem state, System for Assessment of Ecological Condition

NØKKELORD
Norge, Økosystemvurdering, Økosystemtilstand, Økologisk tilstand, System for vurdering av økologisk tilstand, Fagpanelmetoden

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Abstract

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The panel-based assessment of ecosystem condition (PAEC) is an evidence-based approach to assess the condition of Norwegian ecosystems. The assessment is carried out by an expert panel with broad expertise in the ecosystems to be assessed and is inspired by approaches used in international assessments such as IPCC and IPBES. The assessment follows an earlier developed protocol. In this report, PAEC is piloted for major terrestrial **ecosystems** in the county of Trøndelag; forest, alpine, open-lowlands, and wetlands.

For each ecosystem, a list of **indicators** of change in ecosystem condition in response to anthropogenic drivers is developed. The indicators fall within seven main **ecosystem characteristics**: *primary production*, *biomass distribution among trophic levels*, *functional groups within trophic levels, functionally important species, biological diversity, landscape ecological patterns, and abiotic factors*. The expected change in indicators in response to anthropogenic drivers are termed **phenomena**, and their selection is based on published literature, including reference to the confidence of a change being observed in response to anthropogenic drivers and the mechanism leading to a deterioration in ecosystem state. Datasets to quantify each indicator are identified and collated and the quality of each dataset is assessed in terms of its spatial and temporal appropriateness.

In the first assessment step, the **validity** (VP) of each phenomenon is scored and used to infer confidence in the causal relationship between changes in the indicator and anthropogenic drivers. The next step is an evaluation of the biological and statistical significance of the evidence for the occurrence of each phenomenon, termed **evidence** (EP) of the phenomenon. The third step is a consolidated assessment of the ecological state based on the associated indicators and phenomena, first for each ecosystem characteristic, and subsequently for the ecosystem as a whole. The assessment is based on the validity, the quality of the evidence, and the data quality for each phenomenon. This provides a qualitative assessment of deviation from the reference condition of “no deviation”, “limited deviation” or “substantial deviation”. The assessments are each supported by narrative accounts. The pilot assessment involved analysis of 24 datasets documenting 41 indicators. Several indicators were included in multiple ecosystems. In total there were 27 indicators used for forest ecosystems, 24 for alpine ecosystems, and 16 in each of wetlands and open lowlands.

In the **forest ecosystems**, substantial deviation from the reference condition was identified for five of the ecosystem characteristics. The two exceptions were *primary productivity* where there was a limited deviation from the reference condition, and *biological diversity* where there was no deviation from the reference condition (but the latter was based on a single indicator and hence an entirely inadequate indicator coverage). The deviations were found primarily in climatic variables, cervids and their forage and predators, and dead wood. Overall, the forest ecosystem was assessed as having a substantial deviation from the reference condition.

In the **alpine ecosystems**, substantial deviation from the reference condition was identified for the abiotic ecosystem characteristic, largely attributed to indicators associated with temperature, seasonality, and snow. Limited deviation from the reference condition was assessed for *functionally important species* and *primary productivity* (both based on a partially

adequate indicator coverage) and for *biological diversity*, *functional groups within trophic levels* and *landscape ecological patterns* (but these were based on an inadequate indicator coverage). For the ecosystem characteristic *biomass distribution among trophic levels*, the quality of evidence was insufficient to conclude regarding the condition of the single indicator involved, and no overall assessment of this ecosystem characteristic could be undertaken. Overall, the alpine ecosystem was assessed as having limited deviation from the reference condition.

For both **open lowland** and **wetland** ecosystems, several ecosystem characteristics were not assessed due to a lack of relevant indicator datasets. For this reason, no overall assessment of the ecosystems as a whole could be undertaken. However, for both ecosystems, there was a substantial deviation from the reference condition for *abiotic factors* (temperature, seasonality, and snow). In open lowlands, there was a *substantial deviation in functionally important species* (ungulates) and limited deviation in *primary productivity* and *biological diversity*. In wetlands, there was a limited deviation from the reference condition in *primary productivity, biological diversity*, and *landscape ecological patterns*.

Most challenges encountered during this pilot assessment related to the **inadequacy of the datasets** for assessing ecosystem condition. Reasons behind this include that ecosystem extents are not adequately mapped, particularly those characterised by small and fragmented patches, and a taxonomic or geographical limitation of datasets and environmental monitoring. The report suggests **further development of indicators** for operational application. Finally, the report also suggests **knowledge needs and prioritisation for further research** to support the future implementation of ecosystem assessments in Norway.

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Utvidet sammendrag

Jepsen, J.U., Speed, J.D.M., Austrheim, G., Rusch, G., Petersen, T.K., Asplund, J., Bjerke, J.W., Bjune, A.E., Eide, N.E., Herfindal, I., Ims, R.A., Israelsen, M.F., Kapfer, J., Kolstad, A.L., Nordén, J., Sandercock, B., Stien, J., Tveito, O.E., Yoccoz, N.G. 2022. Panel-based Assessment of Ecosystem Condition – a methodological pilot for four terrestrial ecosystems in Trøndelag. NINA Report 2094. Norwegian Institute for Nature Research.

System for vurdering av økologisk tilstand, koordinert av Miljødirektoratet, skal utgjøre fundamentet for en kunnskapsbasert vurdering av økologisk tilstand for norske terrestriske og marine økosystemer som ikke er omfattet av vanndirektivet. Denne rapport er et ledd i utviklingsarbeidet av vurderingsmetoder for bruk i systemet og omhandler en test av metoden *Panel-basert vurdering av økosystemtilstand* (PAEC; Jepsen et al. 2020) for fire terrestre økosystemer geografisk avgrenset til Trøndelag fylke.

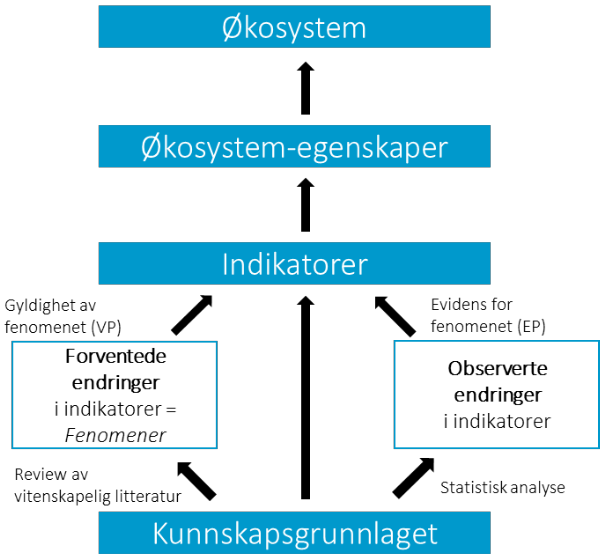
Sentrale rammer for tilstandsvurderinger gjort innen *System for vurdering av økologisk tilstand*
Pilotvurderingen følger rammene for *System for vurdering av økologisk tilstand* slik de er definert i Nybø og Evju (2017). Det betyr at en tilstandsvurdering skal adressere syv konkrete økosystemegenskaper, som hver er representert ved et sett av abiotiske og/eller biotiske indikatorer. De syv økosystemegenskaper er: *Primærproduksjon, Biomassefordeling mellom trofiske nivåer, Funksjonelle grupper innen trofisk nivå, Funksjonelt viktige arter og biofysiske strukturer, Landskapsøkologiske mønstre, Biologisk mangfold* og *Abiotiske forhold*. Referansetilstanden, som man vurderer dagens tilstand mot, er definert som «intakte økosystemer» karakterisert ved at økosystemets økologiske strukturer, funksjoner og produktivitet er opprettholdt. Menneskelig påvirkning kan forekomme, men skal ikke være gjennomgripende eller dominerende. Ett unntak er for seminaturlige økosystemer, hvis opprettholdelse er betinget av menneskelige inngrep slik som slått eller husdyrbeite. Det defineres videre en klimatisk referanse som tilsvarer den klimatiske normalperioden 1961-1990. Se Kapittel 2, **Box 1** og **Box 2** for fullstendige definisjoner, samt Nybø and Evju (2017; Kapittel 3).

Formålet med pilotvurderingen
Hovedformålet med pilotvurderingen har vært å teste vurderingsmetoden PAEC for andre økosystemer enn de arktiske økosystemer hvor metoden hittil er anvendt (Jepsen et al. 2019, Pedersen et al. 2021a). Disse byr på potensielt nye utfordringer når det gjelder datagrunnlag, kunnskap om økosystemets dynamikk, og forståelse av sentrale sammenhenger mellom menneskelige påvirkningsfaktorer og endringer i tilstandsindikatorer. Tilstandsvurderingene som presenteres i denne rapporten skal altså ikke betraktes som gjeldende vurderinger av økologisk tilstand, men som en demonstrasjon av vurderingsmetoden basert på et begrenset indikatorsett. Det er lagt vekt på at indikatorsettet, på tross av at det er begrenset, skal representere realistisk variasjon når det gjelder kunnskapsgrunnlaget (datadekning, graden av forståelse) og påvirkningsfaktorer (typer av påvirkningsfaktorer, og i hvor høy grad disse forventes å samvirke). I tråd med PAEC protokollen har det vært et mål å presentere relativt omfattende anbefalinger for hvordan det anvendte indikatorsett kan suppleres og forbedres frem mot fremtidige operasjonelle vurderinger.

Grunnleggende prinsipper i PAEC
PAEC er en strukturert protokoll for vurdering av økosystemtilstand i forhold til en referansetilstand. Protokollen er hierarkisk. Vurderingene bygges gradvis opp og begynner med en vurdering av det tilgjengelige kunnskapsgrunnlaget. Deretter formuleres forventede endringer i indikatorer (kallet 'fenomener'), og observerte endringer i indikatorer evalueres basert på statistisk analyse. Dette danner til slutt grunnlaget for en helhetlig vurdering av tilstanden for hver økosystemegenskap og for økosystemet som helhet (**Figur S1**).

Formuleringen av fenomener er avgjørende i PAEC. Fenomenene spesifiserer forventede årsakssammenhenger mellom indikatorer og relevante påvirkningsfaktorer (drivkrefter) basert på publisert vitenskapelig litteratur. Disse årsakssammenhengene er verbalt beskrevet som kvalitative prediksjoner (hypoteser) om hvilke retningsbestemte endringer man forventer i en indikator. Fenomenenes gyldighet (VP) uttrykker hvor sikker man er på disse prediksjonene, basert på tilgjengelig vitenskapelig litteratur. Statistisk analyse av de underliggende data avgjør i hvilken grad observerte endringer er i tråd med de oppsatte prediksjonene (EP – evidens for fenomenene). Den statistiske analysen består som oftest av en tidsserieanalyse. Dersom datagrunnlaget ikke tillater dette, p.g.a. for korte serier eller for få gjentak, kan panelet vurdere graden av evidens på annet vis, eksempelvis ved å inspisere forskjeller mellom romlige kontraster eller mellom enkelte kartlegginger gjennomført med noe avstand i tid. Dersom tidsserieanalyser ikke har kunnet gjennomføres, markeres dette i tabellen med metoder (**Table 4.1**) for den enkelte indikator. Fagpanelets vurdering av hvorbetydningsfulle observerte endringer er for økosystemets tilstand ('økologisk signifikans') baserer seg på en helhetsvurdering av omfanget av endringene, i hvor høy grad andre indikatorer i systemet viser relaterte endringer, samt i hvor høy grad det er støtte i litteraturen for at observerte endringer er betydningsfulle Dedikerte statistiske analyser av sammenhengen mellom observerte endringer i indikatorer og tilstand (på indikator-, egenskaps- eller økosystemnivå) er det sjeldent rom for innen rammene for en tilstandsvurdering, men anbefales som en parallell forskningsbasert aktivitet (se Pedersen et al. 2021b).

Sentralt i PAEC er også de ulike kildene av usikkerhet og hvordan disse påvirker vurderingene. Kun én av disse kildene til usikkerhet kan vurderes kvantitativt; nemlig usikkerheten rundt indikatorverdier (typisk endringsrater av tidsserier) basert på statistisk analyse av overvåkingsdata. Andre kilder til usikkerhet, slik som romlige og tidsmessig datadekning, graden av forståelse, og samlet indikatordekning av de syv økosystemegenskapene, vurderes kvalitativt, men basert på et strengt sett med kriterier definert i PAEC protokollen.



Figur S1. *En skjematisk oppsummering av hierarkiet i en tilstandsvurdering etter PAEC (fra Pedersen et al. 2021a). De fire primære nivåene i PAEC (blå bokser) er vurderinger av 1) kunnskapsgrunnlaget, 2) tilstanden til individuelle indikatorer, 3) tilstanden til økosystemegenskaper, og 4) tilstanden til økosystemet som helhet. Vurderingen av individuelle indikatorer baserer seg på i hvilken grad observerte endringer, avdekket ved statistisk analyse (endringsrater) av datagrunnlaget, er i samsvar med de forventede endringer (uttrykt i fenomenene).*

En PAEC vurdering utføres av et vitenskapelig fagpanel. Fagpanelet for denne pilot besto av 18 forskere fra syv ulike forskningsinstitusjoner med ekspertise på hver av de fire økosystemene, samt i de analytiske metodene som er brukt for å vurdere endringer i disse. PAEC-protokollen gir detaljerte instrukser om hvordan hvert enkelt stadium i vurderingen skal gjennomføres og dokumenteres, fra den innledende kartleggingsfasen, gjennom dataanalysen, til den helhetlige vurderingen og rapporteringen. Dette inkluderer definisjoner av vurderingskategorier for de ulike nivåer i vurderingen (blå bokser i figur nedenfor).

Avgrensning av hovedøkosystemer i pilotvurderingen

Pilotvurderingen er geografisk begrenset til Trøndelag fylke for å gi best mulig sammenliknings-grunnlag med en tidligere metodisk pilot gjennomført for den andre vurderingsmetoden som anvendes innen *System for vurdering av økologisk tilstand* (Nybø et al. 2019). Innen denne region adresseres fire ulike landøkosystem; skog, fjell, våtmark og åpent lavland. Definisjonen av disse fire økosystemer er i utgangspunktet gitt i Nybø and Evju 2017. En romlig kartfestet avgrensning er imidlertid nødvendig for å kunne utnytte romlige datasett, og her følger piloten Venter and Stabbetorp 2019 som har utviklet en foreløpig geografisk avgrensning av hovedøkosystemene for bruk innen *System for vurdering av økologisk tilstand*. Vi anvender samme inndeling av skog, fjell, våtmark og åpent lavland som den nyeste Naturindeksen (vedlegg 2 i Jakobsson and Pedersen 2020, **Figur 3.1** i denne rapport). Den geografiske avgrensningen av hovedøkosystemer er utfordrende, i særdeleshet for våtmark og åpent lavland. Dette er inntil videre både en betydelig begrensning og en kilde til usikkerhet i utnyttelsen av heldekkende romlige data, slik som satellittdata eller modellerte klimatiske og hydrologiske data.

Datasett, indikatorer og kunnskapsgrunnlag for pilotvurderingen

Pilotvurderingen bygger på analyser av 24 datasett (**Tabell 3.1**), som understøtter 41 indikatorer. Mange av disse anvendes i to eller flere økosystemer, slik at det totale antallet indikatorer som er vurdert er 27 for skog, 24 for fjell, 16 for våtmark og 16 for åpent lavland (**Kapittel 4**). Datasettene stammer fra ulike tematiske overvåkingsprogrammer på vegetasjon (skog), fauna (smågnagere, fugl, fjellrev/rødrev, store rovdyr, hjortedyr, insekter), samt fra nasjonal statistikk (skogbruk, infrastruktur), globale fjernmålingsprogrammer (vegetasjon, primærproduksjon), samt nasjonale tjenester fra Meteorologisk Institutt og Norges vassdrags- og energidirektorat (klima og hydrologi). Tidligere tilstandsvurderinger av arktiske og marine økosystemer basert på PAEC (Jepsen et al. 2019, Pedersen et al. 2021a) har dratt nytte av tilgangen på data fra økosystem-baserte overvåkingsprogrammer/systemer. En fordel med økosystembasert overvåking for PAEC spesifikt og tilstandsvurdering generelt, er at den er innrettet mot å vurdere fenomener som er spesifikke for det aktuelle økosystem. Både data - og indikatordekning er bedre siden den som regel er modellbasert. Slik økosystembasert overvåking finnes ikke for de fire økosystemer som er adressert i denne pilot. Det fins datakilder som er utelatt i denne piloten, som foreløpig ikke er av et omfang eller varighet som tillater vurdering av tilstand eller endringer i denne. Det gjelder eksempelvis flere overvåkingsprogrammer som er i etableringsfasen (vegetasjon (Evju and Nybø 2017), insekter (Åström et al. 2020a,b) og semi-naturlig eng (Bär et al. 2021a,b). Disse kan imidlertid være datakilder for fremtiden, forutsatt at de oppnår tilstrekkelig dekning for hovedøkosystemene på fylkes/regionsnivå. Utgangspunktet for å vurdere tilstand i denne piloten er med andre ord et ganske annet enn for de arktiske og marine økosystemene, både når det gjelder det konseptuelle grunnlaget for å velge indikatorer og fenomener, og når det gjelder tilfanget av data som har tilstrekkelig romlig og tidsmessig overlapp, og som er innsamlet med metoder som gjør de egnede til sammenlikning. Det anvendte indikatorsettet avspeiler i stor grad tilgjengeligheten av biotiske data fra de fire økosystemer som er adressert. Mens tilgjengeligheten av regionale abiotiske klimadata er god for alle systemer, på tross av de før nevnte utfordringer knyttet til den geografiske avgrensningen, så er tilfanget av andre (ikke-klimatiske) abiotiske og de fleste biotiske overvåkingsdata for særlig våtmark og åpent lavland særdeles sparsomt. For skog og fjell er alle syv økosystemegenskaper representert ved en eller flere indikatorer, mens det for våtmark og åpent lavland er tre økosystemegenskaper som ikke er representert grunnet datamangel. For syv av 41 indikatorer tillot datagrunnlaget ikke at det ble gjennomført en tidsserieanalyse (**Table 4.1**), og graden av evidens for disse er vurdert på annet vis.

Vurderingskategorier for samlet vurdering av økologisk tilstand
Økologisk tilstand for hver av de syv økosystemegenskaper vurderes kvalitativt til en av tre kategorier — fra ingen til betydelige avvik fra referansetilstanden (**Tabell S1**) Kategoritilhørighet er primært avhengig av vurderingen av gyldighet (VP) og evidens (EP) for de underliggende fenomenene (se detaljer i **kapittel 7.1** i denne rapport). I tråd med definisjonen av referansetilstanden som 'intakte økosystemer' (Nybø and Evju 2017), så viser økosystemegenskaper med **begrenset avvik** fra referansetilstanden endringer som indikerer at de er på en endringsbane bort fra en intakt tilstand. Økosystemegenskaper som vurderes til **betydelig avvik** fra referansetilstanden kan ikke lenger sies å være i intakt tilstand. Valget av kategori begrunnes i den tilhørende tekstlige vurdering der også de primære usikkerhetene knyttet til dette valget beskrives.

Tabell S1. *Forkortet definisjon av de tre vurderingskategorier. For full beskrivelse se* ***Box 7.3*** *i rapporten og Jepsen et al. (2020).*

Ingen avvik fra referansetilstanden Basert på det vurderte indikatorsettet, viser en økosystemegenskap i denne kategorien samlet sett ingen eller svært begrensede avvik fra referansetilstanden. Ifølge definisjonen av referansetilstand som er lagt til grunn i *System for vurdering av økologisk tilstand* er egenskapen i hovedsak i en intakt tilstand.
Begrensende avvik fra referansetilstanden Basert på det vurderte indikatorsettet, viser en økosystemegenskap i denne kategorien samlet sett begrensede avvik fra referansetilstanden. Ifølge definisjonen av referansetilstand som er lagt til grunn i *System for vurdering av økologisk tilstand* er egenskapen i hovedsak fortsatt i en intakt tilstand, men det forekommer avvik fra referansetilstanden, som tyder på en utvikling mot en mindre intakt og mer menneskepåvirket tilstand.
Betydelige avvik fra referansetilstanden Basert på det vurderte indikatorsettet, viser en økosystemegenskap i denne kategorien samlet sett betydelige avvik fra referansetilstanden. Ifølge definisjonen av referansetilstand som er lagt til grunn i *System for vurdering av økologisk tilstand* er egenskapen i hovedsak ikke i en intakt tilstand.

Fagpanelets tilstandsvurdering av de syv økosystemegenskaper oppsummeres grafisk i form av sirkeldiagrammer, som er oppdelt i 7 seksjoner, én for hver egenskap.

- Innerste ring viser vurderingen av den samlede indikatordekningen til de kategorier ('tilstrekkelig', 'delvis tilstrekkelig', 'utilstrekkelig'). Dette er en viktig pekepinn på hvor stor vekt vurderingen av en gitt egenskap kan tillegges i den samlede vurderingen av økosystemet som helhet. En 'delvis tilstrekkelig' indikatordekning betyr at indikatorsettet bak vurderingen har viktige mangler og at vurderingen må gjøres med visse forbehold. En 'utilstrekkelig' samlet indikatordekning kan skyldes at indikatorer er helt manglende for en gitt egenskap, som betyr at tilstanden til egenskapen ikke kan vurderes i det hele tatt. Det kan også skyldes at indikatorsettet har så avgjørende mangler at vurderingen av egenskapen må sies å være gjort på helt utilstrekkelig grunnlag. Tilstandskategorier som er tildelt basert på en 'utilstrekkelig' indikatordekning, må behandles med store forbehold, og vises med svakere farge enn øvrige vurderinger i de grafiske oppsummeringer under.

- Mellomste ring viser vurderingen av egenskapens samlede tilstand til de tre tilstandskategorier (**Tabell S1**; 'ingen', 'begrensede', eller 'betydelige' avvik fra referansetilstanden).

- Ytterste ring viser vurderingen av hver enkel indikator med tilhørende fenomen til de samme tre tilstandskategorier.

I sirkeldiagrammene er noen viktige mangler i indikatorsettet synliggjort i form av ikke-fargelagte indikatorer. Dette er indikatorer som fagpanelet anbefaler utviklet og inkludert i fremtiden (se detaljer i **kapittel 7.7** i denne rapporten), men som ikke har vært vurdert i forbindelse med piloten.

Hovedøkosystem Skog
Fagpanelets tilstandsvurdering av skog er oppsummert i **Tabell S2** samt grafisk i **Figur S2** (tilsvarer **Figur 7.2.2** i rapporten). Vurderingen er basert på 27 indikatorer fordelt på alle syv egenskaper. To av egenskapene (*Biologisk mangfold* og *Landskapsøkologiske mønstre*) har imidlertid en samlet indikatordekning som er vurdert til 'utilstrekkelig'. For de øvrige egenskaper er samlet indikatordekning vurdert til 'delvis tilstrekkelig'. Fagpanelet konkluderer dermed at det er mulig å gjøre en vurdering av alle syv egenskaper, men for to av disse gjøres vurderingen på klart utilstrekkelig grunnlag.
Fem av de syv egenskaper (*Biomassefordeling mellom trofiske nivåer, Funksjonelle grupper innen trofisk nivå, Funksjonelt viktige arter og biofysiske strukturer, Landskapsøkologiske mønstre,* og *Abiotiske forhold*) er vurdert til å ha **betydelige avvik** fra referansetilstanden, én (*Primærproduktion*) til å ha **begrensede avvik** og én (*Biologisk mangfold*) til å ha **ingen avvik** fra referansetilstanden.

***Tabell S2**. Oppsummering av de primære avvik observert innen hver økosystemegenskap for skog og de viktigste kilder til usikkerhet i valget av tilstandskategori.*

Primærproduksjon	Økosystemegenskapen viser **begrensede avvik** fra referansetilstanden. Vurderingen er basert på tre indikatorer med tre tilhørende fenomener med god til svært god datadekning. To fenomener har høy gyldighet (VP). Det er evidens for en svak økende trend i produktivitet (grønnhet) for økosystemet i Trøndelag, konsistent med økende trevolum i både produktiv og uproduktiv skog, og økende temperaturer både i og utenfor vekstsesongen (se *Abiotiske forhold*). Usikkerheter i valget av vurderingskategori knytter seg særlig til fravær av indikatorer som belyser endringer i primærproduksjon for busk- og feltsjiktet.
Biomassefordeling mellom trofiske nivåer	Økosystemegenskapen viser **betydelige avvik** fra referansetilstanden. Vurderingen er basert på tre indikatorer med tre tilhørende fenomener med middels datadekning og høy gyldighet (VP). Det er evidens for endringer i biomassefordeling mellom store hjortedyr (elg) og sentrale beiteplanter (ROS-arter), og mellom beitedyr og store rovdyr som utgjør betydelige avvik fra referansetilstanden. Usikkerheter i valget av vurderingskategori knytter seg særlig til begrenset datadekning bak de inkluderte indikatorer, som begrenser mulighetene for å analysere trofiske forholdstall direkte, samt manglende indikatorer på nedbryter-nivået, og på en rekke viktige trofiske relasjoner og næringskjeder, f.eks. planter-smågnagere/hare-små rovdyr.
Funksjonelle grupper innen trofisk nivå	Økosystemegenskapen viser **betydelige avvik** fra referansetilstanden. Vurderingen er basert på to indikatorer med to tilhørende fenomener med god til svært god datadekning og middels til høy gyldighet (VP). Det er evidens for store endringer i beitedyrssammensetningen som betyr et skifte fra gresseter-dominans til lauv- og kvisteter-dominans, som må forventes å ha store konsekvenser for vegetasjonsdynamikken i skogøkosystemet. Det er imidlertid betydelig usikkerhet knyttet til valg av kategori, særlig på grunn av manglende indikatorer på plantevekstformer (utenom trær), sentrale funksjonelle grupper innen planteetere (utenom hjortedyr), smågnagere, insekter, nedbrytere, og rovdyr.
Funksjonelt viktige arter og biofysiske strukturer	Økosystemegenskapen viser **betydelige avvik** fra referansetilstanden. Vurderingen er basert på syv indikatorer med syv tilhørende fenomener med svært god datadekning og høy gyldighet (VP) for flesteparten av fenomenene. Økende bestander av ville hjortedyr, lave nivåer av død ved som en sentral biofysisk struktur, og lave eller fraværende bestander av store rovdyr bidrar til betydelige avvik fra referansetilstanden. Et fenomen kunne ikke vurderes grunnet utilstrekkelig datagrunnlag. Det er ingen store usikkerheter knyttet til valg av kategori, men indikatordekningen er bare 'delvis tilstrekkelig' grunnet manglende indikatorer på funksjonelt viktige arter innenfor artsgrupper som nedbrytere, parasitoider, hakkespetter, samt trær
Landskapsøkologiske mønstre	Økosystemegenskapen viser **betydelige avvik** fra referansetilstanden. Vurderingen er basert på én enkelt indikator, med ett tilhørende fenomen av middels gyldighet (VP) og svært god datadekning. Indikatoren sier at andelen skogsareal som er > 1 km fra større tekniske inngrep er lav (< 25%) og svakt minkende. Dette er et betydelig avvik fra en intakt tilstand. Det er imidlertid betydelig usikkerhet knyttet til valg av kategori, grunnet utilstrekkelig indikatordekning for egenskapen som bør utbedres gjennom inkludering av strukturelle indikatorer som er mer direkte knyttet til økologi, eksempelvis graden av fragmentering, isolasjon av populasjoner, størrelse av skoghabitater, samt trekronestruktur.

***Tabell S2** (fortsatt)*

Biologisk mangfold	Økosystemegenskapen viser **ingen avvik** fra referansetilstanden. Vurderingen er basert på én enkelt indikator, med ett tilhørende fenomen av høy gyldighet (VP) og god datadekning. Den beskriver utviklingen i fuglesamfunn tilknyttet skog. Det er imidlertid betydelig usikkerhet knyttet til valg av kategori, grunnet utilstrekkelig indikatordekning for egenskapen, som bør utbedres gjennom inkludering av indikatorer på diversitet av andre artsgrupper (planter, invertebrater, sopp)
Abiotiske forhold	Økosystemegenskapen viser **betydelige avvik** fra referansetilstanden. Vurderingen er basert på 10 indikatorer med 10 tilhørende fenomener med svært god datadekning og høy gyldighet (VP) for flesteparten av fenomenene. Det er evidens for avvik i økosystemets abiotiske forhold relatert til temperatur og snødekke som utgjør betydelig avvik fra referansetilstanden og må forventes å påvirke økosystemets strukturelle og funksjonelle egenskaper, gjennom endringer i vekstforhold, produktivitet, artsutbredelse og trofiske relasjoner. Det er ingen stor usikkerhet knyttet til valg av kategori, men indikatordekningen er bare 'delvis tilstrekkelig' grunnet manglende indikatorer på snøkvalitet (snøstruktur, regn-på-snø, ising) med relevans for vegetasjon og beiteforhold-, samt albedo.

Basert på det tilgjengelige indikatorsettet, og vurderingen av de syv egenskaper over, konkluderer fagpanelet med at skogøkosystemer i Trøndelag viser **betydelige avvik** fra referansetilstanden med fundamentale strukturelle og funksjonelle endringer sammenliknet med et intakt system, herunder betydelige endringer i de abiotiske forhold relatert til temperatur og snødekke forårsaket av klimaendringer. Disse abiotiske endringer har foreløpig gitt utslag i begrensede biotiske endringer. De viktigste biotiske avvik er relatert til høye bestander av ville hjortedyr, med resulterende endringer i biomasseforhold både innen og mellom trofiske nivåer, fravær eller svært lave bestander av store rovdyr, lave nivåer av død ved, og lav andel av skogøkosystemer som ikke er i nærhet til infrastruktur. Grunnet mangler i indikatordekningen knyttes det stor usikkerhet til valg av kategori for flere av egenskapene, og dermed til vurderingen for økosystemet som helhet.

Figur S2. *Grafisk oppsummering av vurderingen av økologisk tilstand for skog. Den ytterste sirkel viser vurderingen av tilstand på indikatornivå med tilhørende fenomen ID i parentes. Indikatorer som fagpanelet har anbefalt for utvikling og inkludering i frem-tiden (**Tabell 7.7**. i rapporten), men som ikke er en del av denne piloten, er vist med hvite felter for å illustrere noen av de viktigste mangler ved det anvendte indikatorsett. Den midterste sirkel viser vurderingen på egenskapsnivå, mens den innerste sirkel viser den samlede indikatordekning for hver egenskap. Vurderinger som er gjort basert på et samlet indikatorsett som er vurdert som 'utilstrekkelig' ('inadequate'), er vist med svakere farge enn øvrige deler av vurderingen.*

Hovedøkosystem Fjell

Fagpanelets tilstandsvurdering av fjell er oppsummert i **Tabell S3** samt grafisk i **Figur S3** (tilsvarer **Figur 7.3.2** i rapporten). Vurderingen er basert på 24 indikatorer fordelt på alle syv egenskapene. Fire av egenskapene (*Biomassefordeling mellom trofiske nivå, Funksjonelle grupper innen trofisk nivå, Landskapsøkologiske mønstre, Biologisk mangfold*) har imidlertid en indikatordekning som er vurdert til den laveste kategori ('utilstrekkelig'). For de øvrige egenskapene er indikatordekningen vurdert til den mellomste kategorien ('delvis tilstrekkelig'). Egenskapen *Biomassefordeling mellom trofiske nivå* har imidlertid utilstrekkelig evidens for den ene indikator som er inkludert, og en samlet vurdering kan dermed ikke gjøres. Fagpanelet konkluderer dermed at det er mulig å gjøre en vurdering av seks av syv egenskaper, men for tre av disse gjøres vurderingen på klart utilstrekkelig grunnlag.

Av de seks egenskapene er én (*Abiotiske forhold*) vurdert til å ha **betydelige avvik** fra referansetilstanden, og fem (*Primærproduktion, Funksjonelle grupper innen trofisk nivå, Funksjonelt viktige arter og biofysiske strukturer, Landskapsøkologiske mønstre, Biologisk mangfold*) til å ha **begrensede avvik**.

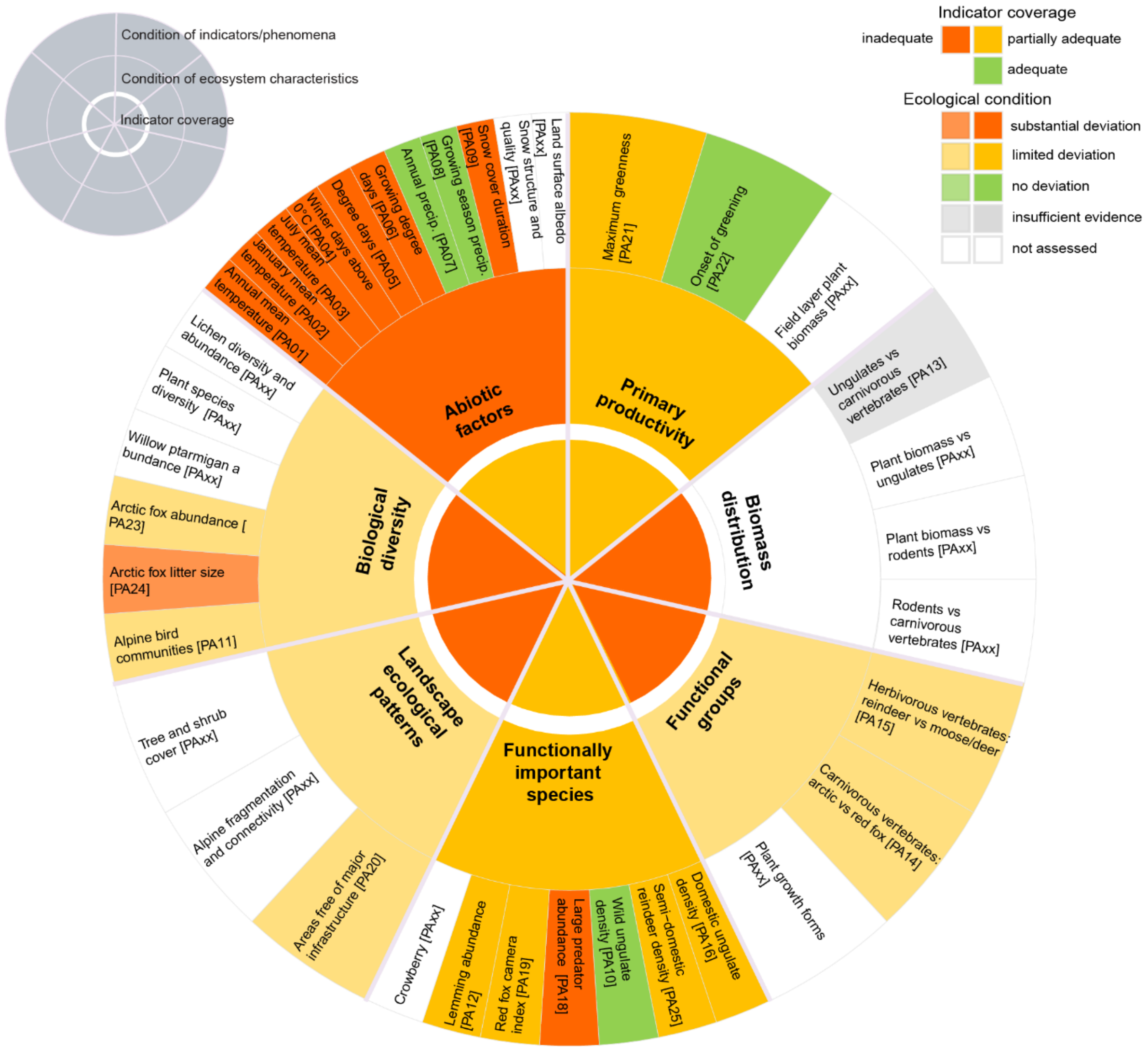
Tabell S3. *Oppsummering av de primære avvik observert innen hver økosystemegenskap for fjell og de viktigste kilder til usikkerhet i valget av tilstandskategori.*

Primærproduksjon	Økosystemegenskapen viser **begrensede avvik** fra referansetilstanden. Vurderingen er basert på to indikatorer med to tilhørende fenomener med svært god datadekning og høy gyldighet (VP). Det er evidens for en svak økende trend i produktivitet (grønnhet) for økosystemet i Trøndelag, konsistent med økende temperaturer både i og utenfor vekstsesongen (se *Abiotiske forhold*) og dokumenterte trender for andre alpine og arktiske områder. Usikkerheter i valget av vurderingskategori knytter seg særlig til fravær av indikatorer som belyser endringer i primærproduksjon og/eller biomasse knyttet til viktige vegetasjonssjikt, f.eks busksjiktet.
Biomassefordeling mellom trofiske nivåer	Én indikator med ett tilhørende fenomen er tilgjengelig, men denne er plassert i evidenskategorien EP='utilstrekkelig' ('insufficient'). Det innebærer at man ikke har tilstrekkelig grunnlag for å vurdere fenomenet. En samlet tilstandskategori for egenskapen kan dermed ikke settes. Egenskapen har utilstrekkelig indikatordekning. Dette bør utbedres gjennom inkludering av indikatorer på biomasseforhold i viktige alpine næringskjeder, herunder planter-smågnagere-små rovdyr. Indikatorer på nedbryternivået er helt manglende.
Funksjonelle grupper innen trofisk nivå	Økosystemegenskapen viser **begrensede avvik** fra referansetilstanden. Vurderingen er basert på to indikatorer med to tilhørende fenomener med god til svært god datadekning og middels til høy gyldighet (VP). Det er evidens for endringer mot et mer borealt system gjennom økende bestander av elg, men endringene vurderes foreløpig som av begrenset betydning for tilstanden til egenskapen. Det er betydelig usikkerhet knyttet til valg av kategori, grunnet utilstrekkelig indikatordekning for egenskapen, som bør utbedres gjennom inkludering av sentrale funksjonelle grupper av planter, øvrige planteetere (smågnagere, insekter), samt øvrige rovdyr/åtseletere (kråkefugl, mårdyr, rovfugl).
Funksjonelt viktige arter og biofysiske strukturer	Økosystemegenskapen viser **begrensede avvik** fra referansetilstanden. Vurderingen er basert på seks indikatorer med seks tilhørende fenomener med middels til svært god datadekning og høy gyldighet (VP). Lave bestander av store rovdyr utgjør et betydelig avvik fra referansetilstanden, mens noe evidens for mindre tydelige lementopper, moderat høye tettheter av boreale rovdyr og tamme beitedyr, samlet sett underbygger valget av kategorien. Det er ingen stor usikkerhet knyttet til valg av kategori, men datadekningen er variabel mellom indikatorer, og indikatordekningen samlet sett er bare 'delvis tilstrekkelig' grunnet fravær av indikatorer som beskriver endringer i vegetasjonsdekket (f.eks krattutbredelse), funksjonelt viktige rovdyr (rovfugl, mårdyr), nedbrytere og insekter.
Landskapsøkologiske mønstre	Økosystemegenskapen viser **begrensede avvik** fra referansetilstanden. Vurderingen er basert på én enkelt indikator, med ett tilhørende fenomen av middels gyldighet (VP) og svært god datadekning. Den beskriver andel fjellareal som er > 1 km fra større tekniske inngrep som svakt minkende. Dette er et avvik fra en intakt tilstand. Det er imidlertid betydelig usikkerhet knyttet til valg av kategori, grunnet utilstrekkelig indikatordekning for egenskapen som bør utbedres gjennom inkludering av strukturelle indikatorer som er mer direkte knyttet til økologi, eksempelvis graden av fragmentering/isolasjon og størrelse av alpine habitater.

***Tabell S3** (fortsatt)*

Biologisk mangfold	Økosystemegenskapen viser **begrensede avvik** fra referansetilstanden. Vurderingen er basert på tre indikatorer med tre tilhørende fenomener med god datadekning og middels (ett fenomen) til høy (2 fenomener) gyldighet (VP). Det er evidens for en nedgang i kullstørrelse hos fjellrev, som inntil videre ser ut til ikke å ha påvirket bestandsstørrelsen. Videre er det nedgang i enkelte alpine fuglearter, konsistent med nedgang i alpine fuglesamfunn generelt på nasjonal og internasjonal skala. Det er imidlertid betydelig usikkerhet knyttet til valg av kategori, grunnet utilstrekkelig indikatordekning for egenskapen som bør utbedres gjennom inkludering av indikatorer på diversitet av andre artsgrupper (planter, invertebrater). Videre er det flere sentrale alpine fuglearter som ikke er inkludert i fugleindikatoren grunnet manglende datadekning på fylkesnivå i de nasjonale overvåkingsdata.
Abiotiske forhold	Økosystemegenskapen viser **betydelige avvik** fra referansetilstanden. Vurderingen er basert på ni indikatorer med ni tilhørende fenomener med svært god datadekning og høy gyldighet (VP). Det er evidens for avvik i økosystemets abiotiske forhold relatert til temperatur og snødekke som utgjør betydelig avvik fra referansetilstanden og må forventes å påvirke økosystemets strukturelle og funksjonelle egenskaper, gjennom endringer i vekstforhold, produktivitet, artsutbredelse og trofiske interaksjoner. Det er ingen stor usikkerhet knyttet til valg av kategori, men indikatordekningen er bare 'delvis tilstrekkelig' grunnet manglende indikatorer på snøkvalitet (snøstruktur, regn-på-snø, ising) med relevans for vegetasjon, beiteforhold, og albedo.

Basert på det tilgjengelige indikatorsettet, og vurderingen av de enkelte egenskaper over, konkluderer fagpanelet med at fjelløkosystemer i Trøndelag viser **begrensede avvik** fra referansetilstanden med fundamentale strukturelle og funksjonelle egenskaper i hovedsak opprettholdt. De betydelige endringer i de abiotiske forhold relatert til temperatur og snødekke forårsaket av klimaendringer har foreløpig gitt begrensede utslag i biotiske indikatorer. De viktigste biotiske avvik er relatert til en regionalt økende produktivitet som er relativt svak på regional skala, men som skjuler stor lokal variasjon både i graden av endring og retning (fra 'bruning' til 'grønning'). Videre ser vi også en nedgang i visse alpine fuglearter, konsistent med dokumenterte endringer nasjonalt og internasjonalt, og økende bestander av boreale hjortedyr og fravær eller svært lave bestander av store rovdyr. Det er stor usikkerhet knyttet til valg av kategori for flere av egenskapene, og dermed også til vurderingen for økosystemet som helhet. Dette skyldes til dels mangler i den samlede indikatordekningen, herunder spesielt fravær av indikatorer knyttet til mellom- og høyalpine sone.



Figur S3. *Grafisk oppsummering av vurderingen av økologisk tilstand for fjell. Se* ***Figur S2*** *for detaljert figurforklaring.*

Hovedøkosystem Våtmark
Fagpanelets tilstandsvurdering av våtmark er oppsummert i **Tabell S4** samt grafisk i **Figur S4** (tilsvarer **Figur 7.4.2** i rapporten). Vurderingen er basert på 16 indikatorer fordelt på fire egenskaper. Tre egenskaper (*Biomassefordeling mellom trofiskenivåer, Funksjonelle grupper innen trofisk nivå, Funksjonelt viktige arter og biofysiske strukturer*) har dermed ingen indikatorer og kan ikke vurderes i denne piloten. Av de fire egenskaper som kan vurderes har tre (*Primærproduktion, Landskapsøkologiske mønstre, Biologisk mangfold*) en samlet indikatordekning som er vurdert til den laveste kategori ('utilstrekkelig'). Egenskapen *Abiotiske forhold* har en samlet indikatordekning vurdert til den mellomste kategorien ('delvis tilstrekkelig'). Fagpanelet konkluderer dermed at det er mulig å gjøre en vurdering av fire egenskaper, men for tre av disse gjøres vurderingen på klart utilstrekkelig grunnlag. En samlet vurdering for økosystemet som helhet kan dermed ikke gjøres basert på det tilgjengelige indikatorsettet.

En av de fire egenskaper som er vurdert (*Abiotiske forhold*) er vurdert til å ha **betydelige avvik** fra referansetilstanden, mens de tre øvrige (*Primærproduktion, Landskapsøkologiske mønstre, Biologisk mangfold*) til å ha **begrensede avvik**.

Tabell S4. *Oppsummering av de primære avvik observert innen hver økosystemegenskap for våtmark og de viktigste kilder til usikkerhet i valget av tilstandskategori.*

Primærproduksjon	Økosystemegenskapen viser **begrensede avvik** fra referansetilstanden. Vurderingen er basert på to indikatorer med to tilhørende fenomener med svært god datadekning og middels gyldighet (VP). Det er evidens for en svak økende trend i produktivitet (grønnhet) for økosystemet i Trøndelag, konsistent med økende temperaturer både i og utenfor vekstsesongen (se *Abiotiske forhold*). Der er betydelige usikkerheter i valget av vurderingskategori særlig knyttet til fravær av indikatorer som belyser endringer i primærproduksjon og/eller biomasse knyttet til sentrale vegetasjonsstrata, f.eks gjengroing av våtmarkshabitater med trær og busker.
Biomassefordeling mellom trofiske nivåer	Ingen indikatorer tilgjengelig. Egenskapen har derfor ikke blitt vurdert.
Funksjonelle grupper innen trofisk nivå	Ingen indikatorer tilgjengelig. Egenskapen har derfor ikke blitt vurdert.
Funksjonelt viktige arter og biofysiske strukturer	Ingen indikatorer tilgjengelig. Egenskapen har derfor ikke blitt vurdert.
Landskapsøkologiske mønstre	Økosystemegenskapen viser **begrensede avvik** fra referansetilstanden. Vurderingen er basert på en indikator med ett tilhørende fenomen med svært god datadekning og middels gyldighet (VP). Den beskriver andel våtmarksareal som er > 1 km fra større tekniske inngrep er lavt (< 50%) og svakt minkende. Dette er et avvik fra en intakt tilstand. Det er imidlertid betydelig usikkerhet knyttet til valg av kategori, grunnet utilstrekkelig indikatordekning for egenskapen som bør utbedres gjennom inkludering av strukturelle indikatorer som er mer direkte knyttet til økologi, eksempelvis graden av fragmentering/isolasjon og størrelse av gjenværende våtmarkshabitater.
Biologisk mangfold	Økosystemegenskapen viser **begrensede avvik** fra referansetilstanden. Vurderingen er basert på en enkelt indikator, med ett tilhørende fenomen av middels gyldighet (VP) og middels datadekning. Den beskriver utviklingen i fuglesamfunn tilknyttet våtmark. Det er imidlertid betydelig usikkerhet knyttet til valg av kategori, grunnet utilstrekkelig indikatordekning for egenskapen, som bør utbedres gjennom inkludering av indikatorer på diversitet av andre artsgrupper (planter, invertebrater). Videre er det flere sentrale fuglearter tilknyttet våtmark som ikke er inkludert i fugleindikatoren grunnet manglende datadekning på fylkesnivå i de nasjonale overvåkingsdata.

***Tabell S4** (fortsatt)*

Abiotiske forhold	Økosystemegenskapen viser **betydelige avvik** fra referansetilstanden. Vurderingen er basert på 12 indikatorer med 12 tilhørende fenomener med svært god datadekning og høy gyldighet (VP) for de fleste fenomener. Det er evidens for avvik i økosystemets abiotiske forhold relatert til temperatur og snødekke som utgjør betydelig avvik fra referansetilstanden og må forventes å påvirke økosystemets strukturelle og funksjonelle egenskaper, gjennom endringer i vekstforhold, produktivitet, artsutbredelse og trofiskerelasjoner. Usikkerheter i valget av vurderingskategori knytter seg særlig til at hydrologiske indikatorer er basert på grove modellerte data, og det er høyst usikkert hvor godt disse representerer faktiske hydrologiske forhold i våtmarksområder. Disse bør suppleres, eller erstattes, med indikatorer på vannstand (overflatevann) basert på en kombinasjon av fjernmålingsdata og feltkalibrering som i høyere grad kan fange opp endringer i våtmarkshydrologi. Videre vil inkludering av en indikator på albedo tillate bedre forståelse av årsakssammenhenger mellom vegetasjonsendringer som påvirker tilstand (f.eks. gjengroing), abiotiske forhold og den regionale tilbakekopling til klima.

***Figur S4.** Grafisk oppsummering av vurderingen av økologisk tilstand for våtmark. Se **Figur S2** for detaljert figurforklaring.*

Hovedøkosystem Åpent lavland

Fagpanelets tilstandsvurdering av åpent lavland er oppsummert i **Tabell S5** samt grafisk i **Figur S5** (tilsvarer **Figur 7.5.2** i rapporten). Vurderingen er basert på 16 indikatorer fordelt på fire egenskaper. Tre egenskaper (*Biomassefordeling mellom trofiske nivåer, Funksjonelle grupper innen trofisk nivå, Landskapsøkologiske mønstre*) har dermed ingen indikatorer og kan ikke vurderes i denne piloten. Av de fire egenskaper som kan vurderes har tre (*Primærproduktion, Funksjonelt viktige arter og biofysiske strukturer, Biologisk mangfold*) en samlet indikatordekning som er vurdert til den laveste kategori ('utilstrekkelig'). Egenskapen *Abiotiske forhold* har en samlet indikatordekning vurdert til den mellomste kategorien ('delvis tilstrekkelig'). Fagpanelet konkluderer dermed at det er mulig å gjøre en vurdering av fire egenskaper, men for tre av disse gjøres vurderingen på klart utilstrekkelig grunnlag. En samlet vurdering for økosystemet som helhet kan dermed ikke gjøres basert på det tilgjengelige indikatorsettet.

To av de fire egenskaper som er vurdert (*Abiotiske forhold*, *Funksjonelt viktige arter og biofysiske strukturer*) er vurdert til å ha **betydelige avvik** fra referansetilstanden, mens de to øvrige (*Primærproduktion, Biologisk mangfold*) til å ha **begrensede avvik**.

Tabell S5. *Oppsummering av de primære avvik observert innen hver økosystemegenskap for åpent lavland og de viktigste kilder til usikkerhet i valget av tilstandskategori.*

Primærproduksjon	Økosystemegenskapen viser **begrensede avvik** fra referansetilstanden. Vurderingen er basert på to indikatorer med to tilhørende fenomener med svært god datadekning og middels gyldighet (VP). Det er evidens for en svak økende trend i produktivitet (grønnhet) for økosystemet i Trøndelag, konsistent med økende temperaturer både i og utenfor vekstsesongen (se *Abiotiske forhold*). Der er betydelige usikkerheter i valget av vurderingskategori grunnet utilstrekkelig indikatordekning, særlig knyttet til fravær av indikatorer som belyser endringer i primærproduksjon og/eller biomasse knyttet til sentrale vegetasjonsgrupper (urter, graminoider busker og trær).
Biomassefordeling mellom trofiske nivåer	Ingen indikatorer tilgjengelig. Egenskapen har derfor ikke blitt vurdert.
Funksjonelle grupper innen trofisk nivå	Ingen indikatorer tilgjengelig. Egenskapen har derfor ikke blitt vurdert.
Funksjonelt viktige arter og biofysiske strukturer	Økosystemegenskapen viser **betydelige avvik** fra referansetilstanden. Vurderingen er basert på tre indikatorer med tre tilhørende fenomener med middels (en indikator) til svært god (to indikatorer) datadekning og høy gyldighet (VP). Det er evidens for endringer i beitedyrsammensetningen som involverer er skifte fra tamme til ville beitedyr, noe som kan forventes å påvirke disses rolle i vedlikehold av semi-naturlige habitater. Det er imidlertid betydelige usikkerheter i valg av kategori grunnet en utilstrekkelig indikatordekning av egenskapen, der indikatorer på funksjonelt viktige plantearter, øvrige insekter og øvrige beitedyr er helt fraværende.
Landskapsøkologiske mønstre	Ingen indikatorer tilgjengelig. Egenskapen har derfor ikke blitt vurdert.
Biologisk mangfold	Økosystemegenskapen viser **begrensede avvik** fra referansetilstanden. Vurderingen er basert på to indikatorer med to tilhørende fenomener med middels til god datadekning og høy gyldighet (VP). Det er evidens for nedgang i enkelte fuglearter tilknyttet det åpne kulturlandskapet, konsistent med nedgang i disse artene nasjonalt og internasjonalt. Det er imidlertid betydelig usikkerhet knyttet til valg av kategori, både grunnet begrenset datadekning for de inkluderte indikatorer og grunnet utilstrekkelig indikatordekning for egenskapen. Denne bør utbedres gjennom inkludering av indikatorer på diversitet av andre artsgrupper (planter, andre invertebrater). Videre er det flere sentrale fuglearter tilknyttet kulturlandskapet som ikke er inkludert i fugleindikatoren grunnet manglende datadekning på fylkesnivå i de nasjonale overvåkingsdata.

Tabell S5 *(fortsatt)*

Abiotiske forhold	Økosystemegenskapen viser **betydelige avvik** fra referansetilstanden. Vurderingen er basert på ni indikatorer med ni tilhørende fenomener med svært god datadekning og høy gyldighet (VP). Det er evidens for avvik i økosystemets abiotiske forhold relatert til temperatur og snødekke som utgjør betydelig avvik fra referansetilstanden og må forventes å påvirke økosystemets strukturelle og funksjonelle egenskaper, gjennom endringer i vekstforhold, produktivitet, artsutbredelse og trofiske relasjoner. Usikkerheter i valget av vurderingskategori knytter seg særlig til hvor godt grove, modellerte klimadata representerer naturlig småfragmenterte habitater som åpent lavland, samt fraværet av indikatorer som beskriver næringsinnhold, og næringsstoffpåvirkning lokalt (særlig nitrogen og fosfor). Videre vil inkludering av en indikator på albedo tillate bedre forståelse av årsakssammenhenger mellom vegetasjonsendringer som påvirker tilstand (f.eks. gjengroing), abiotiske forhold og den regionale tilbakekopling til klima.

Figur S5. *Grafisk oppsummering av vurderingen av økologisk tilstand for åpent lavland. Se* ***Figur S2*** *for detaljert figurforklaring.*

Viktigste kunnskapsbehov og anbefalinger for videreutvikling med tanke på fremtidige operasjonelle tilstandsvurderinger
Pilotvurderingen har avdekket en rekke kunnskapsbehov som er oppsummert i **kapittel 7.7** i rapporten, både i form av en generell diskusjon og en tabell (**Tabell 7.7**) med konkrete anbefalinger til nye indikatorer. Noen av disse kan utvikles basert på eksisterende data, men de fleste vil kreve både utvikling og ny datainnsamling. De mest sentrale kunnskapsbehov og anbefalinger fra fagpanelet oppsummeres som følger:

- En tilstandsvurdering krever at mange ulike typer av overvåkings- og kartleggingsdata anvendes i samme vurdering, og det er en gjennomgående utfordring at disse ofte ikke harmonerer med tanke på design, innsamlingsmetodikk, og oppløsning og dekning i tid og rom. Det avspeiler at de fleste programmer er utviklet individuelt med tanke på overvåking eksempelvis av naturressurser eller enkeltarter og dermed mangler et samlende økosystem-basert design. Det bør vurderes om eksisterende programmer kan suppleres eller justeres slik de kan levere indikatorer som i dag mangler datagrunnlag.

- Noen sentrale overvåkingsprogrammer som er designet til å levere estimater på nasjonal skala har for dårlig dekning til å levere representative estimater på den romlige skala som er indikert for *System for vurdering av økologisk tilstand* (fylkes/regionsskala). Det bør vurderes å supplere disse, slik de oppnår bedre dekning på fylkesnivå.

- Mangelfull geografisk avgrensning av hovedøkosystemer er en gjennomgående utfordring i vurderinger gjort i *System for vurdering av økologisk tilstand*. Det foreløpige kart over hovedøkosystemer (Venter and Stabbetorp 2019) er basert på eksisterende kartgrunnlag og samsvarer ikke nødvendigvis med den konseptuelle definisjonen av hovedøkosystemene i *System for vurdering av økologisk tilstand* (Nybø and Evju 2017) eller NiN. Utvikling av en mer presis økosystemavgrensning i rom er nødvendig, og vil tillate at representativiteten av nasjonale overvåkingsdata i høyere grad kan evalueres for spesifikke økosystem, og gi vesentlig bedre muligheter for effektiv utnyttelse av romlige datasett, herunder utvikling av fjernmålingsbaserte indikatorer.

- Manglende datagrunnlag setter store begrensninger for hvilke typer av indikatorer som kan utvikles. Indikatorsettet som er anvendt i denne piloten er vurdert som mangelfullt (enten ‘utilstrekkelig’ eller ‘delvis tilstrekkelig’) for samtlige egenskaper i alle økosystemer. Dette begrenser i stor grad mulighetene for å vurdere tilstanden til økosystemene som helhet, i særdeleshet for våtmark og åpent lavland som har dårligst tilfang av biologiske data. Videreutviklingen av indikatorer så vel som formulering av nye, bør styres av best mulig empirisk kunnskap, formulert som hypoteser om sammenhenger mellom påvirkningsfaktorer, økologiske prosesser og endringer i tilstand. Fagpanelet har identifisert en liste med sentrale indikatorer for utvikling og inkludering i fremtiden. Disse dekker blant annet:

    - Biomasse og sammensetning av sentrale funksjonelle plantegrupper i alle økosystem
    - Sentrale næringsnett og trofiske relasjoner, f.eks. det smågnager-dominerte næringsnettet på fjellet.
    - Nedbrytere.
    - Mer relevante indikatorer for landskapsøkologiske mønstre herunder habitat fragmentering/isolering og vegetasjonssoneringer som er sensitive for menneskelige påvirkningsfaktorer (f.eks gjengroing av åpne habitater).
    - Biologisk diversitet generelt, og planter, insekter og sopp spesielt.
    - Funksjonelt viktige artsgrupper, f.eks torvmoser i våtmark, krekling i skog og fjell og viktige pollinatorer i flere økosystem.
    - Abiotiske forhold, herunder lokal hydrologi i våtmark, overflaterefleksjon/albedo (alle økosystem) samt karbon og næringsinnhold (C/N og C/P forhold særlig i skog og seminaturlige habitater).

- Økt forskning og utvikling knyttet til koplingen mellom samvirkende påvirkningsfaktorer og tilstanden til indikatorer (årsaks-virkningsforhold) er nødvendig, for å få en bedre kvantitativ forståelse både av den relative betydningen av påvirkningsfaktorer og av betydningen av endringer i enkeltindikatorer for tilstand. En nylig rapport (Pedersen et al. 2021b) diskuterer hvordan slik utviklingsarbeid kan foregå innenfor et PAEC rammeverk.

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Contents

Foreword

On behalf of the Ministry of Climate and Environment, the Norwegian Environment Agency is responsible for the development of the *System for assessment of ecological condition* of terrestrial and marine ecosystems. This report is the product of a project funded by the Norwegian Environment Agency and includes a pilot assessment of four terrestrial ecosystems based on the Panel-based Assessment of Ecosystem Condition (PAEC) protocol.

PAEC is one of two methods developed for use in the *System for assessment of ecological condition*. PAEC forms the basis for a consolidated, evidence-based, assessment of the ecological condition of an ecosystem. In 2021, PAEC has formed the basis for the first full-scale assessments of the ecological condition of arctic tundra ecosystems (Pedersen et al. 2021a). Further, full-scale assessments of the Arctic and Atlantic parts of the Barents Sea, the North Sea, and the Norwegian Sea are underway (2022). In 2020, the Norwegian Environment Agency further commissioned the Norwegian Institute for Nature Research to lead a test of the PAEC protocol (a pilot assessment) for four terrestrial ecosystems: forests, alpine, wetland, and semi-natural/open lowlands, geographically restricted to Trøndelag County, which we report here.

The Scientific panel for the pilot assessment involved 18 researchers from seven Norwegian institutions: The Norwegian Institute for Nature Research (NINA), The Norwegian University for Science and Technology (NTNU), The Norwegian University of Life Sciences (NMBU), The Arctic University of Norway (UiT), the Norwegian Institute of Bioeconomy Research (NIBIO), the Norwegian Meteorological Institute (MET), and the University of Bergen (UiB). NINA has held the project leadership, and the panel was led jointly by Jane Uhd Jepsen (NINA), James Speed, Gunnar Austrheim (both NTNU), and Graciela Rusch (NINA).

The work has followed the workflow for a PAEC assessment as outlined in the PAEC technical protocol and consisted of 1) a scoping phase, where datasets were identified and indicators formulated, 2) an analyses phase with statistical analysis of the data behind each indicator, 3) an assessment phase, where the scientific panel met and discussed the assessment of indicators and ecosystems' characteristics, and 4) the report phase, where the scientific background material and conclusions from the panel were written up in a report according to the PAEC protocol.

The report is a contribution from the entire PAEC Scientific panel, members detailed in Chapter 1. However, several other colleagues also contributed. We thank in particular, John Atle Kålås (NINA) and Christian Pedersen (NIBIO) for assistance with indicators on bird communities based on the TOV-E and 3Q monitoring programs, and Bjørn Økland and Paal Krokene (both NIBIO) for assistance with an indicator based on the national bark beetle monitoring program.

We thank the Norwegian Environment Agency (NEA) for their valuable contributions throughout the process. Eirin Bjørkvoll was the NEA contact for the project. We further thank research directors Cathrine Henaug and Signe Nybø (NINA), for proofreading and quality control of this report.

Tromsø/Trondheim, March 4th 2022

Jane Uhd Jepsen and Graciela Rusch
Project leaders

Introduction to PAEC

Mandated by the Norwegian Ministry of Climate and Environment, the *System for Assessment of Ecological Condition* was developed — for each of the nation's major terrestrial and marine ecosystems not covered by the EU Water Framework Directive — to 1) define criteria for what could be considered "good ecological condition" (e.g. define a "reference condition" for ecosystem assessments; Nybø and Evju 2017) and 2) develop methods for assessing the degree of deviation from this reference condition. Two alternative assessment methods have been developed (Jepsen et al. 2020, Jakobsson et al. 2021). The background for developing the method *Panel-based Ecosystem Assessment of Ecosystem Condition* (PAEC) is an increasing demand for integrated assessments of the condition of entire ecosystem units under intensified anthropogenic pressures. PAEC is inspired by approaches used in several national and international bodies, including the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES 2019), Intergovernmental Panel on Climate Change (IPCC 2022) and the French national ecosystem assessment (EFESE 2022). These bodies share the common notion that the condition or state of complex systems (e.g. climate systems, ecosystems), and the level of evidence for change in the condition of such systems as a result of anthropogenic and natural drivers, are best assessed by broad scientific panels following stringent and structured protocols.

PAEC is a structured protocol for a panel-based assessment of the condition of an ecosystem relative to a specific reference condition (Jepsen et al. 2020). It is a goal that PAEC should provide a framework for making reproducible qualitative assessments based on solid quantitative analyses of the underlying data. The assessment is made in a hierarchical manner and consists of four phases: 1) Scoping, 2) Analysis, 3) Assessment and 4) Reporting and peer review (**Figure 1**). Key to the Scoping Phase, is the formulation of specific formalized expectations (termed *phenomena*) describing expected directional changes in a given indicator or state variable as a result of relevant drivers acting on the system. Phenomena are thus the equivalent of a scientific hypothesis formulated prior to a scientific study. The Analysis Phase consists of a statistical analysis of the underlying data to permit an assessment of the level of evidence for each phenomenon. The Assessment Phase consists of plenary sessions where the assessment panel scrutinizes and assesses the knowledge base underlying the assessment, assesses the condition of each of a set of ecosystem characteristics covering structural and functional components (biotic and abiotic) of the ecosystem, and finally assesses the condition of the entire ecosystem. An independent peer review of the final assessment report with the aim of continuous improvements is a fundamental step in PAEC.

An assessment according to PAEC is primarily a scientific exercise, and the scientific assessment panel should consist of a group of scientists with in-depth knowledge of the focal ecosystem characteristics, as well as relevant quantitative methodology (study design and statistical modelling). However, PAEC is also envisioned to be a tool for adaptive management of ecosystems, or specific ecosystem components. Thus, the protocol allows for the integration of a stakeholder group (consisting for instance of representatives for management agencies responsible for the specific ecosystem) into the assessment process (**Figure 1**). This is non-mandatory, but may serve to broaden PAEC from a purely scientific assessment to an operational and policy-relevant tool for developing management goals and adaptive management strategies for the implementation and assessments of specific management actions. Depending on the type of process in which the protocol is used, the level of stakeholder involvement in the assessment phase may vary across the different phases.

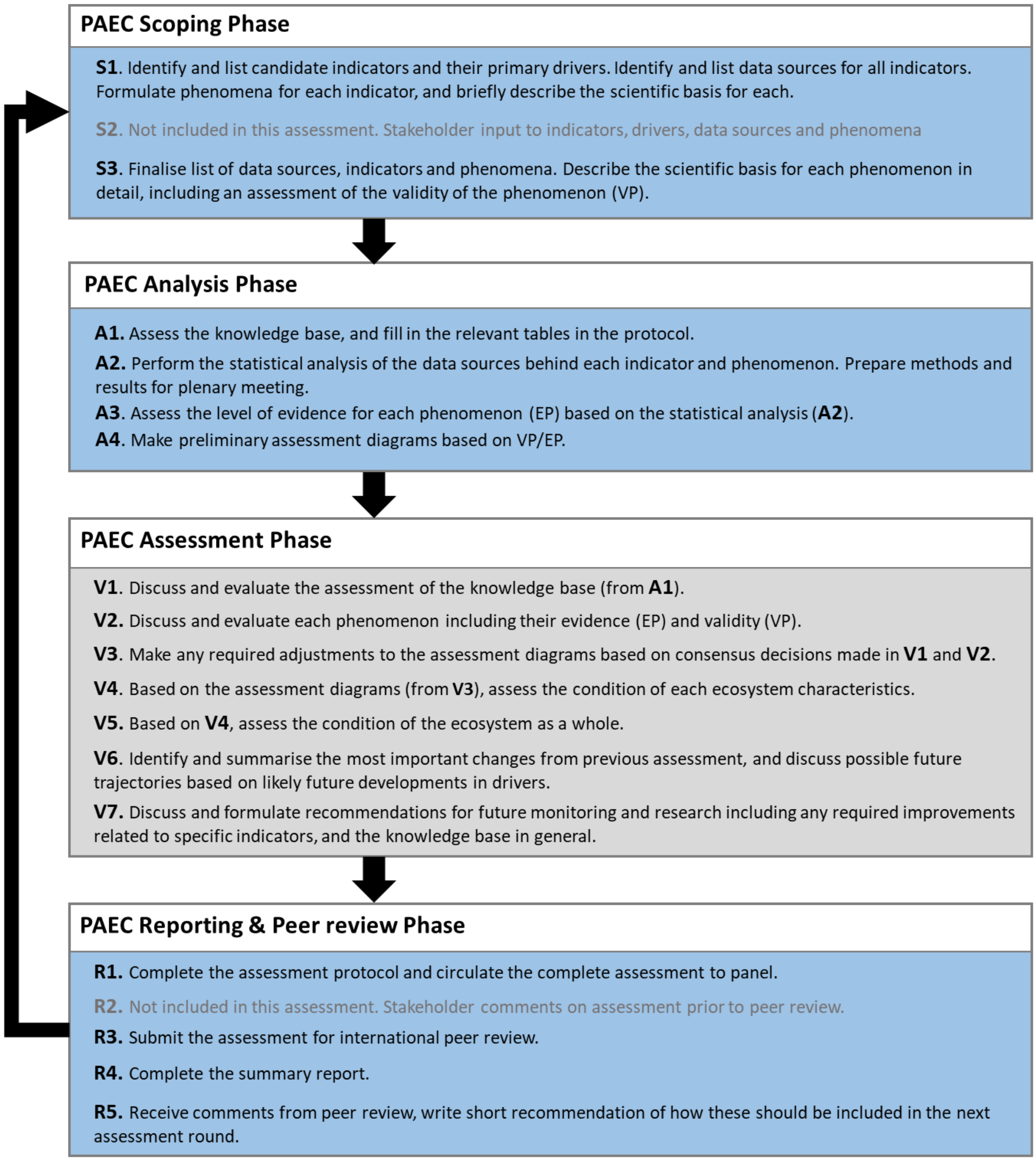


Figure 1. *Summary of the four phases of ecosystem condition assessment according to PAEC, and the main tasks involved in each phase. PAEC allows non-mandatory involvement of a stakeholder group in the assessment panel in addition to the scientific panel. In such cases, the stakeholder group provides input during the Scoping Phase (task S2), participates in the plenary assessment meeting according to agreed terms (tasks V1-V7) and provides comments on the assessment report prior to peer review (R2). Without stakeholder involvement, tasks S2 and R2 are excluded from the assessment process.*

Definition of Terms

Table 1. *Definition of key terms used in the* System for Assessment of Ecological Condition *in general, and in PAEC specifically (from Jepsen et al. 2020).*

Term	Definition
Ecosystem characteristics	Characteristics of an ecosystem underlying how abiotic factors, ecosystem structure and functions interact. In the current assessment framework, seven characteristics are considered: primary productivity, biomass distribution among trophic levels, diversity of functional groups, functionally important species and biophysical structures, landscape ecological patterns, biological diversity, and abiotic factors.
State variable	Ecosystem feature describing an ecosystem characteristic. A state variable measures directly the functions and processes of its corresponding ecosystem characteristic(s). State variables can be used to build models for estimating causal relations between ecosystem characteristics and external drivers and to make quantitative predictions across space and time. One state variable can be associated with several ecosystem characteristics.
Ecosystem condition	The current state of the ecosystem across all ecosystem characteristics, summarizing the state variables, often in terms of their dynamical regime. We consider here the term ecosystem condition synonymous with 'ecosystem state'. State is often used in the context of alternative states, when the ecosystem can shift between regimes that persist at a particular spatial extent and temporal scale, but state changes may also be gradual.
Reference condition	A reference condition describes, the state of the ecosystem at a pre-defined time period (e.g., "a climatic reference period"), or according to specific criteria such as in the absence of local and global human influences ("a pristine state"), or the maintenance of important functional or structural components (e.g., population cycles, "a functional ecosystem"). The reference condition is characterized by the range of variation and covariation among state variables, due to ecosystem dynamics over a period that is long enough to obtain statistically reliable estimates, but with persistent (stable) environmental conditions.
Indicator	A preferably simple and easily interpreted surrogate for a state variable or a driver/pressure (the "canary in the mine"). Because indicators are required to have many properties (e.g. sensitive to changes, applicable over a large area, valid over a wide range of stress, cost-effective), a set of complementary indicators is often required. In this document, the term *indicator* denotes all metrics that are used to describe the focal ecosystem characteristics. Accordingly, it is important to note that indicators may range from *state variables* that directly denote ecological functions and structures, to *surrogate indices* that have more or less validated indirect relations to such functions and structures.
Ecosystem significance	A change in an indicator is of ecosystem significance if it implies ecologically large changes, either in the ecosystem characteristic the indicator is associated with, in other ecosystem characteristics, or generally in ecosystem condition. This is not related to statistical significance.
Phenomenon	An expected directional change in an indicator which is of ecosystem significance, and which can be attributed to one or more relevant drivers. A phenomenon can also specify a level (e.g. 'high'/'low') in addition to the expected directional change. Phenomena are thus the equivalent of scientific hypotheses formulated prior to a scientific study.
Quantitative phenomenon	A phenomenon is quantitative if one can identify and estimate a threshold value for the change in the indicator which, if exceeded, results in a change away from the reference condition which is of ecosystem significance.
Qualitative phenomenon	A phenomenon is qualitative if one cannot identify and estimate such a threshold value, but rather focuses on the type and direction of changes away from the reference condition linked to drivers that can lead to changes of ecosystem significance.

***Table 1** (cont.)*

Term	Definition
Validity of Phenomenon (VP)	Addresses the links between drivers and ecosystem significance by assessing 1) how well we understand the mechanisms by which drivers affect an indicator, and 2) how well we understand how the change in an indicator leads to changes that are of ecosystem significance.
Evidence for Phenomenon (EP)	Assessment of the quality of empirical evidence that 1) the expected change in an indicator has occurred (incl. statistical significance) and 2) the change is of ecosystem significance. The assessment hence considers both the relationship between state variables and indicators, and between indicators and ecosystem condition. The assessment relies upon the consistency in observed changes (over space and time), and the uncertainty of the estimated changes. In particular, a distinction is made between the absence of evidence for a phenomenon due to large uncertainties, and evidence that no change of ecosystem significance has occurred.
Design-based sampling and estimation	Given that one can define a target population with a list of units, design-based sampling uses either probability sampling where the probability that each unit is sampled is known *a priori* (e.g. stratified sampling with more variable strata being sampled more intensively) or some form of systematic sampling (e.g. grid). In the former case, one can use the design to estimate parameters of interest (e.g. averages) with known uncertainty without relying on statistical models.
Model-based sampling and estimation	Aims at maximizing the accuracy of estimates of relationships between predictors (e.g. drivers) and responses (e.g. ecosystem state variables). Designs combine two things: 1) precision of estimates by having large contrasts in predictor values, and 2) accuracy of the functional response by allowing for non-linear responses and by sampling intermediate values of predictors. Model-based estimation uses the model to extrapolate to non-sampled units and is sensitive to the model used, and therefore robustness needs to be evaluated.

1 Composition of the scientific panel

Below we list the participants in the scientific panel, as well as their respective roles and expertise (**Table 1.1**).

Table 1.1. *The composition of the panel leader group, and the scientific assessment panel with definitions of roles. The list is sorted alphabetically within each category.*

Name, institution, email	Role	Expertise with respect to the assessment
Gunnar Austrheim gunnar.austrheim@ntnu.no	Panel leader group, Participant in scientific panel	Forest, alpine and open lowland ecosystems, plant-herbivore interactions, land-use impact
Jane Uhd Jepsen Jane.jepsen@nina.no	Project manager, Panel leader group, Participant in scientific panel, Data management and analysis	Forest and alpine ecosystems, vegetation productivity, food web ecology, plant-herbivore interactions
Graciela Rusch Graciela.rusch@nina.no	Project manager, Panel leader group, Participant in scientific panel	Plant ecology, comparative ecology, ecology of grazing systems, pollination, plant-animal interactions.
James Speed, james.speed@ntnu.no	Panel leader group, Participant in scientific panel	Forest ecology, alpine ecology, plant ecology, plant-herbivore interactions
Johan Asplund, johan.asplund@nmbu.no	Participant in scientific panel	Forest ecosystems, vegetation productivity, functional ecology, food web ecology
Jarle W. Bjerke, jarle.bjerke@nina.no	Participant in scientific panel	Vegetation ecology, climate and environmental effects on vegetation, wetland ecology
Anne E. Bjune anne.bjune@uib.no	Participant in scientific panel	Forest ecosystems, functional ecology, vegetation productivity
Nina E. Eide nina.eide@nina.no	Participant in scientific panel	Alpine ecosystems, community ecology, carnivores and rodents
Ivar Herfindal Ivar.herfindal@ntnu.no	Participant in scientific panel	Population ecology and demography, animal habitat and resource use
Rolf A. Ims Rolf.ims@uit.no	Participant in scientific panel	Alpine and forest ecosystems, food web ecology, bird communities
Markus F. Israelsen Markus.israelsen@nina.no	Data management and analysis	Data analysis, *not a participant in the assessment*
Jutta Kapfer Jutta.kapfer@nibio.no	Participant in scientific panel	Open lowland ecosystems, biodiversity and community ecology
Anders L. Kolstad Anders.kolstad@nina.no	Participant in scientific panel	Forest ecology, plant-herbivore interactions, vegetation ecology.
Jenni Nordén Jenni.norden@nina.no	Participant in scientific panel	Forest ecosystems, biodiversity, carbon dynamics, land-use and climate impacts
Tanja Kofod Petersen Tanja.k.petersen@ntnu.no	Participant in scientific panel, panel secretary,	Functional ecology, land-use impact
Brett K. Sandercock Brett.sandercock@nina.no	Participant in scientific panel	Alpine and wetland ecosystems, population ecology, terrestrial vertebrates
Jenny Stien Jennifer.stien@nina.no	Participant in scientific panel, Data management and analysis	Large predator-herbivore interactions, conservation ecology
Ole Einar Tveito oleet@met.no	Participant in scientific panel, Data management and analysis	Abiotic climatic and hydrological indicators in all ecosystems
Nigel Yoccoz Nigel.yoccoz@uit.no	Participant in scientific panel, Data management and analysis	Alpine and forest ecosystems, statistical analyses, climate impacts

2 Definition of the reference condition

The common framework for all assessments of ecological condition made under the *System for Assessment of Ecological Condition* is defined in Nybø and Evju (2017). In Nybø and Evju (2017), the reference condition is defined as “intact ecosystems”, and the assessment should consider whether or not, or the extent to which, the current condition of the ecosystem and its components deviate from this reference condition.

The recent PAEC assessment of Arctic tundra (Pedersen et al. 2021a) translates (from Norwegian) the definitions from Nybø and Evju (2017) of what constitutes an “intact ecosystem”, and what climatic reference the assessment should be based on. They further reiterate the normative description of the condition of each ecosystem characteristic under the reference condition, also from Nybø and Evju (2017). For an extended discussion however, we refer to Nybø and Evju (2017). We use the same wording here (**Box 1 and 2**) as in Pedersen et al. (2021a). Subsequently, we describe how these definitions have been incorporated in the current pilot assessment of the ecological condition of terrestrial ecosystems in Trøndelag according to PAEC.

Box 1. Definitions from Nybø and Evju (2017), translation from Pedersen et al. (2021a).

Intact ecosystems

Intact, natural and semi-natural, ecosystems are characterised by the maintenance of fundamental structures, functions and productivity. Intact ecosystems are further characterised by having complete food webs, and element cycles. The majority of the food web consists of native species which dominate at all trophic levels and in all functional groups. The species composition, population structure and genetic diversity of native species are results of natural processes occurring through the ecological and evolutionary history of the ecosystem. Intact ecosystems possess characteristics which are not changing systematically over time, but vary within the boundaries of the natural dynamics of the system.

Human influences can be present, but should not be pervasive or dominating, or be a factor which changes the structure, function or productivity of the ecosystem. This means that human influences should not be at a scale which exceeds the impacts of natural pressures (e.g. disturbance) or dominating species (e.g. top predators) in the ecosystem. Further, human influences should not lead to changes which are more rapid or more pervasive than natural pressures in the ecosystem. In semi-natural ecosystems, the human activities which define the system (e.g. grazing, hay cutting) are considered an integral part of the ecosystem.

Reference climate

The climate used as a basis for the assessment of intact ecosystems is a climate as described for the climatic normal period 1961–1990.

Box 2. The normative description from Nybø and Evju (2017) of each of seven ecosystem characteristics under the reference condition, translation from Pedersen et al. (2021a).

Primary productivity: The primary productivity does not deviate substantially from the productivity in an intact ecosystem. Reason: Elevated or decreased primary productivity indicates a system impacted for instance by eutrophication, overgrazing or drought.

Biomass distribution among trophic levels: The distribution of biomass among trophic levels does not deviate substantially from the distribution in an intact ecosystem. Reason: Substantial shifts in biomass distribution between trophic levels indicate a system impacted for instance by removal of top predators.

Functional groups within trophic levels: The functional composition within trophic levels does not deviate substantially from the composition in an intact ecosystem. Reason: Substantial changes in the functional composition within trophic levels indicate a system impacted for instance by loss of functional groups (e.g. pollinators), loss of open habitat species due to encroachment, or super-dominance of certain functional groups or species (e.g. jellyfish in marine habitats).

Functionally important species and biophysical structures: The functions of functionally important species, habitat building species and biophysical structures do not deviate substantially from the functions in an intact ecosystem. Reason: Functionally important species (e.g. small rodents), habitat building species (e.g. coral reefs, kelp forest), and biophysical structures (e.g. dead wood) have vital importance for the population size of a number of species, and changes in their occurrence will hence have functional implications for the ecosystem.

Landscape-ecological patterns: Landscape-ecological patterns are compatible with the persistence of species over time, and do not deviate substantially from an intact ecosystem. Reason: Human influences can lead to changes in landscape-ecological patterns which have implications for the population size and population structure of native species, for instance through habitat fragmentation. Fragmented habitats may not be sufficiently large or connected to permit long-term survival of native species. Climate change, altered area use, pollution and invasive or introduced species may also influence landscape-ecological patterns with implications for population size and composition of native species.

Biological diversity: The genetic diversity, species composition and species turnover do not deviate substantially from an intact ecosystem. Reason: Loss of biological diversity can cause the ecosystem to be less resilient towards pressures and disturbances, and influence the structure, functions and productivity of the ecosystem. Changes in rates of species turnover, due to extinction or colonisation can indicate a modified system.

Abiotic factors: Abiotic condition (physical and chemical) does not deviate substantially from an intact ecosystem. Reason: Human influences (e.g. environmental toxins, fertilization, changed hydrology or acidification) can lead to substantial changes in the physical/chemical structure and function of the ecosystem, which in turn will impact the species composition, function and dynamics of the ecosystem[1].

[1]Abiotic factors are in this context considered to include the climatic conditions under which the ecosystem exists, and climatically derived indicators hence included in the assessment of the ecosystem characteristic Abiotic factors.

The main implications of the above definitions (**Box 1 and 2**) for the current assessment are the following:

- In PAEC, the condition of the ecosystem and its characteristics is classified to categories, depending on the extent to which their current condition deviate from a defined reference condition. Following the definition of the reference condition in **Box 1**, the current assessment hence focuses on the extent to which the ecosystem and its components deviate from an intact ecosystem condition in which the structure, functions and productivity of the ecosystem are under no or limited influence from human pressures including climate change.
- The definition provided in **Box 1** from Nybø and Evju (2017) for the ecosystem characteristic *Biodiversity,* is considered to also include endemic species or other species typical ('defining') for a particular ecosystem. Loss or decline of such species is interpreted as a deviation from an intact ecosystem.
- Phenomena (see Definitions of Terms and Ch. 5) are formulated relative to the reference condition representing an 'intact ecosystem' according to the definition in **Box 1**. This means that a given phenomenon describes the expected directional change away from an intact ecosystem as a result of human pressures.
- Climate change is an influential human pressure, and altered climatic conditions have pervasive impacts on important structural and functional attributes of ecosystems. Climatic indicators hence play an important role in the assessment of the ecosystem characteristic *Abiotic factors*.
- In order to consider the given definition of the reference climate (**Box 1**), climate indicators are analysed and evaluated relative to the average and variability observed during the 1961–1990 climate normal period. This does not imply that 1961–1990 is considered an 'ecological reference period' given that human influences could be extensive already during this time period, or indeed much prior to it. However, it is of relevance to evaluate the extent to which the ecological and climatic data underlying the assessment, can in fact be considered representative for a climate corresponding to the 1961–1990 normal period. This is particularly true for northern ecosystems that already experience climatic conditions which are, in part, substantially different from the conditions before 1990.

The Arctic fox is an example of a species which typify alpine ecosystems. Loss or decline of such species is interpreted as a deviation from an intact ecosystem. Photo: NINA/SNO automatic camera trap, Trøndelag 2017.

3 Ecosystem delineation and data sources

3.1 Delineation of the ecosystems

This pilot is geographically restricted to Trøndelag County. Within this region, four major terrestrial ecosystems are considered: forest, alpine, wetland and open lowland. In principle, the definition of these ecosystems within the *System for Assessment of Ecological Condition* are given in Nybø and Evju (2017) and follows *Natur i Norge* (NiN). NiN classifies natural systems according to a hierarchy of types (Halvorsen et al. 2016), e.g., it is a conceptual classification which allows natural systems to be described and recognised in the field. For an assessment of ecosystem condition across a large region however, it is necessary to delineate the ecosystems not just conceptually, but also geographically in order to utilise spatial data sources such as climate data, remote sensing data or hydrological data. A first attempt at such a geographical delineation for use within the *System for Assessment of Ecological Condition* has been produced based on existing map sources, mainly the Norwegian high and medium resolution land resource data sets, AR5 (Ahlstrøm et al. 2019) and AR50 (Flo-Heggem et al. 2019), and modelled estimates of the forest-alpine boundary, in the form of *Kart over hovedøkosystem i Norge version 1.0* (Venter and Stappetorp 2019). The extent to which a map-based geographical delineation is concurrent with the conceptual definitions of the ecosystems based on NiN types vary, and there are several important discrepancies between NiN classes and the ecosystem map by Venter and Stabbetorp (2019), as many NiN classes cannot be recognized in existing map sources. This is discussed in some detail by Venter and Stabbetorp (2019), and there are ongoing efforts to harmonize and operationalize ecosystem typologies and their geographical representation.

In this assessment, we base the geographical ecosystem delineation of spatial data sets on Venter and Stabbetorp (2019) and choose to use the same categories as the most recent Norwegian Nature Index (NI) for forest, alpine, wetland and open lowland ecosystems (appendix 2 in Jakobsson and Pedersen 2020, and **Figure 3.1**). We highlight that the geographical delineation is particularly challenging for open lowland and wetland. There are a variety of ecological conditions that characterize the different types within for instance open lowland, and there is a lack of correspondence between the conceptual definitions in NiN and available map sources (Venter and Stabbetorp 2019). Open lowland, according to this definition includes semi-natural and natural open areas below the tree line, including boreal heath, coastal heath, semi-natural meadow, and coastal meadow. For a large part these are lowland, and relatively coastal near areas that are maintained by land management such as livestock grazing, mowing and fire, to hinder successional processes of shrub and tree encroachment. However, both semi-natural types and naturally open areas are also located further inland and at higher elevations. Efforts are being undertaken to improve the geographical delineation and classification of open types, utilizing not only existing map sources but also remote sensing data sources (Venter et al. 2019, Framstad et al. 2021b). For the time being, the geographical delineation of the ecosystem termed open lowland in this context, must be approximate, and is likely too conservative.

The definitions of the major ecosystems in Nybø and Evju (2017) contain suggestions for a further subdivision into ecosystem types, either according to NiN or other criteria (for instance a division of the alpine ecosystem into low, middle and high alpine ecosystem types). While this has ample merit and should be pursued in the continued development of the *System for assessment of ecological condition*, the methodological development required to arrive at a corresponding geographical delineation into relevant ecosystem types is much beyond the scope of this pilot. However, when the data sources permit, we show indicator values for what we consider relevant strata within an ecosystem (for instance different forest types within the forest ecosystem).

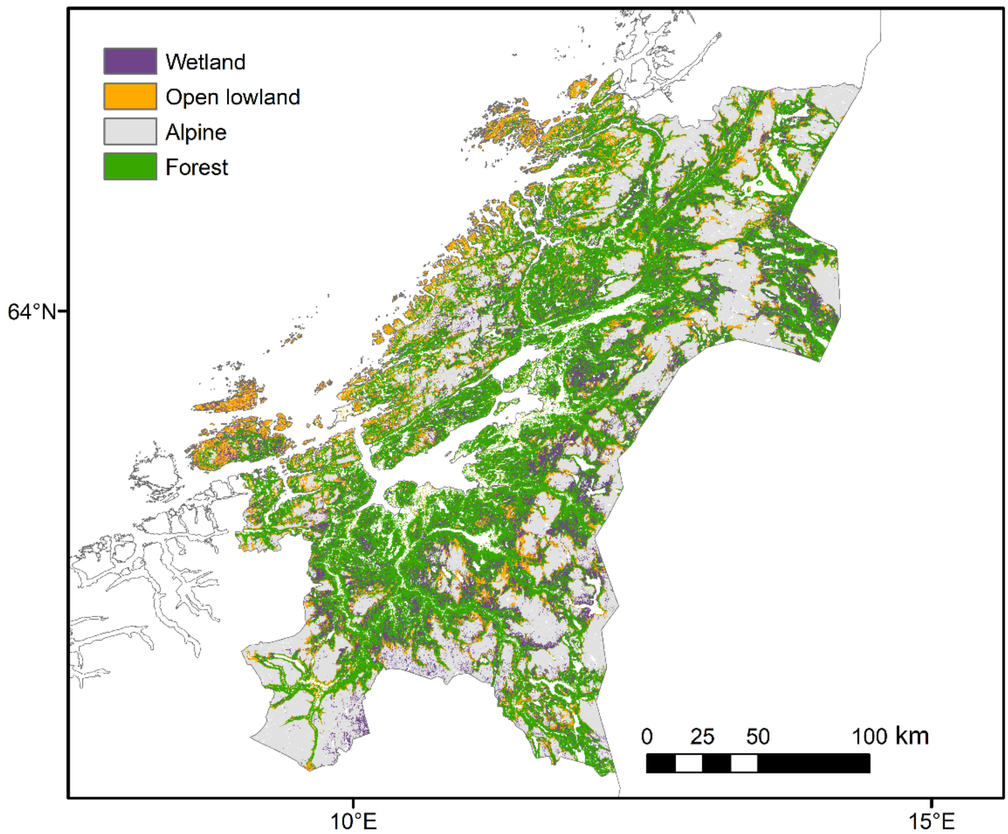


Figure 3.1*. A map of the geographical delineation of the four ecosystems in Trøndelag based on Venter and Stabbetorp 2019, and Jakobsson and Pedersen 2020.*

3.2 General considerations regarding data sources

The datasets pertaining to this pilot (details in **Table 3.1**) for Trøndelag County, come from a number of separate thematic monitoring programs on vegetation (forests), and animal species/species groups (small mammals, foxes, large carnivores, birds, ungulates, bumble bees, butterflies), as well as from national statistics (forestry related activities, infrastructure development), global remote sensing programs (vegetation, primary productivity), and the national services from the Norwegian Meteorological institute and the Norwegian Water Resource and Energy Directorate (climate and hydrology). In contrast, the recent PAEC assessment for Arctic ecosystem (Pedersen et al. 2021a, Arneberg et al. unpublished[1]) could rely on ecosystem-based monitoring programs/systems dedicated to the specific ecosystems being assessed (e.g. COAT (www.coat.no) and MOSJ (www.mosj.no) for Arctic tundra, and the Joint Norwegian/Russian Ecosystem survey for the Barents Sea; Meeren and Prozorkevich 2021). The strength of ecosystem-based monitoring in context of PAEC is that the data sampling design is tailored for assessing phenomena (e.g. via model based sampling) that are specific for the targeted ecosystems and that they provide time series so rates of change, for instance in population densities or biological interactions, can be assessed even in absence of information about reference conditions. Such systematic sampled time series were not available for the four ecosystems in Trøndelag. In recent years, several national scale monitoring programmes have been initiated or are planned, such as the Area representative monitoring of terrestrial ecosystems (ANO, Evju and Nybø 2018, Tingstad et al. 2019), the National programme for insect monitoring (Åström et

[1] Arneberg, P. et al. (in prep.). Panel-based assessment of ecological condition in the Arctic part of the Barents Sea. Assessment currently in progress.

al. 2020a,b) and the National area-representative monitoring of semi-natural grassland (ASO; Bär et al. 2021a,b). These programmes may represent data sources for the future, so long as they require sufficient site coverage for the main ecosystems at the target spatial scale for the assessments of ecological condition (currently region/county-level). However, their temporal and spatial coverage is currently limited, and insufficient for quantifying change over time. While space-for-time substitutions can be used for making ecological inferences (Pickett 1989), in particular about slow ecological processes, it can lead to erroneous conclusions unless based on independent knowledge regarding the state which each site represents along the relevant natural (e.g. environmental, successional) and/or anthropogenic (e.g. impact) driver gradients (Damgaard 2019, Kratz et al. 2003). Currently, the extent to which the sampling design employed in the above-mentioned monitoring programs represent relevant space-for-time substitutions has not been sufficiently evaluated, and this should be done prior to basing ecological condition indicators on space-for-time substitutions (Blois et al. 2013). In some parts of the county, quite extensive mapping of natural and seminatural areas using the Nature in Norway (NiN) protocol (Halvorsen et al. 2016) have been undertaken. However, the NiN-mapping is typically targeted towards areas of particular concern which makes it a less suitable means to inform about the general condition of an ecosystem. NiN-mapping is also rarely repeated for an area and provides no information about change in the ecosystem condition. Another challenge with these monitoring programmes is that they focus on one or a few species groups (i.e. plants or insects). They will therefore not provide information about ecological changes over the entire ecosystem, or interspecific interactions. Important taxa such as fungi and vertebrates, and functional groups such as decomposers and detritivores are not adequately monitored. Finally, there are concerns related to representativity of some national monitoring programs supplying data to this assessment, due to low site coverage at the target spatial scale of the *System for assessment of ecological condition* (region/county-scale; Nybø and Evju 2017). Programs that are designed for national scale assessment may have too coarse a spatial resolution (sampling intensity) to allow robust regional assessments.

The lack of appropriate programmes for systematically monitoring ecosystems over time and for several species groups and abiotic factors means that the point of departure for this pilot for assessing changes in the condition of ecosystem components, and the ecosystem as a whole, is very different from previous PAEC assessment, in terms of the conceptual basis for choosing indicators (see below) and phenomena, the availability of data overall, and the interoperability of data sources given by the degree of spatial, temporal and methodological overlap between data sets.

A few indicators rely on satellite data, and we have chosen to use medium resolution data (MODIS) rather than data from the temporally more restricted, but spatially more detailed Sentinel satellites, since the ability to assess whether changes have occurred over time (i.e. long time series) is essential. It must also be stressed that even the MODIS data provide rather short time series (21 years) compared to the time scales of ecological change and the chosen reference period. Combining the legacy from MODIS with spatially more detailed satellite data from sentinel/Copernicus, and with coarser-resolution satellite data with longer coverage (e.g. the AVHRR GIMMS data, Tucker et al. 2005) is an obvious avenue both for improvement of the knowledge base for future assessments, and for improvement of existing remote sensing based indicators, which we discuss further in Chapter 7.7.

The climate and hydrological data applied for this assessment are modelled gridded data from SeNorge2, which are spatially continuous and represent variability in time and space with a spatial resolution of 1 x 1 km (Lussana et al. 2018a,b, Beldring et al. 2003). This provides a common, and well documented data set which is uniform across all terrestrial ecosystems in Norway, and which covers the entire climatic reference period. However, they are spatially coarse, modelled data, which have limitations further addressed in this report.

Most indicators that include densities of ungulates (both livestock and wildlife) use an existing data set of ungulate metabolic biomass, estimated across Norway (Speed et al. 2019). This dataset estimates metabolic biomass, allowing for demographic structure across livestock based upon agricultural statistics, and wild species based on hunting statistics. Data is available every 10th year from 1949 to 2009 as well as 2015. This dataset was selected for most indicators since it provides the best estimate of long-term dynamics and uses a comparable approach across species. However, for indicators that focus on the ecosystem characteristic of biomass distribution between trophic levels, the decadal dataset often overlapped poorly with datasets quantifying other trophic levels (i.e. plants or carnivores). For some of these, annual density estimates were used; while these were shorter in duration, they provided better overlap with the other trophic levels. For other indicators of this characteristic, browsing pressure data were used and made reference to published studies on plant performance at given browsing pressure.

3.3 Choice and utility of indicators

The current assessment is a methodological pilot. The main purpose of the pilot is to test the assessment methodology for new ecosystems, with potentially different challenges related to data availability and the level of understanding of driver-response relationships, than the terrestrial and marine Arctic ecosystems for which the PAEC protocol has hitherto been used (Jepsen et al. 2019, Pedersen et al. 2021a, Arneberg et al. unpublished)[1]. The indicator set included in this pilot is not as complete as would be required for making an operational assessment. However, the set of indicators included represent realistic variability with respect to driver relationships (types of drivers and complexity in these relationships), understanding (phenomena of both higher and lower validity), and data coverage. Further, it is extensive enough to illustrate all aspects of the hierarchical (i.e. indicators - ecosystem characteristics – ecosystem) assessment method in PAEC. It has been a requirement that the indicators should be founded on some level of conceptual understanding of the “impact pathways” of the most important drivers, and hence allow us to cover the assumed most important phenomena (expected directional change away from the reference condition as a result of these drivers). Some included indicators may be tentatively formulated with obvious avenues for improvement, either by including additional or different data sources, or by developing more suitable or comprehensive indicator metrics or statistical models. Such specific concerns are addressed for each indicator in **Appendix 1** under “Recommendations for future development of the indicator”.

For two of the ecosystems in particular (wetland and open lowland), low data availability has placed severe limitations on the number and types of indicators which could be included in the pilot. For this reason, it has been a goal also to provide extensive recommendations for additional indicators which should be considered for development and inclusion in future operational assessments, in order to achieve a more adequate indicator coverage over time. These recommendations are placed in Chapter 7.7.

Table 3.1. *Description of data sources used for the assessment of ecological condition of the four ecosystems in Trøndelag. The column 'Country wide coverage' indicates whether the data sources are available for the whole of Norway.*

Data set name	Data set ID	Data set DOI/URL	Owner institution	Contact person	Content and methods	Temporal coverage	County wide coverage
Temperature	D01	https://thredds.met.no/thredds/catalog/senorge/seNorge2/provisional_archive/catalog.html578-4b04-b5d3-7adf0c5a1e60	Norwegian Meteorological Institute (MET)	Ole Einar Tveito, MET	Daily gridded data with 1x1 km spatial resolution (Lussana et al. 2018a,b)	1957-2020	Yes
Precipitation	D02	https://thredds.met.no/thredds/catalog/senorge/seNorge2/provisional_archive/catalog.html578-4b04-b5d3-7adf0c5a1e60	Norwegian Meteorological Institute (MET)	Ole Einar Tveito, MET	Daily gridded data with 1x1 km spatial resolution (Lussana et al. 2018a,b)	1957-2020	Yes
Snow cover	D03	https://thredds.met.no/thredds/catalog/senorge/seNorge2/provisional_archive/catalog.html578-4b04-b5d3-7adf0c5a1e60	Norwegian Meteorological Institute (MET)	Ole Einar Tveito, MET	Daily gridded data with 1x1 km spatial resolution (Lussana et al. 2018a,b)	1957-2020	Yes
MODIS EVI	D04	https://e4ftl01.cr.usgs.gov/MOLT/MOD13Q1.006/	NASA Goddard Space Flight Center, Ocean Ecology Laboratory, Ocean Biology Processing Group, Moderate Resolution Imaging Spectroradiometer (MODIS) Terra	Torkild Tveraa, NINA	EVI every 16 days through the entire year with 250 x 250 m resolution based on the MODIS product MOD13Q1 (Huete et al. 2002)	2000-2020	Yes
National Forest Inventory (NFI)	D05	https://www.nibio.no/om-nibio/vare-fagdivisjoner/divisjon-for-skog-og-utmark/landsskogtakseringen	Norwegian Institute of Bioeconomy Research (NIBIO)	Aksel Granhus, NIBIO	Surveys of 250 m^2 permanent plots in a 5-year rotational scheme (Viken 2018). For the present assessment, individual plots are identified by a unique ID, and spatially identified to the level of municipalities.	1994-2019 (2-5 rotations)	Yes

Table 3.1 *(cont.)*

Data set name	Data set ID	Data set DOI/URL	Owner institution	Contact person	Content and methods	Temporal coverage	County wide coverage
Areas without major infra-structure	D06	https://kartkata-log.geonorge.no/?text=villmark	Norwegian Environment Agency	--	«Inngrepsfri Natur i Norge (INON)». National-wide maps (one per status year) showing areas located > 1 km and > 5 km from larger technical in-frastructure	1988, 1998, 2003, 2008, 2013, 2018	Yes
Semidomestic reindeer abundance	D07	Reinbase.no - Overvåkings-program for tamrein - Rein-drift og rovvilt	NINA	Torkild Tveraa, NINA	Annual reported counts by reindeer districts of the abundance of rein-deer at district scale	1981 – 2020	Yes
Large carni-vores	D08	https://rovdata.no/	rovdata.no managed by the Norwegian Institute for Nature Research (NINA)	Jennifer Stien, NINA	The annual number of lynx, wolver-ine, and bear reproductions.	1996-2021 (variable btw species)	Yes
Fox camera traps	D09	Pending upload to gbif early 2022	Norwegian Institute for Na-ture Research (NINA)	Nina E. Eide, NINA	Camera trap stations placed on ex-perimental carcasses in late winter (6 weeks) in Børgefjell, Lierne and Sylan in Trøndelag	2011-2019	No
Butterflies and bumble-bees	D10	https://www.gbif.org/da-taset/aea17af8-5578-4b04-b5d3-7adf0c5a1e60	Norwegian Institute for Na-ture Research (NINA)	Jens Åström, NINA	Monitoring of bumblebees and but-terflies along 1 km transects at 52 sites in Norway, of which 18 fall within Trøndelag (each transect con-sists of 20 sub-transects of 50 m).	2011-2020	No
Ungulate bio-mass	D11	https://doi.org/10.1371/journal.pone.0217166	Norwegian University of Science and Technology (NTNU)	James Speed, NTNU	Metabolic biomass of ungulate herbi-vores (wild and livestock) in munici-pal (kommune) shapefiles.	1949 - every 10 years to 2009, plus 2015	Yes

***Table 3.1** (cont.)*

Data set name	Data set ID	Data set DOI/URL	Owner institution	Contact person	Content and methods	Temporal coverage	County wide coverage
Bark beetles	D12	https://www.nibio.no/tema/skog/skogskadeovervaking-i-norge/barkbilleovervaking	Norwegian Institute of Bioeconomy Research (NIBIO)	Bjørn Økland, NIBIO	Annual monitoring of European spruce bark beetle (*Ips typographus*) by pheromone trapping (Økland and Beachell 2020)	1979-2021,	No
Bird communities TOV-E	D13	https://tov-e.nina.no/Fugl/Default.aspx#	Norwegian Institute for Nature Research (NINA) and Norsk Ornitologisk Forening (NOF/BirdLife Norway)	John Atle Kålås, NINA	Monitoring of breeding bird communities with annual surveys of point counts and transects in fixed route surveys in a national-level grid. https://tov-e.nina.no/hekkefugl	2006-2020	Yes
Trenching	D14	https://www.ssb.no/statbank/table/03677/tableViewLayout1/	Statistics Norway (SSB)	Terje Olav Rundtom, SSB	The length of trenching and the area affected by trenching in mire and forest per year, county-level (SSB Table 03677: *Skoggrøfting. Tørrlagt areal og grøftelengde, etter region, år og statistikkvariabel*)	1968-2020	Yes
Soil water content	D15	https://beta.senorge.no/map	Norwegian Meteorological Institute (MET), Norwegian Water Resources and Energy Directorate (NVE)	Ole Einar Tveito, MET	SeNorge variable gwb_sssrel	1957-2020	Yes
Ground water condition	D16	https://beta.senorge.no/map	Norwegian Meteorological Institute (MET), Norwegian Water Resources and Energy Directorate (NVE)	Ole Einar Tveito, MET	SeNorge variable gwb_gwtcl	1957-2020	Yes
Bird communities 3Q	D18	https://www.nibio.no/tema/landskap/systematisk-overvaking-av-jordbrukslandskap/3q/3q-overvaking-av-fugler	Norwegian Institute of Bioeconomy Research (NIBIO)	Christian Pedersen, NIBIO	Monitoring of bird communities in agricultural areas, ~3-year rotational scheme. Pedersen et al. 2020 http://hdl.handle.net/11250/2646864	2000-2017	Yes (in agricultural land)

Table 3.1 *(cont.)*

Data set name	Data set ID	Data set DOI/URL	Owner institution	Contact person	Content and methods	Temporal coverage	County wide coverage
Forest fertilization	D19	https://www.ssb.no/statbank/table/05543	Statistics Norway (SSB)	Terje Olav Rundtom, SSB	Used only as supporting information for forest indicators which might be influenced by forest fertilization. Contains statistics on the area of forest subject to subsidized fertilization (SSB table 05543: *Gjødsling av skog. Areal og kostnad (F) 1997 – 2020*)	1997-2020	Yes
Forest tending of young stands	D20	https://www.ssb.no/statbank/table/05544	Statistics Norway (SSB)	Terje Olav Rundtom, SSB	Used only as supporting information for forest indicators which might be influenced by forest tending practices. Contains statistics on the area of forest subject to subsidized tending of young stands (SSB table 05544: *Ungskogpleie. Areal og kostnad (F) 1995 – 2020*)	1995-2020	Yes
Forest pesticide use	D21	https://www.ssb.no/statbank/table/05542	Statistics Norway (SSB)	Terje Olav Rundtom, SSB	Used only as supporting information for forest indicators which might be influenced by forest chemical treatment. Contains statistics on the area subject to subsidized chemical treatment targeted at weeds and young deciduous trees (SSB table 05542: *Kjemisk rydding og ugrasskontroll. Areal og kostnad (F) 1995 – 2020*)	1995-2020	Yes
Arctic fox abundance and litter size	D22	https://rovdata.no/	Norwegian Environment Agency (Mdir)	Nina E. Eide, NINA	Annual monitoring of known Arctic fox dens for registration of occurrence of breeding, including minimum litter size.	1988-2020 (variable between areas). Shared protocol from 2003	Yes (for all arctic fox populations)

Table 3.1 *(cont.)*

Data set name	Data set ID	Data set DOI/URL	Owner institution	Contact person	Content and methods	Temporal coverage	County wide coverage
Browsing pressure on ROS species	D24	--	NINA	Erling Solberg, NINA	Data originates from D05 (National Forest Inventory rotation 10-12). The summary statistics were obtained through personal communication with E. Solberg, and correspond to updated versions of the data used in Solberg et al. (2017)	2010-2020	Yes
Rodent trap-ping series	D25	https://nina.share-point/com/sites/15539200	Norwegian Environ-ment Agency (Mdir)	Nina E. Eide, NINA	Rodent snap trapping data from the Terrestrial monitoring Program (TOV); Viermadalen and Åmotsdalen (Framstad 2021), and a shorter trap-ping series from Børgefjell in (2006, onwards)	1992-2020	No
Reindeer abundance	D26	https://hjorteviltregis-teret.no	Naturdata	--	Estimates/counts of the number of wild reindeer in herds in Trøndelag (Snøhetta, Knutshø and Forollhogna). "Kalvetelling" is used as the counting method; this is done during summer, prior to harvest	1991-2017	Yes

4 Estimation of indicators and rates of change

This section describes methods for how indicator values are calculated, based on the datasets presented in Chapter 3. Here, we give a brief tabular summary (**Table 4.1**) of the specific methods used for each indicator, including methods used to estimate statistical uncertainties. **Appendix 1** *Supplementary information on indicators* is an important addition to this chapter. It includes details regarding the overall analytical framework used to estimate rates of change in abiotic indicators and indicators based on time-series (**Appendix 1**, Chapter 1). It further includes graphical representations of all indicator values and background data for these values, as well as supplementary methods for estimating indicator values where required. Indicators which are used across several or all ecosystems only feature once both in **Table 4.1** and **Appendix 1**.

Both large and small herbivores are key drivers of vegetation change and indicators for several ecosystem characteristics. Domestic sheep grazing in forest (top left, photo: Jutta Kapfer). Deer grazing on cultural land (top-right, photo: Ivar Herfindal). Cattle grazing on cultural land (bottom left, photo: Ivar Herfindal). The impact of lemming grazing in an alpine snow bed (bottom right, photo: Rolf A. Ims).

Table 4.1. *Methods for estimating indicators from the data sets. Data set ID refer to* ***Table 3.1****. See also* ***Appendix 1*** *for details on individual indicators.*

Ecosystem	Ecosystem characteristics	Indicator [indicator ID]	Data set ID	Methods
All	Primary productivity	Maximum greenness [F10, A10, W10, S10]	D04	Remotely sensed estimates are used (i.e. cover the whole ecosystem). Annual maximum productivity in the growing season is calculated as maximum EVI per pixel across all observed values in June–August each year. The indicator values are time series of the average maximum greenness per year. Rate of change in maximum greenness across all years is calculated per pixel with AR models as described in Appendix 1. The spatial distribution of the rate of change (e.g. browning/greening trends) is further presented in a map.
All	Primary productivity	Onset of greening [F11, A11, W11, S11]	D04	Remotely sensed estimates are used (i.e. cover the whole ecosystem). Annual onset of greening (DOY) is calculated per pixel as the date where EVI is higher than 50 % of maximum greening. The indicator values are time series of the average onset of greening per year. Rate of change in onset of greening across all years is calculated per pixel with AR models as described in Appendix 1. The spatial distribution of the rate of change (e.g. earlier/later green-up) is further presented in a map.
Forest	Primary productivity	Tree volume [F22]	D05	The indicator is based on the variable *vmprha* (volume under bark per ha) from the National Forest Inventory. The indicator values are mean and variation of this variable across all plots in Trøndelag, divided according to dominant tree species and harvest class over 5 rotations. The data are not suited for time series regression analysis.
Forest	Biomass distribution among trophic levels	ROS species versus moose [F18]	D05, D11, D24	The indicator consists of two components: ROS species volume (see indicator ROS volume) and moose density (see indicator Wild ungulate density). The data series lack overlap and ratio between the two trophic levels (ROS : moose) can therefore not be analysed directly. We therefore present each level individually as well as additional summary statistics which quantify the trophic relationship directly. These are from the National Forest Inventory and show the % of ROS shoots which are browsed over 3 rotations.
Forest	Biomass distribution among trophic levels	Bilberry versus deer and moose [F24]	D05, D11	The indicator consists of two components: bilberry coverage (see indicator Bilberry coverage) and the total metabolic biomass of moose and red deer (see indicator Wild ungulate density). The data series lack overlap and ratio between the two trophic levels (bilberry : deer and moose) can therefore not be analysed directly.
Forest, Alpine	Biomass distribution among trophic levels	Ungulates versus carnivorous vertebrates [F25, A24]	D11, D08, D26	For forest, the ungulate level is represented by the total metabolic biomass of wild ungulates (moose, red deer, and roe deer; see Indicator Wild ungulate density). For alpine, this level is represented by estimates of total population size of wild- and semidomestic reindeer. For both ecosystems, the carnivore level is represented by the density of large carnivores which typify the ecosystem (forest: wolf, brown bear and lynx; alpine: wolverine; see indicator Large predator abundance). The time series have partial overlap, but the temporal and spatial structure of the two data sets for forest species does not permit the ratio between the two trophic levels (forest ungulates : forest carnivores) to be analysed directly For alpine species, the ratio between the two trophic levels is analysed directly for a relatively short period.

Table 4.1. *(cont.)*

Ecosystem	Ecosystem characteristics	Indicator [indicator ID]	Data set ID	Methods
Forest	Functional groups within trophic levels	Plant growth forms: deciduous proportion [F27]	D05	The indicator is based on the variables *vmprha* (volume under bark per ha) and *vmprhal* (volume of deciduous under bark per ha) from the National Forest Inventory. The indicator values are mean and variation of this variable across all plots in Trøndelag, divided according to dominant tree species and harvest class over 5 rotations. The data are not suited for time series regression analysis.
Forest	Functional groups within trophic levels	Herbivorous vertebrates: browsers versus grazers [F19]	D11	The indicator is based on estimated total biomass of each species of domestic ungulates per municipality in Trøndelag (Speed et al. 2019 and Appendix 1) at decadal intervals since 1949. The total browser versus grazer pressure for a given point in time is calculated based on the estimated contribution of each ungulate species to each of these two forage groups (classified in Austrheim et al. 2011). This classification includes both domestic, semi-domestic and wild ungulates. The indicator value is the log ratio between the proportion browsers:grazers. The rates of change are calculated using AR models as described in Appendix 1.
Alpine	Functional groups within trophic levels	Herbivorous vertebrates: reindeer:moose/deer [A22]	D11	The indicator is based on estimated total biomass of each species of domestic ungulates per municipality in Trøndelag (Speed et al. 2019 and Appendix 1) at decadal intervals since 1949. The indicator value is the log ratio between the more alpine ungulates species (wild and semi-domestic reindeer) versus the more subalpine ungulate species (moose and red deer). The rate of change is calculated with AR models as described in Appendix 1.
Alpine	Functional groups within trophic levels	Carnivorous vertebrates: arctic versus red fox [A21]	D09	The indicator value is the log-ratio between Arctic fox and red fox camera indices per alpine area. Camera indices express the proportion of days a given fox species is captured by camera traps, out of the total number of trapping days (see indicator red fox camera index). The rate of change is calculated with AR models as described in Appendix 1.
Forest	Functionally important species and biophysical structures	Bark beetle abundance [F14]	D12	The indicator value is the mean number of bark beetles of the species *Ips typographus* per monitoring trap. The analysis is done separately for Nord- and Sør-Trøndelag, to adhere to the same geographical regions as the national bark beetle monitoring program which supply the data. Rate of change across all years is calculated based on mean values with AR models as described in Appendix 1.
Forest, Alpine, Open lowland	Functionally important species and biophysical structures	Wild ungulate density [F16, A17, S14]	D11	The indicator is based on estimated total biomass of each species of wild ungulates per municipality in Trøndelag (Speed et al. 2019 and Appendix 1) at decadal intervals since 1949. The indicator value for wild ungulates in forest ecosystems is the total metabolic biomass of moose, red deer and roe deer. The indicator value for wild ungulates in alpine ecosystems is the total metabolic biomass of wild reindeer and muskox. The indicator value for wild ungulates in open lowland ecosystems is the total metabolic biomass of red deer. The rates of change are calculated using Mixed effects models as described in Appendix 1.

Table 4.1. *(cont.)*

Ecosystem	Ecosystem characteristics	Indicator [indicator ID]	Data set ID	Methods
Alpine	Functionally important species and biophysical structures	Semi-domestic reindeer density [A13]	D11	The indicator is based on estimated total biomass of each species of domestic ungulates per municipality in Trøndelag (Speed et al. 2019 and Appendix 1) at decadal intervals since 1949. The indicator value is the total metabolic biomass of semi-domestic reindeer. The rates of change are calculated using AR Mixed effects models as described in Appendix 1.
Forest, Alpine, Open lowland	Functionally important species and biophysical structures	Domestic ungulate density [F17, A16, S13]	D11	The indicator is based on estimated total biomass of each species of domestic ungulates per municipality in Trøndelag (Speed et al. 2019 and Appendix 1) at decadal intervals since 1949. The indicator value for domestic ungulates in forest ecosystems is the total metabolic biomass of sheep, cattle and goats. The indicator value for domestic ungulates in forest ecosystems is the total metabolic biomass of sheep. The indicator value for domestic ungulates in open lowland ecosystems is the total metabolic biomass of cattle. The rates of change are calculated using AR Mixed effects models as described in Appendix 1.
Forest	Functionally important species and biophysical structures	Dead wood volume [F21]	D05	The indicator is based on the variables *DODVED_10CM_VMPRHA* and *DODVED_30CM_VMPRHA* (volume of dead wood > 10 cm and > 30 cm) from the National Forest Inventory. The indicator values are mean and variation of this variable across all plots in Trøndelag, divided according to dominant tree species over 3 rotations. The data are not suited for time series regression analysis.
Forest	Functionally important species and biophysical structures	ROS volume [F28]	D05	The indicator is based on the variable *ROS_10CM_VMPRHA* (volume of rowan, aspen and goat willow per ha) from the National Forest Inventory. The indicator values are mean and variation of this variable across all plots in Trøndelag, divided according to dominant tree species over 5 rotations. The data are not suited for time series regression analysis.
Forest	Functionally important species and biophysical structures	Bilberry coverage [F20]	D05	The indicator is based on the variable *BLAABAER_GJSN* (% coverage of bilberry) from the National Forest Inventory. The indicator values are mean and variation of this variable across all plots in Trøndelag, divided according to dominant tree species over 2 rotations. The data are not suited for time series regression analysis.
Forest, Alpine	Functionally important species and biophysical structures	Large predator abundance [F23, A15]	D08	The indicator value is the abundance of large predators expected to be present in forest (wolf, brown bear and lynx) and alpine (wolverine) ecosystems respectively. The rates of change are calculated using AR models as described in Appendix 1.
Alpine	Functionally important species and biophysical structures	Red fox camera index [A14]	D09	The indicator value is the proportion of days where red foxes are captured by camera traps per alpine area. The rate of change is calculated with AR models as described in Appendix 1.

Table 4.1. *(cont.)*

Ecosystem	Ecosystem characteristics	Indicator [indicator ID]	Data set ID	Methods
Alpine	Functionally important species and biophysical structures	Lemming abundance [A18]	D25	The indicator is an annual abundance index (captures/100 trap nights) of lemmings per monitoring areas. The rate of change is calculated with AR models as described in Appendix 1.
Open lowland	Functionally important species and biophysical structures	Bumblebee abundance and species richness [S17]	D10	The indicator value is the mean number of identified bumblebee species and mean abundance within 1.5×1.5km grid cells, as counted along 1 km transects at three occasions during summer from 2012 to 2019. The original dataset encompasses 52 sites in Norway, the analyses here only included the 18 sites in Trøndelag. The rate of change is calculated with AR models as described in Appendix 1.
Forest, Alpine, Wetland	Landscape ecological patterns	Areas free of major infrastructure [F12, A12, W12]	D06	The indicator value is the total area which is > 1 km from major technical infrastructure for each status year (1988, 1998, 2003, 2008, 2013). The data are not suited for time series regression analysis.
Alpine	Biological diversity	Alpine bird communities [A23]	D13	The indicator values are composite population indices scaled using 2008 as a base year (2008 = index value 1.0). Indices are presented for a subset of bird species considered typical for alpine ecosystems and for a small number of guilds within this community. Single species indices are first calculated using standard statistical methodology as described in Appendix 1 (TRIM models; Bogaart et al. 2020). Multi-species composite indices are then calculated as geometric means across all contributing species.
Forest	Biological diversity	Forest bird communities [F15]	D13	The indicator values are composite population indices scaled using 2008 as a base year (2008 = index value 1.0). Indices are presented for a subset of bird species considered typical for forest ecosystems and for a small number of guilds within this community. Single species indices are first calculated using standard statistical methodology as described in Appendix 1 (TRIM models; Bogaart et al. 2020). Multi-species composite indices are then calculated as geometric means across all contributing species.
Wetland	Biological diversity	Wetland bird communities [W16]	D13	The indicator values are composite population indices scaled using 2008 as a base year (2008 = index value 1.0). Indices are presented for a subset of bird species considered typical for wetland ecosystems. Single species indices are first calculated using standard statistical methodology as described in Appendix 1 (TRIM models; Bogaart et al. 2020). Multispecies composite indices are then calculated as geometric means across all contributing species.
Open lowland	Biological diversity	Farmland bird communities [S16]	D13, D18	This indicator utilizes two different datasets with different data coverage but an overlap in the included species. The indicator values are composite population indices scaled using 2008 (D13) or 2002 (D18) as a base year (index value = 1.0). Indices are presented for a subset of bird species considered typical for farmland. Single species indices are first calculated using standard statistical methodology as described in Appendix 1 (TRIM models; Bogaart et al. 2020). Multispecies composite indices are then calculated as geometric means across all contributing species.

Table 4.1. *(cont.)*

Ecosystem	Ecosystem characteristics	Indicator [indicator ID]	Data set ID	Methods
Open lowland	Biological diver-sity	Butterfly abundance and diversity [S15]	D10	The indicator value is the mean number of identified butterfly species and mean abundance within 1.5×1.5km grid cells, as counted along 1 km transects at three occasions during summer from 2012 to 2019. The original dataset encompasses 52 sites in Norway; the analyses here only included the 18 sites in Trøndelag. The rate of change is calculated with AR models as described in Appendix 1.
Alpine	Biological diver-sity	Arctic fox abundance [A19]	D22	The indicator value is the annual number of litters observed per alpine area. Here including data from three subpopulations: Børgefjell, Blåfjellet/Hestkjølen/Skjækerfjellet, and Kjølifjellet/Sylane. The rates of change are calculated using AR models as described in Appendix 1.
Alpine	Biological diver-sity	Arctic fox litter size [A20]	D22	The indicator value is the minimum estimates of litter sizes observed per alpine area averaged over all litter observed in a given area in a given year. The rates of change are calculated using AR models as de-scribed in Appendix 1.
All	Abiotic factors	Annual mean tem-perature [F01, A01, W01, S01]	D01	The indicator is the yearly average of daily mean air temperature from gridded (modelled) data. The rate of change in the indicator is calculated using linear models as described in Appendix 1. The spatial distri-bution of mean values during the climatic reference period (1961 - 1990) and rates of change after 1991 (e.g. cooling/warming trends) are further presented in a map.
All	Abiotic factors	January mean tem-perature [F02, F02, W02, S02]	D01	The indicator is the yearly average of daily mean air temperature in January from gridded (modelled) data. The rate of change in the indicator is calculated using linear models as described in Appendix 1. The spatial distribution of mean values during the climatic reference period (1961-1990) and rates of change after 1991 (e.g. cooling/warming trends) is further presented in a map.
All	Abiotic factors	July mean tempera-ture [F03, A03, W03, S03]	D01	The indicator is the yearly average of daily mean air temperature in July from gridded (modelled) data. The rate of change in the indicator is calculated using linear models as described in Appendix 1. The spa-tial distribution of mean values during the climatic reference period (1961-1990) and rates of change after 1991 (e.g. cooling/warming trends) is further presented in a map.
All	Abiotic factors	Winter days above 0°C [F04, A04, W04, S04]	D01	The indicator is the yearly average number of days during the winter season (Nov.– Apr.) that have an average temperature above 0°C from gridded (modelled) data. The rate of change in the indicator is cal-culated using log-linear models as described in Appendix 1. The spatial distribution of mean values dur-ing the climatic reference period (1961-1990) and rates of change after 1991 (e.g. increasing/decreasing trends) is further presented in a map.
All	Abiotic factors	Degree days [F05, A05, W05, S05]	D01	The indicator is the yearly average number of days that have an average temperature above 5°C from gridded (modelled) data. The rate of change in the indicator is calculated using log-linear models as de-scribed in Appendix 1. The spatial distribution of mean values during the climatic reference period (1961-1990) and rates of change after 1991 (e.g. increasing/decreasing trends) is further presented in a map.

Table 4.1. *(cont.)*

Ecosystem	Ecosystem characteristics	Indicator [indicator ID]	Data set ID	Methods
All	Abiotic factors	Growing degree days [F06, A06, W06, S06]	D01	The indicator is the yearly average of the sum of temperatures > 5°C during the growing season (May – Oct.) from gridded (modelled) data. The rate of change in the indicator is calculated using log-linear models as described in Appendix 1. The spatial distribution of mean values during the climatic reference period (1961 - 1990) and rates of change after 1991 (e.g. increasing/decreasing trends) is further presented in a map.
All	Abiotic factors	Annual precipitation [F07, A07, W07, S07]	D02	The indicator is the yearly accumulated precipitation from gridded (modelled) data. The rate of change in the indicator is calculated using log-linear models as described in Appendix 1. The spatial distribution of mean values during the climatic reference period (1961 - 1990) and rates of change after 1991 (e.g. increasing/decreasing trends) is further presented in a map.
All	Abiotic factors	Growing season precipitation [F08, A08, W08, S08]	D02	The indicator is the yearly accumulated precipitation during the growing season (May - Oct.) from gridded (modelled) data. The rate of change in the indicator is calculated using log-linear models as described in Appendix 1. The spatial distribution of mean values during the climatic reference period (1961 - 1990) and rates of change after 1991 (e.g. increasing/decreasing trends) is further presented in a map.
All	Abiotic factors	Snow cover duration [F09, A09, W09, S09]	D03	The indicator is the yearly average number of days with snow cover during the winter season (Nov. – Apr.) from gridded (modelled) data. The rate of change in the indicator is calculated using log-linear models as described in Appendix 1. The spatial distribution of mean values during the climatic reference period (1961-1990) and rates of change after 1991 (e.g. increasing/decreasing trends) is further presented in a map.
Wetland	Abiotic factors	Soil water content during growing season [W14]	D15	The indicator contains two metrics generated from the same gridded (modelled) data set; the annual mean soil water content and the annual number of days in which the mean soil water content drops below an arbitrary low limit (< 40%; i.e. representing 'dry' days). The rate of change in the indicator is calculated using log-linear models as described in Appendix 1.
Wetland	Abiotic factors	Ground water condition during growing season [W15]	D16	The indicator is based on gridded (modelled) data which classify the ground water condition into 5 levels depending on the deviation from a long-term reference. The indicator value is the annual number of days in which the ground water condition is in the lowest two categories (GWC = 'low' or 'very low'; i.e. representing 'dry' days). The rate of change in the indicator is calculated using log-linear models as described in Appendix 1.
Forest, Wetland	Abiotic factors	Trenching [F13, W13]	D14	The indicator is based on official statistics on the forest and wetland area in Trøndelag that has been drained by subsidized trenching activities. The indicator value is the annual area and the cumulative total area. The data are not suited for time series regression analysis.

5 Assessment of deviations from the reference condition

This chapter describes the overall approach used to assess deviation from the reference condition. In a tabular format (**Table 5.1**), we list which phenomena are linked to each individual indicator, the main anthropogenic drivers of change for each indicator, and the general approach used to assess whether, and to what degree, the phenomena have occurred. This is followed (Chapter 5.1) by a more detailed text describing the scientific evidence base for each indicator. We use the definitions of the major anthropogenic direct drivers of change[2] in the Global Assessment report of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES 2019) and refer more specifically to the following sub-categories:

- Changes in land use
  - Habitat transformation and loss
  - Habitat fragmentation
  - Land-use intensification (including grazing and browsing intensity and other land management practices directly affecting the vegetation cover)
- Direct exploitation of organisms.
  - Harvest
  - Wildlife (incl. game) management
- Climate change
- Pollution
  - Fertilizer use
- Invasion of alien species (not relevant in this assessment since no indicators were included where invasion of alien species were considered an important driver of change).

The abundance of dead wood is monitored as part of the NFI and is an important indicator for forest ecosystems. Dead wood contributes to soil formation and nutrient cycling, and changes in the amount and diversity of dead wood influence the richness and community structure of dead wood dependent species. Photo: Anne Bjune (left), Jutta Kapfer (right).

[2] IPBES 2019, p.5: *The direct drivers of change in nature with the largest global impact have been (starting with those with most impact): changes in land and sea use; direct exploitation of organisms; climate change; pollution; and invasion of alien species.*

***Table 5.1**. A list of all phenomena including the overall approach used to determine the extent to which each phenomenon has occurred. The three possible approaches are (Jepsen et al. 2020): 1) the phenomenon is assessed relative to an estimated quantitative threshold value ('quantitative phenomena'), 2) the phenomenon is assessed relative to variation estimated from the indicator time series (the type and/or direction of rates of change) or other qualitative or quantitative information about a reference condition ('qualitative phenomena'), 3) the phenomenon is assessed relative to observed and expected effects of changes in the indicator on other components of the ecosystem (i.e. ecosystem significance). Note that some phenomena express both direction (e.g. 'increase'/'decrease') and state (e.g. 'high'/'low').*

Ecosystem	Ecosystem characteristics	Indicator [indicator ID]	Phenomenon [phenomenon ID]	Main anthropogenic drivers	Approach
All	Primary productivity	Maximum greenness [F10, A10, W10, S10]	Changes in maximum greenness [PF28, PA21, PW17, PS17]	Climate change, land-use intensification	2) and 3)
All	Primary productivity	Onset of greening [F11, A11, W11, S11]	Earlier onset of greening [PF29, PA22, PW18, PS18]	Climate change	2) and 3)
Forest	Primary productivity	Tree volume [F22]	Changes in tree volume [PF30]	Land-use intensification, climate change	2) and 3)
Forest	Biomass distribution among trophic levels	ROS species versus moose [F18]	High or increasing biomass of moose relative to ROS species [PF13]	Wildlife management, climate change	2) and 3)
Forest	Biomass distribution among trophic levels	Bilberry versus deer and moose [F24]	Changes in the relative density of bilberry and deer [PF14]	Land-use intensification, wildlife management, climate change	2) and 3)
Forest, Alpine	Biomass distribution among trophic levels	Ungulates versus carnivorous vertebrates [F25, A24]	High or increasing density of ungulates relative to large carnivores [PF15, PA13]	Wildlife management, climate change	2) and 3)
Forest	Functional groups within trophic levels	Plant growth forms: deciduous proportion [F27]	Low or decreasing deciduous proportion [PF16]	Land-use intensification, climate change	2) and 3)
Forest	Functional groups within trophic levels	Herbivorous vertebrates: browsers versus grazers [F19]	Changes in the composition of functional groups within the herbivore vertebrate community [PF17]	Wildlife management, land-use intensification, climate change	2) and 3)
Alpine	Functional groups within trophic levels	Herbivorous vertebrates: reindeer:moose/deer [A22]	Changes in the composition of functional groups within the herbivore vertebrate community [PA15]	Climate change, wildlife management, land-use intensification	2) and 3)
Alpine	Functional groups within trophic levels	Carnivorous vertebrates: arctic versus red fox [A21]	Decreasing occurrence of arctic fox relative to red fox [PA14]	Wildlife management, climate change	2) and 3)
Forest	Functionally important species and biophysical structures	Bark beetle abundance [F14]	Increasing abundances of bark beetles resulting in increasing frequency or severity of outbreak episodes [PF18]	Climate change, land-use intensification	2) and 3)

***Table 5.1**. (cont.)*

Ecosystem	Ecosystem characteristics	Indicator [indicator ID]	Phenomenon [phenomenon ID]	Main anthropogenic drivers	Approach
Forest, Alpine	Functionally important species and biophysical structures	Wild ungulate density [F16, A17, S14]	Changes in density of wild ungulates [PF19, PA10]	Climate change, wildlife management	2) and 3)
Alpine	Functionally important species and biophysical structures	Semi-domestic reindeer density [A13]	Changes in density of semi-domestic reindeer [PA25]	Land-use intensification, climate change	2) and 3)
Forest, Alpine	Functionally important species and biophysical structures	Domestic ungulate density [F17, A16, S13]	High or increasing density of domestic ungulates [PF20, PA16]	Land-use intensification	2) and 3)
Forest	Functionally important species and biophysical structures	Dead wood volume [F21]	Low or decreasing dead wood volume [PF21]	Land-use intensification	2) and 3)
Forest	Functionally important species and biophysical structures	ROS volume [F28]	Low or decreasing ROS volume [PF22]	Land-use intensification, climate change, wildlife management	2) and 3)
Forest	Functionally important species and biophysical structures	Bilberry coverage [F20]	Low or decreasing bilberry coverage [PF24]	Climate change, land-use intensification, wildlife management	2) and 3)
Forest, Alpine	Functionally important species and biophysical structures	Large predator abundance [F23, A15]	Low or decreasing large predator abundance [PF23, PA18]	Wildlife management	2) and 3)
Alpine	Functionally important species and biophysical structures	Red fox camera index [A14]	Increasing or high proportion of days with red fox captures by camera traps [PA19]	Climate change, wildlife management, land-use intensification	2) and 3)
Alpine	Functionally important species and biophysical structures	Lemming abundance [A18]	Less frequent, less distinct peaks in the lemming cycle [PA12]	Climate change	2) and 3)
Open lowland	Functionally important species and biophysical structures	Bumblebee abundance and species richness [S17]	Low or decreasing bumblebee abundance or diversity [PS15]	Habitat loss, habitat fragmentation, pollution, climate change	2) and 3)

***Table 5.1**. (cont.)*

Ecosystem	Ecosystem characteristics	Indicator [indicator ID]	Phenomenon [phenomenon ID]	Main anthropogenic drivers	Approach
Forest, Alpine, Wetland	Landscape ecological patterns	Areas free of major infrastructure [F12, A12, W12]	Low or decreasing areas free of major infrastructure [PF25, PA20, PW15]	Habitat loss, habitat fragmentation.	2) and 3)
Forest, Wetland	Landscape ecological patterns	Trenching [F13, W13]	Large or increasing area affected by historical or present-day trenching [PF26, PW16]	Habitat loss	2) and 3)
Alpine	Biological diversity	Alpine bird communities [A23]	Decreasing abundances and/or species diversity within the community of alpine birds [PA11]	Climate change	2) and 3)
Forest	Biological diversity	Forest bird communities [F15]	Decreasing abundances and/or species diversity within the community of forest birds [PF12]	Climate change, habitat loss, land-use intensification	2) and 3)
Wetland	Biological diversity	Wetland bird communities [W16]	Decreasing abundances and/or species diversity within the community of wetland birds [PW13]	Climate change, habitat loss, land-use intensification	2) and 3)
Open lowland	Biological diversity	Farmland bird communities [S16]	Decreasing abundances and/or species diversity within the community of farmland birds [PS11]	Habitat loss, land-use intensification, pollution, climate change	2) and 3)
Open lowland	Biological diversity	Butterfly abundance and diversity [S15]	Decreasing butterfly abundance or diversity [PS10]	Habitat loss, habitat fragmentation, pollution, climate change	2) and 3)
Alpine	Biological diversity	Arctic fox abundance [A19]	Absence of sustained increase in Arctic fox abundance despite conservation efforts [PA23]	Climate change, wildlife management, land use intensification	2) and 3)
Alpine	Biological diversity	Arctic fox litter size [A20]	Small or decreasing litter size [PA24]	Climate change, wildlife management	1), 2) and 3)
All	Abiotic conditions	Annual mean temperature [F01, A01, W01, S01]	Increasing annual temperature [PF01, PA01, PW01, PS01]	Climate change	2) and 3)
All	Abiotic conditions	January mean temperature [F02, F02, W02, S02]	Increasing January temperature [PF02, PA02, PW02, PS02]	Climate change	2) and 3)

***Table 5.1**. (cont.)*

Ecosystem	Ecosystem characteristics	Indicator [indicator ID]	Phenomenon [phenomenon ID]	Main anthropogenic drivers	Approach
All	Abiotic conditions	July mean temperature [F03, A03, W03, S03]	Increasing July temperature [PF03, PA03, PW03, PS03]	Climate change	2) and 3)
All	Abiotic conditions	Winter days above 0°C [F04, A04, W04, S04]	Increasing number of winter days above 0°C [PF04, PA04, PW04, PS04]	Climate change	2) and 3)
All	Abiotic conditions	Degree days [F05, A05, W05, S05]	Increasing number of degree days [PF05, PA05, PW05, PS05]	Climate change	2) and 3)
All	Abiotic conditions	Growing degree days [F06, A06, W06, S06]	Increasing growing degree day sum during the growing season [PF06, PA06, PW06, PS06]	Climate change	2) and 3)
All	Abiotic conditions	Annual precipitation [F07, A07, W07, S07]	Changes in annual precipitation [PF07, PA07, PW07, PS07]	Climate change	2) and 3)
All	Abiotic conditions	Growing season precipitation [F08, A08, W08, S08]	Changes in precipitation during the growing season [PF08, PA08, PW08, PS08]	Climate change	2) and 3)
All	Abiotic conditions	Snow cover duration [F09, A09, W09, S09]	Shorter season with snow cover [PF09, PA09, PW09, PS09]	Climate change	2) and 3)
Wetland	Abiotic conditions	Soil water content during growing season [W14]	Decreasing soil water content or increasing number of days with low soil water content [PW10]	Climate change	2) and 3)
Wetland	Abiotic conditions	Ground water condition during growing season [W15]	Increasing number of days with low ground water level [PW12]	Climate change	2) and 3)

5.1 Scientific evidence base for the phenomena

This section contains a short textual description of the scientific evidence base of the phenomenon formulated for each indicator supported by references to the scientific literature. The description contains the following elements:

1. A brief normative description of each indicator under the reference conditions.
2. The most important biotic and abiotic drivers of change in the indicator (summarized in **Table 5.1**).
3. A rating of the current understanding of the link(s) between drivers and changes in the indicator as either certain or less certain. The rating also includes how well the indicator is known to capture the expected state change. The rating is needed to assess the validity of the phenomenon (VP) in Chapter 7.
4. A rating of the current understanding of the role of the indicator in the ecosystem, and hence our understanding of the importance of changes in the indicator for ecosystem condition, as good or less good. The rating is needed to assess the validity of the phenomenon (VP) in Chapter 7.
5. A description of why the occurrence of the phenomenon constitutes a deviation away from the reference condition which are likely to be of ecosystem significance, with potential examples of how changes in the indicator can be considered of **ecosystem significance**.

The scientific evidence base for indicators which are used across several ecosystems is only described once.

5.1.1 Primary productivity

Indicator(s): Maximum greenness [F10, A10, W10, S10]
Phenomenon: Changes in maximum greenness [PF28, PA21, PW17, PS17]
Ecosystem characteristic: Primary productivity
Under the reference condition, maximum greenness is mainly limited by temperature and moisture during the growing season. The indicator will vary between different types of vegetation and landscape, for instance owing to topographic, edaphic and hydrological conditions. Data from field-based or remote sensing-based studies covering the climatic baseline (1961-1990) are unavailable for most ecosystems. However, consistent change rates in indicators monitored by remote sensing over more recent decades, when interpreted in relation to changes in relevant drivers, provide good indicators of change, and are widely used both globally (Caparros-Santiago et al. 2021) and for northern and boreal regions (Berner et al. 2020).

The most important anthropogenic drivers of change in this indicator are climate change (i.e. changed growing conditions), forestry, through its effects on forest age, structure and species composition (Sulla-Menashe et al. 2018), land use and land conversion, and grazing by wild and managed herbivores (Bråthen et al. 2017). Climate change can also influence this indicator indirectly through intensification of forest pest outbreaks (Jepsen et al. 2011, Marini et al. 2017), increasing frequency or severity of grassland, heathland or forest fires (Venäläinen et al. 2020, Krikken et al. 2021) or through reduced grazing pressure from rodents in alpine habitats due to absence or suppression of cyclic peak years (Ims et al. 2011, Olofsson et al. 2012). The links to anthropogenic drivers (climatic and biotic) are considered certain, but changes in remote sensing derived greenness (or indeed total plant biomass) are often complex results of multiple drivers operating at different scales, making it a challenge to distinguish the effects of different drivers. The understanding of the effects of changes in greening patterns, as a proxy for changes in green biomass/plant productivity, are assessed as good for forest and alpine ecosystems, but less good for the open lowland and wetland ecosystems, due to less studies targeting these ecosystems. Plant productivity influences the availability of forage for large and small herbivores, and implications have been shown for example for body mass and reproductive success of ungulates in alpine and tundra habitats (Hamel et al. 2011, Henden et al. 2021b, Tveraa et al. 2013). Changes in both directions may indicate a worsened condition, depending on the cause, and thus needs to be interpreted relative to relevant drivers. Greening trends can be considered of **ecosystem significance** if, for example, i) they can be linked to increasing encroachment by shrubs and trees in open habitat ecosystems (alpine, open lowland and wetland) or drying out of wetlands, ii) productivity over time in alpine habitats approaches or corresponds to that of forest or tall shrub areas below the tree line. Browning trends may indicate vegetation damage during winter, or deteriorated growing conditions during summer, and can be considered of ecosystem significance if, for example, i) they can be linked to detrimental weather effects and are extensive enough to affect the availability for grazers, ii) they affect the land use patterns of grazers or game animals, iii) they can be linked to climatically intensified forest disturbance, such as wildfires and pest outbreaks.

Indicator(s): Onset of greening [F11, A11, W11, S11]
Phenomenon: Earlier onset of greening [PF29, PA22, PW18, PS18]
Ecosystem characteristic: Primary productivity
Onset of greening indicates the timing of the spring green-up of vegetation, which is primarily climatically determined. Under the reference condition, this indicator will hence vary within the bounds given by the climate regime during the climatic reference period 1961–1990. Although data on climate are available from this period, the climate variables of interest currently lack the spatial resolution required to define snow conditions and temperatures relevant for vegetation and thus also to set absolute reference values for this indicator.

The most important anthropogenic driver of changes in this indicator is climate change. Start of the growing season is affected by temperature and snowmelt, and the links to these drivers are assessed as <u>certain</u> (e.g., Schwartz et al 2006, Vitasse et al. 2011, Piao et al. 2015, Iler et al. 2017, Buermann et al 2018). The timing of the start of the growing season is crucial to many trophic interactions (Durant et al. 2005, Høye et al. 2007) and, like the indicator *Maximum greenness*, can influence body mass, reproductive success and seasonal migration patterns of ungulates, for example (Tveraa et al. 2013, Kerby and Post 2013, Debeffe et al. 2019). Such effects can be either positive (Tveraa et al. 2013) or negative (Kerby and Post 2013), depending on the underlying mechanism of action. Advancing onset of greening can also lead to mismatching phenologies for migratory species with implications of population trends (e.g., Saino et al. 2011), and influence CO2 exchange in boreal mires (Peichl et al. 2015). Although studies are accumulating documenting many such direct effects of changes in onset of greening, there are still significant shortcomings in our understanding across ecosystems, especially of lagged effects (see for instance Buermann et al. 2018). Overall, the understanding of the effects of changes in onset of greening for ecosystem condition is assessed as good for forest ecosystems and <u>less good</u> for wetland and open lowland ecosystems. Changes in the start of the growing season can be considered of **ecosystem significance** if, for example, they result in increased temporal (trophic) mismatch between native species and their food resources, such as the timing of reindeer calving versus spring green-up, the timing of pollinator activity versus flowering (Richman et al. 2020), or between arrival dates versus food resources of migratory species.

Indicator(s): Tree volume [F22]
Phenomenon: Changes in tree volume [PF30]
Ecosystem characteristic: Primary productivity
Tree volume is a key property of forests. It is an important sustainability indicator also underlying calculations of forest biomass and carbon stocks. Under the reference condition, changes in tree volume reflect climate, local site productivity and natural successional processes including natural disturbances (Nybø et al. 2017).

The most important anthropogenic drivers of change for this indicator are forest management (in managed productive forest land), and climate change (all forest land; e.g. Lämås et al. 2015, Kuuluvainen and Gauthier 2018, Kuuluvainen et al. 2021). In addition, management of large herbivores can indirectly influence forest composition and growth and hence tree volume.

Although the link to forest management as a driver of tree volume in managed forests is certain, the overall link to drivers for this indicator is assessed as uncertain, due to complex interactions between biotic and climatic drivers and silvicultural management.

Tree volume across contrasts in management intensity, productivity (productive/unproductive forest) and harvest classes, will be indicative of the possible mechanisms behind changes in the indicator *Maximum greening* and hence aid the overall assessment of the ecosystem characteristic *Primary productivity*. Further, biodiversity and the composition of the biological assemblages found in forest ecosystems vary not just with management intensity (Savilaakso et al. 2021), but also with above and below ground carbon stocks (e.g. Asbeck et al. 2021). However, the understanding of the importance of change in tree volume per se, both for the condition of the characteristic *Primary productivity* and the forest ecosystem generally is considered less good. Changes in tree volume can be considered of **ecosystem significance** if, for example it mirrors changes in management which adversely affects habitats and/or biodiversity.

5.1.2 Biomass distribution among trophic levels

Indicator(s): ROS species versus moose [F18]
Phenomenon: High or increasing biomass of moose relative to ROS species [PF13]
Ecosystem characteristic: Biomass distribution among trophic levels
The ROS species complex is named after the Norwegian common names of the three species rowan (Rogn, *Sorbus aucuparia*), aspen (Osp, *Populus tremula*) and goat willow (Selje, *Salix caprea*). All three are strongly favored forage species of the moose (Eurasian elk, *Alces alces*) (Hörnberg 2001, Månsson et al 2007, Wam et al. 2010). Under the reference condition, moose and ROS species coexist at intermediate densities in Trøndelag forest ecosystems, although rowan and goat willow are more prevalent than aspen.

The most important anthropogenic drivers of change in this indicator are forest management practices (clear-cutting and tending of young stands) and management (directed harvesting) of the moose population. The links to these drivers are assessed as certain. ROS species rapidly colonise clear-cut harvested areas. However, the main commercial timber species are spruce and pine. These are often planted, and ROS species are thinned (cut) during early successional stages to reduce competition with the commercial conifer species. The moose population has increased greatly over the past few decades (Speed et al. 2019). This has been attributed to directed harvesting (age- and sex-biased harvests quotas that gives a population structure dominated by adult females) (Lavsund et al. 2003, Solberg et al. 1999, Sæther et al. 2003), widespread adoption of clear-cutting increasing the prevalence of young deciduous trees (Wam et al. 2016) and reduction in use of outlying land for livestock grazing (Speed et al. 2019). By selectively feeding on ROS species, high densities of moose can induce failure of recruitment of mature trees of ROS species (Kolstad et al. 2018a, Solberg et al. 2012). The height growth of rowan is constrained when around 20% of shoots are browsed (Speed et al. 2013), and aspen may be even more sensitive to browsing (Edinius et al. 2015). The understanding of high or increasing biomass of moose relative to ROS species is considered good. High or increasing biomass of moose relative to ROS species can be considered of **ecosystem significance** since ROS species (in particular rowan) can be viewed as keystone species in boreal forests, providing forage for a range of species (Kolstad et al. 2018b).

Indicator(s): Bilberry versus deer and moose [F24]
Phenomenon: Changes in relative biomass of bilberry and deer and moose [PF14]
Ecosystem characteristic: Biomass distribution among trophic levels
Bilberry is a highly selected food source for red deer and partly moose, and grazing intensity is found to strongly impact bilberry biomass (Speed et al. 2013, Hegland et al. 2005). Under the reference condition, the biomass distribution among trophic levels will depend on habitat type and successional stage (Speed et al. 2014). Plant and herbivores coexist in a wide range of bilberry forest habitats if high densities of red deer are prevented.

The most important anthropogenic drivers of change in this indicator are wildlife management, forestry (i.e. land-use intensification) and climate change. The link to the drivers is assessed as certain. Wildlife management measures regulating red deer densities, and forestry actions such as density of trees (Eldegard et al. 2019) and climate change (Meisingset et al. 2015) determining environmental factors for bilberry and tree species affect the relative biomass of this indicator. Climate may severely impact bilberry biomass due to extreme weather events. An example is the winter drought in Central-Norway in 2014, which caused a massive reduction in bilberry biomass (Speed et al. 2014). The understanding of the importance of change in relative biomass of bilberry and deer and moose is assessed as good, although the varying indirect impact of other herbivore species (vertebrates and invertebrates) and extreme weather events make interactions more complex. Bilberry and red deer are considered to be keystone species in many forest ecosystems and changes in their ratio can be of high ecological significance. High or increased ratios of red deer are found to have implications for e.g., different invertebrate dynamics such as beetles and caterpillars (Hegland et al. 2005, Melis et al. 2006). Bilberry is also an important food source for smaller vertebrate herbivores (Dahlgren et al. 2007), and severe reductions in bilberry biomass are expected to have indirect effects on a wide range of birds and rodents. Changes in relative biomass of bilberry and deer and moose can be considered of **ecosystem significance** if for example they have a negative impact on invertebrates, or ii) they have a negative effect on bird and rodent species dependent on bilberry.

Indicator(s): Ungulates versus carnivorous vertebrates [F25, A24]
Phenomenon: High or increasing density of ungulates relative to large carnivores [PF15, PA13]
Ecosystem characteristic: Biomass distribution among trophic levels
Under the reference condition for alpine and forest ecosystems, the ratio between ungulates and large carnivores will be weighted towards ungulates, but abundance of large carnivores will reflect a functioning apex predator community. Wild ungulates in the reference condition have moderate abundance while lynx, bear, wolf, wolverine and golden eagle are present and functionally important species in both alpine and forest ecosystems. In intact systems, wolverine and golden eagle typify large predator species in alpine ecosystems and lynx, brown bear and wolf typify large predator species in forest ecosystems. However, there is interaction between all large predator species in both ecosystems. Data for large predators is on a county scale and improved data quality (number of territories in forest ecosystems) is advised for golden eagle. Data is absent for wolf as the management policy is for the non-establishment of this species in the county.

The most important anthropogenic drivers of change in wild ungulate populations in alpine ecosystems are resource management (harvesting), climate change, and land use change through winter mortality, seasonal movements and population regulation of domestic reindeer herds, predator control and reduction of area (particularly the building of several large wind parks in recent years) (Uboni et al. 2016). The most important anthropogenic drivers of change in wild ungulate populations in forest ecosystems are resource management, competition with domestic ungulates and the abundance of large predators (Solberg et al. 1999, Lavsund et al. 2003, Herfindal et al. 2017). The link between drivers and wild ungulates in alpine and forest ecosystems is assessed as certain. The most important anthropogenic driver of change in large carnivores is natural resource management with populations maintained at low densities (and low population viability) to allow the functioning of the sheep and reindeer industries (Swenson and Andrén 2005). The link to this driver is assessed as certain. The understanding of changes in relative biomass of ungulates and large carnivores is considered good. The ratio of ungulates to large predators can be considered of **ecosystem significance** when population viability of large carnivores is assessed as low (Norwegian Biodiversity Information Centre 2021) as the apex predator guild is non-functional. The result of this is that ungulate vertebrates are not under top-down predator control. This can result in high ungulate densities with impacts on ecosystem functioning (Côté et al. 2004, Ford and Goheen 2017) and top-down regulation of ungulates is solely though resource management. Both predators and human hunters contribute to a "landscape of fear" in Norway, affecting the habitat-use of ungulates (Lone et al. 2014), and the presence of large predators can have additional impacts on ecosystems through shaping the foraging strategy of ungulates.

5.1.3 Functional groups within trophic levels

Indicator(s): Plant growth forms: deciduous proportion [F27]
Phenomenon: Low or decreasing deciduous proportion [PF16]
Ecosystem characteristic: Functional groups within trophic levels
Species composition is essential for the ecological functions of a forest, affecting both biodiversity and net biomass production (Shanin et al. 2014, Ampoorter et al. 2019). Under the reference condition, the proportion of deciduous trees versus coniferous trees is determined by the natural conditions and dynamics in the forest (Nybø et al. 2017).

The most important anthropogenic drivers of change in this indicator are forest habitat transformation, land-use intensification (forest stand homogenisation and densification), wildlife management and climate change (Acácio et al. 2017, Ampoorter et al. 2019, Leidinger et al. 2021). The links to these drivers are assessed as certain. Forestry favors monocultures (single tree species stands) and coniferous tree species. In addition, other forestry practices include wildlife management (regulation of wild herbivores through hunting), disease and pest control, and the use of machinery (affecting topography, soil characteristics, and biodiversity) (Nybø et al. 2017). Climate change indirectly acts via disturbance, such as fire, storms, floods and avalanches, and environmental stress, such as drought. The links to these drivers are assessed as certain.

The understanding of the importance of changes in proportion of deciduous tree within forest stands is considered less good. Forest biodiversity is generally expected to increase with tree species diversity (Gamfeldt et al. 2013, Ampoort et al. 2020), and deciduous trees in boreal conifer forests add to the structural and compositional diversity of the forests and offers hosts or substrates to deciduous-associated species. Multi-species stands are also expected to have higher soil carbon stocks than single species stands (Gamfeldt et al. 2013, Liu et al. 2018). Tree species richness in boreal forests tends to have positive influence on biomass production (Gamfeldt et al. 2013). Decreasing the proportion of deciduous tree volume relative to coniferous tree volume can be considered of **ecosystem significance** if, for example, i) it also affects diversity and abundance on other trophic levels, including soil biodiversity, ii) it affects overall forest structure, species composition and forest soil biogeochemical properties and functions.

Indicator(s): Herbivorous vertebrates: browsers versus grazers [F19]
Phenomenon: Changes in the composition of functional groups within the herbivore vertebrate community [PF17]
Ecosystem characteristic: Functional groups within trophic levels
Large herbivores exist on a continuum from pure grazers, through intermediate feeders, to pure browsers. Under the reference condition, forest ecosystems are habitat for species throughout the continuum (Gordon 2003).

The most important anthropogenic drivers of change in this indicator in forest ecosystems are the management of domestic ungulates (i.e., livestock; sheep, cattle, goats) and the management (through directed hunting) of wild ungulates (i.e., moose, red deer and roe deer). The understanding of the link between the drivers and the indicator is assessed as certain. Recent changes in management have involved reduced abundances of livestock in outlying land, including forest regions, and increased abundances of wild ungulates (Speed et al. 2019). This has caused an increase in browsers versus grazers (Austrheim et al. 2011). The understanding of importance of changes in the composition of functional groups within the herbivore vertebrate community is considered good. Since browsers and grazers have quite different diets, changes in the ratio of these can influence the ecosystem dynamics through impacts on vegetation, and cascading impacts on ecosystems (Kolstad et al. 2018a). Highly abundant browsers can prevent establishment of deciduous tree species (Kolstad et al. 2018b). Changes in the ratio between herbivorous vertebrate browsers and grazers can be considered of **ecosystem significance** for example if highly abundant browsers prevent establishment of deciduous tree species.

Indicator(s): Herbivorous vertebrates: reindeer versus moose/deer [A22]
Phenomenon: Changes in the composition of functional groups within the herbivore vertebrate community [PA15]
Ecosystem characteristic: Functional groups within trophic levels
Under the reference condition, reindeer are widespread in alpine ecosystems, including both wild reindeer and semi-domestic reindeer while moose and deer are sporadic.

The major anthropogenic drivers of change in this indicator are climate change and natural resource management resulting in decreasing populations of wild reindeer, and upward movement (borealisation) of boreal moose and deer into the alpine zone. The understanding of the link between drivers and indicator is assessed as certain. Moose have been observed to be moving into the Arctic tundra in Alaska (Tape et al. 2016). This may be in response to vegetation change (increasing productivity or increasing availability of woody plant species or the ultimate driver of temperature. The structure of herbivore communities relates more closely to temperature than vegetation across the boreal-forest to Arctic-tundra biomes scales (Speed et al. 2021). However, less is known about elevational shifts in habitat use of moose and deer, but the dynamics appear complex with seasonal and weather effects (Herfindal et al. 2017, Mysterud 1999). The understanding of importance of changes in the composition of functional groups within the vertebrate community is considered less good. Changes in the ratio of reindeer versus moose can be considered of **ecological significance** if for example, the change is of large enough magnitude that the levels of herbivory on different plant functional groups are altered.

Indicator(s): Carnivorous vertebrates: Arctic versus red fox [A21]
Phenomenon: Decreasing occurrence of arctic fox relative to red fox [PA14]
Ecosystem characteristic: Functional groups within trophic levels
Under the reference condition, alpine tundra ecosystems have a considerable proportion of Arctic vertebrate carnivores specialising on rodents (e.g., mustelids, Arctic fox, long-tailed skua, rough-legged buzzard).

The most important anthropogenic drivers of change in this indicator are climate change and natural resource management, changing the relative abundance of-, and competition between species within the carnivorous vertebrate community. The links to these drivers are assessed as certain, with natural resource management likely to act more strongly than climate change.
Arctic fox was common in alpine tundra habitats in Scandinavia, highly adapted to the harsh winter climate with overall limited and unstable prey availability (cyclic rodents). Rodent-specialist species are affected negatively by suppressed and increasingly irregular rodent population cycles characterised by a smaller proportion of lemming owing to higher winter temperatures (Ims et al. 2017, Kausrud et al. 2008). Many facets of natural resource management have however, also opened the Alpine tundra to boral generalist species, facilitating their way into the mountains. The red fox benefits from increased resource availability from human activity around roads and cabins at high altitudes (Selås et al. 2010, Rød-Eriksen et al. 2020), increasing ungulate populations (Selås and Vik 2006, Henden et al. 2014) and from milder winters and overall higher productivity in low alpine tundra (Elmhagen et al. 2015). Vast access to subsidies cause stabilisation of the food availability, enough to support permanent presence of e.g., red foxes in alpine tundra ecosystems. It is also possible that the politically determined absence of large predators contributes to a wider distribution of red fox (Ehrich et al. 2016, Rød-Eriksen 2020). The understanding of the importance of decreasing occurrence of arctic fox relative to red fox is

considered <u>good</u>, although the relative importance of different drivers remains unclear, and is also likely to vary between mountain areas. 'Borealisation' could cause reduced biodiversity in alpine tundra ecosystems and the phenomenon reinforces itself because boreal species (e.g., red fox) outcompete Arctic species (e.g., Arctic fox), both through direct and indirect competition (Elmhagen et al. 2017, Hamel et al. 2013a). Moreover, owing to increased dominance of particularly red fox, borealisation will have functional implications, also by increasing predation pressure on ground-nesting birds (Henden et al. 2021a, Rød-Eriksen et al. 2020). Changes in the ratio of arctic fox and red fox can be considered of **ecosystem significance** if, for example, i) increased presence of red fox negatively affects the abundance or presence of Arctic foxes.

Both Arctic and red foxes are monitored using camera traps, and this provide an opportunity for assessing the relative occurrence of the two specie. Photo: NINA/SNO automatic camera trap, Trøndelag.

5.1.4 Functionally important species and biophysical structures

Indicator(s): Bark beetle abundance [F14]
Phenomenon: Increasing abundances of bark beetles resulting in increasing frequency or severity of outbreak episodes [PF18]
Ecosystem characteristic: Functionally important species and biophysical structures
The European spruce bark beetle (*Ips typographus*) is the most important forest pest in European and Norwegian spruce forests (Wermelinger 2004, Hlásny et al. 2019). Under the reference condition, univoltine (one generation per year) populations are naturally occurring in spruce forest in Trøndelag, with low propensity for the occurrence of stand killing outbreaks.

The most important anthropogenic drivers of change in this indicator are climate change and forest management practices via its effects on stand composition (Faccoli and Bernardinelli 2014). Large population outbreaks may be triggered by wind throw events, warm summers or precipitation deficits (Marini et al. 2013, Marini et al. 2017) and the links to these drivers is assessed as <u>certain</u> (Hlásny et al. 2021). The number of generations which the species is able to complete per growing season contributes to forest mortality (Jönsson et al. 2012) and is determined mainly by heat accumulation during the growing season (Lange et al. 2010). From 2021, the Norwegian bark beetle monitoring program (NIBIO 2021) includes model estimates also for the predicted dates for completion of a second generation. The model estimates (Lange et al. 2009, Økland et al. 2021) show that during the 1961-1990 climatic reference, bark beetle populations in Norway would mostly complete one generation per year (univoltinism). Ongoing climate change improves the conditions for completing a second generation (bivoltinism), and the proportion of localities which complete a second generation is increasing also in Norway (Økland et al. 2021). Model estimates for Norway predict that, with continued climate change, bivoltinism will become the new norm particularly in the southern parts of the country. The understanding of the importance of increasing abundance of bark beetles resulting in increasing frequency or severity of outbreak episodes is considered less good. Although the direct effects of stand killing outbreaks on forest structure and composition are reasonably well understood, indirect ecosystem effects of intensified bark beetle outbreaks (for example on soil carbon cycling, forest food webs and trophic interactions and biodiversity), are less well studied, and may be contribute to both an improved and a worsened ecological state, depending on context and post outbreak management interventions (e.g., Thom and Seidl 2016, Thorn et al. 2017). Increasing abundances of bark beetles can be considered of **ecosystem significance** if, for example, they result in increasing frequency or severity of stand killing outbreak events with adverse effects on native biodiversity.

Indicator(s): Wild ungulate density [F16, A16, S14]
Phenomenon: Changes in density of wild ungulates [PF19, PA10, PS13]
Ecosystem characteristic: Functionally important species and biophysical structures
Under the reference condition, forest and alpine ecosystems have moderate abundances of wild ungulate herbivores that are regulated jointly by resource availability and top-down predator control. Wild ungulates in Norway include moose (*Alces alces*), red deer (*Cervus elaphus*), roe deer (*Capreolus capreolus*), wild reindeer (*Rangifer tarandus*), and muskox (*Ovibos moschatus*). All species are native, except for the muskox which was present during the Pleistocence, but its (re-)introduction between the 1920s and 1950s classify it as a non-native species. The red deer was previously sporadic in Trøndelag but is spreading northward along the coast (Rosvold et al. 2013, Speed et al. 2019). For the current assessment, we divide these into one indicator for wild ungulates which primary typify alpine ecosystems (A16; wild reindeer, and musk ox), one indicator for wild ungulates which primarily typify forest ecosystems (F16; moose, red deer, and roe deer) and one indicator for wild ungulates which typify open-lowland ecosystems (red deer). These are large herbivores, ranging from about 15 kg for a small roe deer to about 500 kg for a large moose. As an effect of their size, the main ecological effect of wild ungulates, both now and in the reference state, is the disturbance effect related to feeding and trampling (Persson et al. 2000, Beguin et al. 2011, Kolstad et al. 2018a). This pronounced effect on the primary productivity qualifies wild ungulates as functionally important species.

The main anthropogenic drivers of wild ungulate abundances across alpine and forest ecosystems are directed harvesting (Solberg et al. 1999, Lavsund et al. 2003) and competition from domestic ungulates (Austrheim et al. 2011, Herfindal et a. 2017, Wam and Herfindal 2018), and additionally in forest ecosystems, the abundance of predators and forestry practices affecting food availability. The link between the drivers and the indicator is assessed as certain. There is, however, more certainty about the effect of directed harvesting and altered forestry practices, than there is for the effect of intraspecific competition and predation. In addition, natural climate variation (Bø and Hjeljord 1991, Herfindal et al. 2006, Herfindal et al. 2020), was a significant driver of species abundances and community assembly in the reference state. Climate change may therefore become an important anthropogenic driver of change for this indicator in the future, but this is not yet observed. The understanding of the importance of altered wild ungulate abundance for primary productivity and plant species composition is considered good for both alpine (Bernes et al. 2015) and forest ecosystems (Bernes et al. 2018, Speed et al. 2014, Kolstad et al. 2018a). However, knowledge gaps remain, associated with understanding the nature of long-term versus transient effects, and wild ungulate interactions with forestry and domestic ungulates. Changes in wild ungulate abundance can be considered of **ecosystem significance** if, for example, i) increased abundances lead to overgrazing/-browsing that can alter successional trajectories and influence species composition in forests, ii) reduced abundances lead to excessive regrowth in semi-natural nature types (Côté et al. 2004).

Indicator(s): Semi-domestic reindeer density [A13]
Phenomenon: Changes in density of semi-domestic reindeer [PA25]
Ecosystem characteristic: Functionally important species and biophysical structures
Reindeer are a native species in Norway. There is a long tradition and history of herding reindeer in the Trøndelag region. Under the reference condition, semi-domestic reindeer are a functionally important herbivore in alpine ecosystems. However, they are expected to be present at low

abundances in the winter-time due to their natural migration pattern and are expected to have limited trophic functions (e.g., as grazer or as carcass for opportunistic predators/scavengers) during this season (Henden et al. 2014, Tveraa et al. 2013).

The most important anthropogenic drivers of change in semi-domestic reindeer are climate change and resource management decisions related to population sizes and harvest levels (Hausner et al. 2011, Tveraa et al. 2007, Tveraa et al. 2014). The link between the drivers and the semi-domestic reindeer are assessed as certain. There is a large body of literature detailing reindeer impacts on vegetation dynamics. This was synthesized in a systematic review (Bernes et al. 2015). The impacts of semi-domestic reindeer and wild reindeer are not separable. Lichen cover decreases with reindeer grazing, and species richness is negatively affected by high intensity of reindeer grazing, and low temperatures (Bernes et al. 2015). They contribute towards maintaining the vegetation's characteristic (intact) condition (Bråthen 2017), counteract overgrowth by expansion of forest, and provide the most significant ecosystem service for reindeer herders and the Sámi population (Hausner et al. 2011). The understanding of the importance of altered semi-domestic reindeer density is assessed as good. Increasing densities of domestic ungulates can be considered of ecosystem significance if for example lichen cover or biomass is substantially reduced, or if the species richness of vascular plants is reduced.

Indicator(s): Domestic ungulate density [F17, A16, S13]
Phenomenon: High or increasing density of domestic ungulates [PF20, PA16]
Phenomenon: Changes in density of domestic ungulates [PS12]
Ecosystem characteristic: Functionally important species and biophysical structures
Domestic ungulates (livestock) have a long history of free-ranging grazing during the summer season across alpine, forest and open-lowland ecosystems (Speed et al. 2012, Ross et al. 2016), however, all are non-native species, thus are treated as a separate indicator to semi-domestic reindeer. In the reference state, forests and alpine ecosystems in Trøndelag have low densities of livestock. Domestic ungulate densities have at times been considerably higher than today, yet the reference state is here chosen to reflect a state when human influence on the ecosystems was minor, and considerably less important than the natural processes. In open lowland ecosystems, under the reference condition, domestic ungulates are at medium densities at which they maintain open ecosystems by preventing encroachment of woody plants and contribute to the maintenance of high species diversity.

Sheep and semi-domestic reindeer are the main domestic ungulates in alpine ecosystems (Speed et al. 2019). Cattle were formerly abundant in forest, alpine and open lowland ecosystems but have declined greatly in more recent decades (Austrheim et al. 2008, Speed et al. 2019). Both cattle and sheep are both widely distributed and common in open lowland ecosystems. Due to high densities and large food requirements, domestic ungulates are considered functionally important species because of their capacity to modify ecosystem structure. In alpine ecosystems the presence of sheep prevents tree line advance (Speed et al. 2010). Low sheep densities support a higher aggregate of ecosystem services than either high densities of sheep, or the absence of sheep (Austrheim et al. 2016).

The main anthropogenic drivers of domestic ungulate abundance are livestock management and associated market forces and national policies including subsidies. The link between the drivers and the indicator for domestic ungulates is considered certain. The understanding of the importance of high or increasing density of domestic ungulates is assessed as good for alpine and open lowland ecosystems and less good for forest ecosystems. Changes in domestic ungulates can be considered of **ecosystem significance** if, for example, i) increased abundances lead to overgrazing that can alter species composition, ii) reduced abundances lead to excessive regrowth in semi-natural nature types.

Indicator(s): Dead wood volume [F21]
Phenomenon: Low or decreasing dead wood volume [PF21]
Ecosystem characteristic: Functionally important species and biophysical structures
Under the reference condition the amount of dead wood is equal to the amount in a forest under natural conditions (Nybø et al. 2018). The volume of dead wood is closely related to dead wood diversity (Siitonen 2001, Müller and Bütler 2010, Nordén et al. 2013, Kuuluvainen and Gauthier 2018) and is an important biophysical structure in forests reflecting both forest dynamics and biodiversity (Rolstad et al. 2004).

The most important natural drivers of change of the volume of dead wood in forests are forest fires, storms, floods, avalanches, insect attacks, pathogenic fungi, and forest age (Framstad et al. 2020). The most important anthropogenic drivers of change in this indicator are associated with forestry practices. Forest management, especially clear-cutting forestry with short rotation times (60-120 years), thinning, salvage logging after natural disturbances and suppression of forest fires prevents the formation of dead wood (e.g. Koivula and Vanha-Majamaa 2020), especially that of large diameter. The links to these drivers are assessed as certain. The understanding of the importance of low or decreasing dead wood volume for ecosystem condition is considered good. Dead wood contributes to soil formation and nutrient cycling (Harmon et al 1986), and changes in the amount and diversity of dead wood influence the richness and community structure of dead wood dependent species (Siitonen 2001, Müller and Bütler 2010, Laussace et al. 2011, Nordén et al. 2013, Gao et al. 2015), and is important in the carbon cycle (Siitonen 2001, Weggler et al. 2012). About 7500 species in the Nordic countries are associated with dead wood (Stokland et al. 2012) and in Norway it is estimated that 17% of species on the Norwegian Red List for Species are associated with dead wood (Norwegian Biodiversity Information Centre, biodiversity.no). A threshold volume of dead wood for the occurrence of red-listed fungi and insects is 20-30 m^3 ha^{-1} (Müller and Butler 2010, Junninen and Komonen 2011), above which the likelihood of occurrence of red-listed species increases with dead wood volume. In Trøndelag, productive forest land has on average 12.1 m^3 ha^{-1} of dead wood (Storaunet and Rolstad 2015), and substantially less (5-10 m^3 ha^{-1}) in pine and deciduous forest (see Appendix 1 for this indicator). Low or decreasing volume of dead wood can be considered **ecosystem significance** if, for example, i) it adversely affects the affiliated biodiversity in the forest and ii) the number and size of habitats available for deadwood dependent species.

Indicator(s): ROS volume [F28]
Phenomenon: Low or decreasing ROS volume [PF22]
Ecosystem characteristic: Functionally important species and biophysical structures
Under the reference condition, ROS (ROS= rowan, aspen and goat willow) species are abundant as early successional species after disturbances, provided that cervid browsing are low.

The most important anthropogenic drivers of change in this indicator are increased density of cervids and forest management. The links to these drivers are assessed as certain. The ROS species are all pioneer species and especially *Populus tremula* and *Salix caprea* are very light demanding. As such, their establishment is dependent on natural or anthropogenic disturbances. *Populus tremula*, in particular, is favoured by forest fires. ROS-species volumes are measured in the five latest NFI-rotations and have not decreased during this period. However, contemporary levels are lower than “natural” levels (Norwegian Environment Agency 2021a, Jakobsson and Pedersen 2020). ROS species are highly preferred forage for moose and other cervids. Still, there is little evidence for links between browsers and ROS abundance in the National Forest Inventory data, likely due to lack of long time-series (Myking *et al.* 2011, 2013). ROS species have been supressed through chemical and mechanical removal, but this practice have been reduced by 80% and 50%, respectively, over the last decades (Rognstad and Steinset 2012). Further, ROS species are now encouraged to be saved when tending young stands. The reduction in early stand tending could have compensated for negative effects of increased browsing. Several epiphytes (e.g., lichens and bryophytes) are associated with ROS species (Framstad et al. 2008, Kivinen et al. 2020, Kouki et al. 2004), and a reduction of ROS abundance will ultimately reduce populations of such species. These keystone species also host various fungi, insects, and birds, in addition to being important for browsers. The understanding of the importance of low or decreasing volumes of ROS species for forest ecosystems is assessed as good (Framstad et al. 2008). For ROS species, low volumes can be considered of **ecosystem significance** if for example it leads to declines in red-listed ROS-associated species.

Indicator(s): Bilberry coverage [F20]
Phenomenon: Low or decreasing bilberry coverage [PF24]
Ecosystem characteristic: Functionally important species and biophysical structures
Under the reference condition, bilberry coverage is equal to the amount in a forest under natural conditions.

The most important anthropogenic driver of change in this indicator is forestry (e.g. too dense or too open forests). The links to these drivers are assessed as certain. Bilberry prefer partial shading, and drastically decrease when stand density gets too high (Hedwall et al. 2013, Eldegard et al. 2019). In Norwegian 80-year-old spruce forests, bilberry abundance peaks at 30 m^2 ha^{-1}, while lower basal area is needed in younger forests (Eldegard et al. 2019). Bilberry abundance is negatively affected by clear-cutting and increase with stand age (Altegrim et al. 1996, Hedwall et al. 2013, Eldegard et al. 2019). Bilberry coverage has only been assessed in two NFI rotations. However, coverage is lower than in forests with little human impact (Norwegian Environment Agency 2021a, Jakobsson and Pedersen 2020).The understanding of the importance of low or decreasing bilberry abundance for forest ecosystems is considered good. Bilberry is a keystone species that is an important food resource for a diverse group of vertebrate and invertebrate species, and also their predators (Hjeljord et al. 1990, Karlsen et al. 2013, Hertel et al. 2016, Spitzer et al. 2021). Low bilberry coverage can be considered of **ecosystem significance** if, for example, it adversely affects the affiliated biodiversity.

Coniferous forest understory with bilberry dominance. Photo: Rolf A. Ims.

Indicator(s): Large predator abundance [F23, A14]
Phenomenon: Low or decreasing large predator abundance [PF23, PA18]
Ecosystem characteristic: Functionally important species and biophysical structures
Under the reference condition, lynx, bear, wolf, wolverine and golden eagle are present and functionally important species in both alpine and forest ecosystems. In intact systems, wolverine and golden eagle typify large predator species in alpine ecosystems and lynx, brown bear and wolf typify large predator species in forest ecosystems. However, there is interaction between all large predator species. Data for large predators is on a county scale and improved data quality (number of territories in forest ecosystems) is advised for golden eagle, hence it is not included in the assessment. Data is absent for wolf as management policy is non-establishment of this species in the county.

The most important anthropogenic driver of change in large carnivores is natural resource management. The link to this driver is assessed as certain. For carnivores, abundance is indicated by estimated number of reproducing females and is managed by a combination of species-specific hunting quotas and/ or individual removal. The time series varies with species with 1996 - 2020 for lynx, 2001 - 2020 for wolverine and 2008 - 2020 for brown bear (rov.data.no). The lynx time series period 1996 - 2013 is not directly comparable to 2014 onwards due to a change in methodology. All mammalian carnivore species are assessed as having low population viability in the recently updated Norwegian Red List for Species (Norwegian Biodiversity Information Centre 2021). Management efficiency directed towards removal varies, and the number of reproducing wolverine and lynx have reached or exceeded their target abundance for several years (Tovmo and Mattisson 2021, Tovmo et al. 2021). Bear population size is slightly below the target size (Fløystad et al. 2021). Golden eagle abundance is indicated by estimated number of active territories over a 5 year period and the time series is short (2010 - 2014; 2015 - 2019). Abundance remains within the target population set in 2004 (Mattisson et al. 2020, rovdata.no). The species was protected in 1968 and the current most important drivers of change are probably natural resources.

The understanding of the effects of low or decreasing populations of large predators on forest and alpine ecosystems is assessed as good. As top predators, they have the potential to induce trophic cascades (Ford and Goheen 2015), affecting densities of meso-carnivores (Elmhagen et al. 2010), herbivore densities and plant community structure, and thus are functionally important in these ecosystems. However, their role is diminished due to management directed at maintaining low population size aimed at allowing functionality of the sheep and reindeer industry (lovdata.no). Erosion of trophic cascades can lead to increased herbivore density, in turn increasing grazing pressure and altered plant community structure (Suominen and Oloffson 2000, Speed et al. 2013, Speed et al. 2014). Prey species in forest and alpine ecosystems include sheep, semi-domesticated and wild reindeer, roe and red deer and losses of sheep and semi-domesticated animals can be considerable (rovbase.no). For lynx, loss of sheep is in part dependent on availability of wild prey (Odden et al. 2013, Gervasi et al. 2014) while for wolverine, condition of seasonal prey (reindeer calves) plays a role in determining diet in summer months (Mattisson et al. 2016). Wolverine also interacts with lynx, scavenging on lynx kills (Mattisson et al. 2016). Low or decreasing large predator abundance can be considered of **ecosystem significance** if for example population viability is assessed as low according to the Norwegian Species Red List consistently over monitoring periods.

Indicator(s): Red fox camera index [A14]
Phenomenon: Increasing or high proportion of days with red fox captures by camera traps [PA19]
Ecosystem characteristic: Functionally important species and biophysical structures
Under the reference condition, established red fox populations are distributed only in the most productive parts of the low alpine zone (e.g. primarily forested areas in close vicinity to more continuous alpine tundra areas).

The most important anthropogenic drivers of change are climate change, land use and wildlife management/ harvest. The links to these drivers are assessed overall as certain with regard to red fox expansion, while the overall increase in abundance is mainly driven by increased resource availability. The red fox benefits from increased resource availability from human activity around highways and cabins at high altitudes (Selås et al. 2010, Rød-Eriksen et al. 2020), increasing ungulate populations (Selås and Vik 2006, Henden et al. 2014) and from milder winters and overall higher productivity in low alpine tundra areas (Elmhagen et al. 2015). Reduced abundance of apex carnivores have likely also released an increase in abundance of meso carnivores, such as red fox. This is more likely to happened in forested areas where wolf and lynx occur (Elmhagen et al. 2010) but could possibly also increase invasion to alpine habitats.

Increased presence of red fox, particularly at higher altitudes relates to degree of human impact (Rød-Eriksen et al. 2020), density of ungulate carcasses (Henden et al. 2014) as well as climatic constraints, such as snow depth and temperature (Gomo et al. 2020). Expansion of the species could cause 'borealisation' of the alpine communities and thus cause degraded ecological condition of this ecosystem including decreased abundance of Arctic fox and ground-nesting birds (Elmhagen et al. 2017, Henden et al. 2021a, Rød-Eriksen et al. 2020; see also indicator A21).

The camera index is affected by both abundance and activity of scavenging species attracted to baits. The understanding of changes in this indicator describing the state of the red fox population is assessed as good (Hamel et al. 2013a,b, Henden et al. 2014, Rød-Eriksen et al. 2020), but the indicator appears to be very sensitive to abundance of alternative prey and must be interpreted carefully in terms of relative densities per se (Gomo et al. 2020, 2021).

For red fox, an increased proportion of days with red fox captures by camera traps can be considered of **ecosystem significance** if, for example, i) the increase occurs in the inner parts of contiguous alpine tundra areas (far from forested areas), ii) increased presence of red fox results in reduced presence of the arctic fox and abandonment of den sites (Tannerfeldt et al. 2002, Killengreen et al. 2007, Selås et al. 2010).

Indicator(s): Lemming abundance [A18]
Phenomenon: Less frequent, less distinct peaks in the lemming cycle [PA12]
Ecosystem characteristic: Functionally important species and biophysical structures
Under the reference condition, 3-5-year population cycles in the Norwegian lemming (*Lemmus lemmus*) occur regularly in alpine ecosystem in Fennoscandia (Angerbjörn et al. 2001), with a sufficient regularity and amplitude to support viable populations of lemming-dependent predator species (e.g., Arctic fox; Elmhagen et al. 2002, Ims et al. 2018), and to maintain snowbed vegetation through grazing (Virtanen 2000).

The most important anthropogenic driver of change in this indicator is climate change. Lemmings are vulnerable to a mild winter climate, particularly decreasing snow cover and increased presence of hard snow layers and basal ice (Berteaux et al. 2017, Kausrud et al. 2008, Ehrich et al. 2020). This link is assessed as certain. The understanding of the importance of less frequent, less distinct peaks in the lemming cycle are considered good. Reduced abundance of lemming owing to greater irregularity and/or dampening of lemming cycles in a warmer climate, results in decreased reproductive success among alpine lemming specialists (Ims et al. 2017). For example, absence of a single lemming peak year (which means 7-year period of low lemming abundance), can have a decisive negative impact on the viability of an Arctic fox population with a generation time of about four years (Henden et al. 2008). Such changes in lemming cycles will also affect the vegetation characteristic of snowbeds, which is in part maintained by regular perturbation by lemming (Olofsson et al. 2012, Virtanen 2000). The assessment of this indicator should take into consideration the peak years' frequency and season-specific amplitude. Seasonality is important because the predators are most sensitive to resource availability in spring. The underlying data should have adequate temporal coverage (at least 15–20 years) to permit documentation of changes. Fewer and/or less pronounced lemming peaks can be considered of **ecosystem significance** if, for example, i) lemming peaks are too small or infrequent to maintain populations of lemming specialists, ii) lemming peaks are too small or infrequent to contribute towards maintaining characteristic snowbed vegetation.

Indicator(s): Bumblebee abundance and species richness [S17]
Phenomenon: Decreasing bumblebee abundance or diversity [PS15]
Ecosystem characteristic: Functionally important species and biophysical structures
Under the reference condition, bumblebee abundance and species richness in open lowlands is supported by an open vegetation, with a regularly recurring disturbance regime.

The indicator measures the occurrence frequency (abundance) and diversity of wild bumblebees. The monitoring program on butterflies and bumblebees is currently the most complete data series informing about state and trends of these pollinator groups (2009 to date, Åström et al. 2021). The data are collected in open lowland and forest habitats, in three regions, including Trøndelag. Land management (grazing, mowing, fire, fertilisation, neighbouring forest management), land abandonment and land intensification (use of pesticides), as well as climate change are major anthropogenic drivers of change. The link between the major drivers and the indicator is assessed as <u>certain</u> for open lowland ecosystems. Specifically, low abundance or decline in bumblebee populations has been documented as a result of land use change, including the loss of open semi-natural habitats due to e.g. abandonment or lack of/irregular management (Sydenham et al. 2022), the use of pesticides (Crall et al. 2019), the proportion of flower-poor land-cover types in the surrounding landscape (Kallioniemi et al. 2017), and not least climate change (Settele et al. 2016, Sirois-Delisle and Kerr 2018). It has been observed that climate warming coincides with bumble bees ranges moving to higher altitudes in desynchrony with their flower resources (Pyke et al. 2016), with important consequences to biodiversity and pollination services in open lowlands and beyond. The understanding of the importance of decreasing bumblebee abundance or diversity is therefore considered <u>good</u> for open lowland ecosystems. Low levels or decline in bumblebee abundance or species diversity can be considered of **ecosystem significance** if, for example, reduced pollination success/rate affects plant diversity and productivity and reduced seed or fruit sets, and with cascading effects on plant-herbivore networks.

5.1.5 Landscape ecological patterns

Indicator(s): Areas free of major infrastructure [F12, A12, W12]
Phenomenon: Decreasing areas free of major infrastructure [PF25, PA20, PW15]
Ecosystem characteristic: Landscape ecological patterns
Under the reference condition, all alpine, forest and wetland ecosystems are essentially unaffected by larger technical/industrial installations.

The indicator corresponds to the Norwegian *Environmental Indicator 1.1.8* (Norwegian Environment Agency 2021b) and measures the proportion of area which is considered unaffected by larger technical/industrial installations (threshold buffer from infrastructure > 1 km). It thus includes both areas which are defined as 'free of infrastructure' (1 - 5 km band width), and areas which are defined as 'wilderness' (> 5 km from infrastructure) according to the Norwegian definition. Infrastructure development is the only driver of change in this indicator. The link between this driver and the indicator is thus assessed as <u>certain</u> for all three ecosystems. Loss of wilderness areas through infrastructure development, and the resulting fragmentation and reconfiguration of natural habitats, has a multitude of direct and indirect effects on natural ecosystems (Coffin 2007), including altered area use and migration routes of large herbivores (Wolfe et al. 2000, Eftestøl et al. 2021), loss of pastures for reindeer husbandry (Tyler et al. 2021), altered dispersal options and genetic diversity (Lino et al. 2019, Zambrano et al. 2019), spread and establishment of alien species (Mortensen et al. 2009) and altered hydrological regimes (Williams-Mounsey et al 2021). Loss of area unaffected by infrastructure is therefore seen as a development towards a more degraded ecological condition. However, large contrasts can be expected in the presence and strength of negative effects of technical installations depending on context and taxonomic group. The understanding of the importance of decreasing areas free of major infrastructure is therefore assessed as less good for all three ecosystems. This also means that even though loss of wilderness areas due to infrastructure development must in itself be seen as a deterioration of the ecological condition of an ecosystem, it is not considered possible to set an absolute threshold for when this loss of natural habitat becomes critical in general terms. It will depend on the type of perturbation, how and where it occurs relative to key habitats such as foraging or breeding grounds, and the types of mitigating measures installed (habitat corridors etc). Loss of wilderness areas can be considered of **ecosystem significance** if, for example, i) the loss of area adversely affects movement patterns or productivity of wild or semi-domestic ungulates, or ii) dispersal, genetic composition or population persistence of native biodiversity, iii) infrastructure developments adversely affect the hydrological integrity of wetland ecosystems, iv) infrastructure developments facilitate the spread and establishment of alien species with adverse effects on native biodiversity.

5.1.6 Biological diversity

Indicator(s): Alpine bird communities [A23]
Phenomenon: Decreasing abundance and/or species diversity within the community of alpine birds [PA11]
Ecosystem characteristic: Biological diversity
Under the reference condition, the composition of the bird community is characterised by bird species adapted to open habitats with sparse or short-statured vegetation composed of cryptogams and prostrate vascular plants in the high- and middle alpine bio-climatic zones, and more erect shrubby vegetation in the low alpine zone or the forest-alpine ecotone. A guild of avian predators is also dependent on periodic cyclic peaks of small rodents in open habitats to reproduce successfully.

The most important anthropogenic driver of change in alpine birds is probably the direct and indirect effects of climate change, although land use, harvest and other anthropogenic factors may be involved (Lehikoinen et al. 2014). The links to climate change as a driver are assessed as less certain. Climatic drivers can lead to phenological mismatch, especially among birds that migrate long and medium-long distances although recent research indicates that trends in Fennoscandian alpine birds are not different between residents and migrants. The entire community can also be affected indirectly when changes in the periodicity and magnitude of rodent dynamics can lead to increased predation by reducing the frequency of years with low predation pressure (Kausrud et al. 2008), especially at southern latitudes with greater warming (Bowler et al. 2020). There are also indications that increased primary productivity increases predation on the nests of ground-breeding birds, in particular, in the upper bioclimatic sub-zones (Ims et al. 2019). There is also some evidence for negative impacts of phenological mismatch, which affects migration and access to food supply during nesting (Carey 2009, Crick 2004, Miller-Rushing et al. 2010). Species that are specifically adapted to the habitat structures or trophic conditions in intact alpine ecosystems are expected to decline due to habitat loss in a warming climate (Lehikoinen et al. 2014, 2019) and to changes in alpine grazing regimes that affect tree line dynamics (Bryn and Potthof 2018). Lastly, field experiments from Trøndelag have shown that high levels of harvest can lead to additive mortality for Willow Ptarmigan (Sandercock et al. 2011). Thus, three sub-groups/guilds of the alpine bird community are considered separately under this indicator: two guilds based on vegetation structure and preferences for open and shrubby habitats, and a third guild based on trophic condition – avian predators specialised on cyclic small rodents. Alpine birds are in decline across Scandinavia (Lehikoinen et al. 2019) and two species are red-listed as vulnerable (Gyrfalcon) or endangered in Norway (Lapland Bunting, Stokke et al. 2021). The understanding of the significance of changes in alpine birds as an indicator is good. Changes in bird communities can be considered of **ecosystem significance** if alpine species that are normally abundant or define alpine bird communities are lost.

Indicator(s): Forest bird communities [F15]
Phenomenon: Decreasing abundance and/or species diversity within the community of forest birds [PF12]
Ecosystem characteristic: Biological diversity
Under the reference condition, the composition of the bird community is characterised by a diverse community with species adapted to a variety of canopy structure and density of stands combined with open areas.

The most important anthropogenic drivers of change in this indicator are forestry management and climate change. The links to these two drivers are assessed as certain. Due to the pervasive impact of industrial forestry practices on the composition and structure of forest ecosystems, the forest bird community is expected to deviate significantly from an intact condition. Birds expected to be most affected are species that are specialised on nest sites such as cavity-nesters, or species that require habitats or food resources that are now scarce, such as the late successional stages of pristine forest (e.g., White-backed Woodpecker and Siberian Jay, Bradter et al. 2021). Climate change can cause phenological mismatches, which affect migration and access to food resources during nesting and has been identified as generic mechanism that affects many species (Carey 2009, Crick 2004, Miller-Rushing et al. 2010), but lagged or indirect effects of climate change may also be involved (Jenouvrier 2013). Due to the simultaneous action of forestry and climate change during the timeframe when monitoring data on bird communities are available, it may be difficult to distinguish the relative impact of these two drivers. However, both drivers have been expected, and indeed observed, to impact boreal bird communities in Fennoscandia negatively (Laaksonen and Lehikoinen, 2013, Lehikoinen et al. 2016, Virkkala 2016). The understanding of the significance of changes in forest birds as an indicator is good. Change in bird communities can be considered of **ecosystem significance** if forest species that are normally abundant become rare or if key species that define forest bird communities are lost.

Indicator(s): Wetland bird communities [W16]
Phenomenon: Decreasing abundance and/or species diversity within the community of wetland birds [PW13]
Ecosystem characteristic: Biological diversity
Under the reference condition, the bird community (typically waterfowl, waders and other waterbirds) is characterised by species that feed or breed in habitats with high ground water levels or inflow of surface water, such as bogs, mires, swamps and humid meadows.

The most important anthropogenic drivers of change in this indicator are land use change and climate change. The links to these drivers are assessed as less certain. Land use change leading to changes in the hydrology of wetlands (drainage by trenching/ conversion of wetlands to different ecosystems (e.g. forest or agricultural areas). causes deterioration, fragmentation and loss of habitats for wetland bird communities. Furthermore, habitat quality has also been affected by acidification, eutrophication, and hydropower development, especially in wetlands at low elevations Many wetland birds are in decline regionally in Fennoscandia (Lehikoinen et al. 2016, Lindström et al. 2019), and nine species are red-listed as vulnerable (Northern Shoveler, Common Scoter, Velvet Scoter, Smew, Eurasian Coot, Horned Grebe) or endangered in Norway (Garganey, Greater Scaup, Little Grebe, Stokke et al. 2021). Climate change impacts that are assumed to impact bird populations more generally (Jenouvrier 2013) should be kept in mind, however many of the wetland birds in Trøndelag are found within a wide climate envelope in Europe. In addition, all boreal and alpine wetland birds are migratory so habitat alterations and other pressures in wintering areas or migration stopover sites can also drive the change in this indicator and therefore should also be taken into account.
The understanding of the significance of changes in wetland birds as an indicator is good. Changes in bird communities can be considered of **ecosystem significance** if species that are normally abundant wetland birds become rare or extinct.

Indicator(s): Farmland bird communities [S16]
Phenomenon: Decreasing abundance and/or species diversity within the community of farmland birds [PS11]
Ecosystem characteristic: Biological diversity
Under the reference condition, the farmland bird community is characterised by species adapted to open natural habitats such as grasslands, meadows and coastal or upland heathlands. The total area of naturally open habitats has been diminished severely due to human land use and habitat conversion. Nevertheless, cultural areas based on traditional grazing practices represent habitats for farmland birds whenever kept in a semi-natural state by means of non-intensive land use regimes (for instance semi-natural salt meadows).

The most important anthropogenic drivers of change in this indicator are land use change and climate change. The links to these two drivers are assessed as certain. Changes in land use which exert negative impacts on bird species associated with semi-natural habitats include intensive agricultural regimes with tilling or haying that destroy nests, conversion to large monocultures of crops that homogenise cultural landscapes, and more intensive use of fertilisers, herbicides and pesticides to increase agricultural yields. Abandonment of traditional, non-intensive land use regimes is also a threat to birds associated with open semi-natural habitats, because encroachment of woody shrubs or trees leads to habitat loss. The cumulative effects of a suite of land use drivers are considered the main cause of the observed pan-European decline of farmland birds associated with semi-natural ecosystems (Donald et al. 2006). Several species of farmland birds are declining in Norway (Lislevand et al. 2021), and four species are red-listed as vulnerable (Common Quail, Yellowhammer), endangered (Curlew), or critically threatened in Norway (Northern Lapwing, Stokke et al. 2021). Climate change that impacts bird populations more generally (Jenouvrier 2013) should be kept in mind, although many of the birds associated with semi-natural habitats in Trøndelag are found within a wide climate envelope in Europe. Most birds associated with semi-natural habitats are migratory. Hence, habitat alterations and other pressures in wintering areas or migration stopover sites must also be taken into account.
The understanding of the significance of changes in farmland birds as an indicator is good. Changes in bird communities can be considered of **ecosystem significance** if species that are normally abundant in cultural landscapes become rare or extinct.

Indicator(s): Butterfly abundance and diversity [S15]
Phenomenon: Decreasing butterfly abundance or diversity [PS10]
Ecosystem characteristic: Biological diversity
Under the reference condition, butterfly abundance and diversity of open non-agricultural lowlands in Norway is supported by the area and ecological condition of flower-rich habitats, mostly grasslands and heathlands, with a regularly recurring disturbance regime. These habitats, a major resource for pollinators, have been shaped by long-term traditional extensive land-use (e.g. mowing, grazing, burning).

The most important anthropogenic drivers of change in this indicator are land use change (shrub and forest encroachment), land-use intensification (levels of grazing, mowing, fire and fertilization), pollution (including the use of agro-chemicals) and climate change. The link between the major individual drivers and the indicator is thus assessed as certain for open lowland ecosystems, however, the consequences of land-use and climate change can result in opposite outcomes (Warren et al. 2001), making the separation of effects of individual drivers challenging. Decreasing butterfly abundance and diversity are expected to result from: (1) climate change disrupting plant-pollinator interactions and threatening susceptible species (Memmott et al. 2007). Climate change can also increase abundance and diversity of butterflies in northern ranges, where they may be expected to respond positively to higher temperatures (Warren et al. 2001), (2) habitat loss and degradation, (3) changes in land cover towards less flower-rich and more homogenous landscapes and landscapes with higher proportion of agricultural land (Seibold et al. 2019), (4) land-use intensification (e.g. fertilization, use of pesticides, monocultures), as well as land abandonment causing declines in pollinator flower resources (Pedersen et al. 2020). The availability of maps of semi-natural habitats is very limited in Norway, and it is not possible to establish the impacts of changes in extent and condition of these habitats. However, there are ongoing efforts to fill these gaps (Sydenham et al. 2021, Sydenham et al. 2022, Venter et al. 2019). Decreasing butterfly abundance and diversity will have important consequences to biodiversity and pollination of crops and plant communities in open lowlands and beyond (Warren et al. 2021). The understanding of the importance of decreasing butterfly abundance or diversity is therefore assessed as good for open lowland ecosystems. Low levels or decline in butterfly populations are of **ecosystem significance** if, for example, reduced pollination success/rate affects plant diversity and productivity and reduces seed or fruit sets, and cascading effects on plant-herbivore networks.

Indicator(s): Arctic fox abundance [A19]
Phenomenon: Absence of sustained increase in Arctic fox abundance despite conservation efforts [PA23]
Ecosystem characteristic: Biological diversity
Under the reference condition, Arctic fox occurs in a viable metapopulation across the alpine and arctic tundra in Scandinavia; in Trøndelag the Arctic fox is found in the largest mountain patches connected with smaller sub-populations. Historic notes and systematic records of old Arctic fox dens reveals that the species had a wide distribution in Norway (Eide et al. 2020, Rød-Eriksen 2020), in some regions even stretching down to the coast, as in Finnmark (Ims et al. 2017a). The Arctic fox was protected as early as in 1930 but has been critically endangered in Norway for a long time (Henriksen and Hilmo 2015), but recently lifted to endangered (Norwegian Biodiversity Information Centre 2021).

The most important anthropogenic drivers of change in this indicator are climate change (indirect), land use and natural resource management (acting mostly indirectly through the red fox). The links to these drivers are assessed as certain. Historically, hunting has been assumed to be an important driver, but the species continued to decline despite early protection from hunting. The understanding of the importance of an absence of sustained increase in Arctic fox abundance despite conservation efforts is assessed as good (Eide et al. 2017). Less stable winter climate, with higher temperatures, cause formation of ice layers in the snowpack and on the ground surface, which could dampen rodent cycles (Kausrud et al. 2008, Ims et al. 2011), and following structural changes in the rodent communities with smaller proportions of lemmings (Ims et al. 2017a). As a specialist, this could have devastating effects on the Arctic fox reproduction and litter size (e.g., Angerbjörn et al. 1991, Ims et al. 2018). Many facets of natural resource management have also opened the alpine tundra to the superior boreal competitor, the red fox (Elmhagen et al. 2017). The red fox benefits from increased resource availability from human activity around roads and cabins at high altitudes (Selås et al. 2010, Rød-Eriksen et al. 2020), increasing ungulate populations (Selås and Vik 2006, Henden et al. 2014) and from milder winters and overall higher productivity in low alpine tundra (Elmhagen et al. 2015). Vast access to subsidies causes stabilization of the food availability, enough to support permanent presence of red fox in these naturally poor ecosystems. Increased competition from a growing red fox population displaces the Arctic fox from their historic den sites, especially in the most productive low alpine zone (Killengreen et al. 2007, Tannerfeldt et al. 2002). The species is subject to intensive conservation efforts (supplemental feeding, release of captive breed foxes as well as red fox culling) through a joint Norwegian-Swedish action plan (Eide et al. 2017), trying to save the species from extinction (Angerbjörn et al. 2013, Landa et al. 2017, Hemphill et al. 2020). Absence of a sustained increase in the Arctic fox population (the number of breeding pairs) despite conservation efforts is considered of **ecosystem significance**, because it indicates that the alpine ecosystem has no capacity to sustain a viable population of Arctic fox.

Indicator(s): Arctic fox litter size [A20]
Phenomenon: Small or decreasing litter size [PA24]
Ecosystem characteristic: Biological diversity
Under the reference condition, Arctic fox litter size is strongly influenced by the cyclic availability of rodents, varying from 1-18 cubs, producing the largest litters in the rodent peak phase (litter size above 9 is regularly observed), while few or no cubs are born in the rodent-low phase.

Average litter size for Artic foxes in Scandinavia is reported to be 6.3 (Angerbjörn et al. 1995), varying over the rodent cycle: 6.38 cubs in the increase phase, 7.11 in the peak phase and 3.84 in the decrease phase (Meijer et al. 2013).

The most important anthropogenic driver of changes in this indicator is likely indirect effects of climate change. This link is in general assessed as certain. A less stable winter climate, with higher temperatures, leads to formation of ice layers in the snowpack and on the ground surface, which could dampen rodent cycles (Kausrud et al. 2008, Ims et al. 2011) leading to weaker numerical responses among predators. Furthermore, the rodent community structure itself could have a strong impact on the litter size with higher litter sizes when lemmings are dominating rodent abundance (Ims et al. 2017a). In persistently small populations, inbreeding may also play a role in decreasing litter size (Norén et al. 2016). Small litters owing to lack of lemmings or other conditions, are a clear indication of a degraded ecological condition. Supplemental feeding over the winter contributes to increase the litter size and indicates a weaker link to the rodent cycle under the rodent low phase (Eide et al. 2020). It could be that conservation actions run over time impact on litter size, originating from which animals reproduce in captivity and hence which cubs are released into the wild and the qualities they carry. Supplemental feeding also represents a stable food resource, that the species could adapt to either by adjusting reproductive performance (e.g. litter size) or by selection towards smaller litter size. Although possible impacts originating from conservation actions have not yet been explored, changes in the species biology must be considered a negative change to the species and the ecosystem. Although the understanding on which factors regulate arctic fox litter size is good, it is important to understand the origin of these spatio-temporal changes in litter size, as changes in the species ecology could have a large impact if conservation measures are ceased. The understanding of the importance of changes in Arctic fox litter size is assessed as good. For Arctic fox, small litter size can be considered of **ecosystem significance** if, for example, i) it is generally smaller than that which is observed among other lemming-dependent Arctic fox populations or ii) declines due to supplementary feeding lead to fundamental changes in the reproductive ecology of the Arctic foxes.

5.1.7 Abiotic factors

Indicator(s): Annual mean temperature [F01, A01, W01, S01]
Phenomenon: Increasing annual mean temperature [PF01, PA01, PW01, PS01]
Ecosystem characteristic: Abiotic factors
In the given definition of the reference condition for this assessment (Ch. 2), the reference climate is defined as a climate corresponding to the 1961–1990 normal period. This means that under the reference condition, each of the climate variables is within the range of variability observed during the period 1961–1990. Since the climatic data records covers the entire climatic reference period, deviations from this reference condition can be assessed directly.

The most important anthropogenic driver of changes in this indicator is climate change. IPCC concludes that human-induced increase of global surface temperature reached approximately 1.09 °C [0.95 to 1.20] above pre-industrial levels [1850-1900] in the decade 2011-2020, increasing at 0.2 °C per decade (high confidence) (Masson-Delmotte et al. 2021). Changes are larger on land (1.59 °C increase), and the boreal forest will likely see the largest temperature increase in the 21st century of all forest biomes (Gauthier et al. 2015). The link to anthropogenic drivers is therefore assessed as certain for all temperature-derived indicators, including *Annual mean temperature.* Annual air temperature is the key observational indicator of climate change globally and is a driver of major changes in various components of northern ecosystems (Box et al. 2019, IPCC 2014) from boreal forest productivity (Boisvenue and Running 2006, Ruiz-Pérez and Vico 2020) to upper limit of alpine grasslands (Bürli et al. 2021). Mean annual air temperature (MAAT) is one of the key determinants of Arctic and alpine permafrost, which in Trøndelag is discontinuous and restricted to the high mountain areas in northern and southern part of the region (Gisnås et al. 2017).

The understanding of the ecological importance of changes in annual mean temperature is assessed as good for forest and alpine ecosystems, but less good for open lowland and wetland ecosystems. Increased annual temperatures can be linked to increased tree growth when temperature is a limiting factor (I.e. at high altitudes or latitudes; Venäläinen et al. 2020) but can also lead to decreased growth of Norway spruce at lower altitudes/latitudes (Andreassen et al. 2006, Lloyd and Bunn 2007). Increased annual temperatures may lead to increase in vascular plants species richness on alpine summits (Steinbauer et al. 2018). Increased annual temperatures may lead to increased tree layer in peatlands, but feedback loops and the confounding effect of nitrogen deposition prevent firm conclusions (Hedwall et al. 2017).

Increased annual temperatures can be considered of **ecosystem significance** if, for example, i) they integrate effects of seasonal temperature changes that are linked to ecological processes. Increasing temperatures in the cold season may reduce energetic requirements for predators, but negatively affect mammalian herbivores, and higher temperatures in the growing season increase plant growth but can increase tree mortality if associated with drought, insect outbreaks and fire (Allen et al. 2010, Venäläinen et al. 2020). Together these effects will change the relative abundance of trophic levels. Seen in conjunction with the indicators, January mean temperature and July mean temperature, this indicator contributes towards our understanding of climate impact pathways on ecosystem characteristics.

Indicator(s): January mean temperature [F02, A02, W02, S02]
Phenomenon: Increasing January mean temperature [PF02, PA02, PW02, PS02]
Ecosystem characteristic: Abiotic factors
In the given definition of the reference condition for this assessment (Ch. 2), the reference climate is defined as a climate corresponding to the 1961–1990 normal period. This means that under the reference condition, each of the climate variables is within the range of variability observed during the period 1961–1990.

The most important anthropogenic driver of changes in this indicator is climate change. IPCC concludes that human-induced warming reached approximately 1°C above pre-industrial levels in 2017, increasing at 0.2°C per decade (high confidence) (Allen et al. 2018). The link to anthropogenic drivers is therefore assessed as certain for all temperature-derived indicators, including *January mean temperature.* The indicator January mean temperature should be seen as an indicator of temperature during the coldest part of the year and assessed in connection with the indicator *Winter days above 0°C*, which have more specific and documented links to ecological effects of higher winter temperatures in northern ecosystems. The understanding of the importance of changes in winter temperatures, is assessed as good, despite less explicit links to ecological effects than the other winter climate indicator *Winter days above 0°C*. These indicators should be viewed in concert. Increased January temperatures can be considered of **ecosystem significance** if, for example, they result in more frequent above-zero temperatures leading to increased icing and reduced grazing for native herbivores, or increased winter damage to evergreen vegetation (Bokhorst et al. 2009, Bjerke et al. 2017, Callaghan et al. 2011). Change in January temperature can also impact winter thermal conditions on the ground with consequences for fine-scale vegetation patterns (Niittynen et al. 2020b). Winter temperature changes linked to higher January temperature can also shorten the soil frost period, resulting in an increased risk of forest wind damage (Venäläinen et al. 2020).

Indicator(s): July mean temperature [F03, A03, W03, S03]
Phenomenon: Increasing July mean temperature [PF03, PA03, PW03, PS03]
Ecosystem characteristic: Abiotic factors
In the given definition of the reference condition for this assessment (Ch. 2), the reference climate is defined as a climate corresponding to the 1961–1990 normal period. This means that under the reference condition, each of the climate variables is within the range of variability observed during the period 1961–1990.

The most important anthropogenic driver of changes in this indicator is climate change. IPCC concludes that human-induced warming reached approximately 1°C above pre-industrial levels in 2017, increasing at 0.2°C per decade (high confidence) (Allen et al. 2018). The link to anthropogenic drivers is therefore assessed as certain for all temperature-derived indicators, including *July mean temperature.* The understanding of the ecological importance of changes in July mean temperature is assessed as good for forest and alpine ecosystems, and as less good for open lowland and wetland ecosystems. Increased July temperature increases alpine plant and tree growth when growing season temperature is limiting but can also lead to increased negative impacts through drought and fire. The two extreme warm summers in 2014 and 2018 (Wilcke et al. 2020) led to large–scale forest fires in Sweden (Gustafsson et al. 2019, Kelly et al. 2021) and Finland (Lehtonen and Venäläinen 2021). Extreme summer drought associated with high July temperatures can also lead to tree mechanical dysfunction (e.g. stem cracks; Rosner et al. 2018) and therefore increased damage due to storm or heavy snowfall. In alpine regions, bioclimatic subzones associated with low, middle and high alpine vegetation may be heavily reduced, leading to loss of ecosystem functions, or cease to exist completely ("disappearing climates"; Williams et al. 2007). Microclimatic variation may compensate for increase in July temperature and lead to a higher resilience of alpine vegetation than expected using spatially smoothed gridded values (Williams et al. 2007, Körner and Hiltbrunner 2021). Such changes are considered of **ecosystem significance**.

Indicator(s): Winter days above 0°C [F04, A04, W04, S04]
Phenomenon: Increasing number of winter days above 0°C [PF04, PA04, PW04, PS04]
Ecosystem characteristic: Abiotic factors
In the given definition of the reference condition for this assessment (Ch. 2), the reference climate is defined as a climate corresponding to the 1961–1990 normal period. This means that under the reference condition, each of the climate variables is within the range of variability observed during the period 1961–1990.

The most important anthropogenic driver of changes in this indicator is climate change. IPCC concludes that human-induced warming reached approximately 1°C above pre-industrial levels in 2017, increasing at 0.2°C per decade (high confidence) (Allen et al. 2018). The link to anthropogenic drivers is therefore assessed as certain for all temperature-derived indicators, including *Winter days above 0°C.* Frequent/long-lasting mild periods in winter imply increased risk of winter damage to vegetation (all ecosystems) and "rain-on-snow" events that negatively affect grazing conditions for large and small herbivores particularly in alpine ecosystem (Kausrud et al. 2008, Callaghan et al. 2011). Decrease in soil frost period will increase wind damage risk (Venäläinen et al. 2020). The understanding of the significance of increasing frequency of winter melt days is assessed as good. Similarly, as for the indicator *January mean temperature*, increasing number of winter days with temperatures above 0°C can be considered of **ecosystem significance** if, for example, they result in increased icing and reduced grazing for native herbivores, suppression of lemming peaks in alpine ecosystems, or increased winter damage to evergreen vegetation (Bokhorst et al. 2009, Bjerke et al. 2017, Callaghan et al. 2011).

Indicator(s): Degree days [F05, A05, W05, S05]
Phenomenon: Increasing number of degree days [PF05, PA05, PW05, PS05]
Ecosystem characteristic: Abiotic factors
In the given definition of the reference condition for this assessment (Ch. 2), the reference climate is defined as a climate corresponding to the 1961–1990 normal period. This means that under the reference condition, each of the climate variables is within the range of variability observed during the period 1961–1990.

The most important anthropogenic driver of changes in this indicator is climate change. IPCC concludes that human-induced warming reached approximately 1°C above pre-industrial levels in 2017, increasing at 0.2°C per decade (high confidence) (Allen et al. 2018). The link to anthropogenic drivers is therefore assessed as certain for all temperature-derived indicators, including *Degree days.* This indicator is closely linked to the growing season (see indicator *Growing* *degree days* and references therein), and the understanding of the importance of changes in this indicator for ecosystem condition is assessed as good, particularly for the ecosystem characteristic *Primary productivity*. For alpine ecosystems, historic records on conditions below the alpine-forest ecotone can to some degree be used as a guide for threshold values of this indicator. If current conditions in the alpine zones approach or correspond to historic conditions in the lower-elevation zones, this indicates that the alpine has shifted to a different climate regime. Such changes are considered of **ecosystem significance**.

Indicator(s): Growing degree days [F06, A06, W06, S06]
Phenomenon: Increasing growing degree days sum during the growing season [PF06, PA06, PW06, PS06]
Ecosystem characteristic: Abiotic factors
In the given definition of the reference condition for this assessment (Ch. 2), the reference climate is defined as a climate corresponding to the 1961–1990 normal period. This means that under the reference condition, each of the climate variables is within the range of variability observed during the period 1961–1990.

The most important anthropogenic driver of changes in this indicator is climate change. IPCC concludes that human-induced warming reached approximately 1°C above pre-industrial levels in 2017, increasing at 0.2°C per decade (high confidence) (Allen et al. 2018). The link to anthropogenic drivers is therefore assessed as certain for all temperature-derived indicators, including *Growing degree days.* Growing degree day sum is a common proxy of the thermal growing season (Førland et al. 2004) and the understanding of the importance of changes in this indicator for ecosystem condition via plant growth is assessed as good (Schmidt et al. 2018, Wipf 2010, Carlson et al 2017, Buermann et al. 2014), particularly for the ecosystem characteristic *Primary productivity*. A better understanding of the lagged response to spring warming and seasonal compensation due to seasonal water deficits is, however, needed (Buermann et al. 2018). For alpine ecosystems, historic records on conditions in below the alpine-forest ecotone can to some degree be used as a guide for threshold values of this indicator. If current conditions in the alpine zones approach or correspond to historic conditions in the lower-elevation zones, this indicates that the alpine has shifted to a different climate regime. Such changes are considered of **ecosystem significance**.

Indicator(s): Annual precipitation [F07, A07, W07, S07]
Phenomenon: Changes in annual precipitation [PF07, PA07, PW07, PS07]
Ecosystem characteristic: Abiotic factors
In the given definition of the reference condition for this assessment (Ch. 2), the reference climate is defined as a climate corresponding to the 1961–1990 normal period. This means that under the reference condition, each of the climate variables is within the range of variability observed during the period 1961–1990.

The most important anthropogenic driver of changes in this indicator is climate change. This link is assessed as certain (Bintanja and Selten 2014, Christensen et al. 2013, Zhang et al. 2013). Increased annual precipitation is expected in the northern regions, but with major spatial variations and seasonal heterogeneity (Callaghan et al. 2011, Hanssen-Bauer et al. 2017). For example, increasing frequency and duration of blocking patterns may lead to more extreme seasonal values (Wilcke et al. 2020), with large scale ecosystem consequences that are poorly reflected in changes in average values. Mid Norway, including the Trøndelag region is expected to experience increased precipitation both annually and during the growing season (Hanssen-Bauer et al. 2017). Changes in annual precipitation will affect the hydrology of all ecosystems, for example through increased paludification (accumulation of organic matter) in alpine and boreal areas with increasing precipitation (Skre et al. 2002), with implications for plant growing conditions, especially the spread of thicket and forest (Crawford et al. 2003, Simard et al. 2007, Laamrani et al. 2020). Increased annual precipitation may compensate for the effects of increased temperature and associated drought and water deficits in the growing season.

The understanding of the importance of changes in the precipitation regime for ecosystem condition is assessed as less good for all ecosystems, although effects of precipitation on mire condition, for instance via control on peat surface moisture levels (Kokfelt et al. 2009) is more direct and somewhat better understood than for remaining ecosystems. Changes in precipitation can be considered of **ecosystem significance** if, for example, they compensate for negative effects of increased growing season temperature and associated fire and water stress (Ruiz-Pérez and Vico 2020, Venäläinen et al. 2020), or slow down or even reverse shifts in vegetation (e.g. alpine to boreal) through paludification (Crawford et al. 2003).

Indicator(s): Growing season precipitation [F08, A08, W08, S08]
Phenomenon: Changes in precipitation during the growing season [PF08, PA08, PW08, PS08]
Ecosystem characteristic: Abiotic factors
In the given definition of the reference condition for this assessment (Ch. 2), the reference climate is defined as a climate corresponding to the 1961–1990 normal period. This means that under the reference condition, each of the climate variables is within the range of variability observed during the period 1961–1990.

The most important anthropogenic driver of changes in this indicator is climate change. This link is assessed as certain (Bintanja and Selten 2014, Christensen et al. 2013, Zhang et al. 2013). Increased precipitation is expected in the northern regions, but with major spatial variations and seasonal heterogeneity (Callaghan et al. 2011, Hanssen-Bauer et al. 2017). Mid Norway incl Trøndelag region is expected to experience increased precipitation both annually and during the growing season (Hanssen-Bauer et al. 2017). However, increasing frequency and duration of blocking patterns may lead to more extreme seasonal values and annual variability (Wilcke et al. 2020).

Increased annual precipitation may compensate for the effects of increased temperature and associated drought and water deficits in the summer season. This has been emphasized (Buermann et al. 2014, 2018). The understanding of the importance of changes in the precipitation regime for ecosystem condition is assessed as less good for all ecosystems, although effects of precipitation on mire condition, for instance via control on peat surface moisture levels (Kokfelt et al. 2009) is more direct and somewhat better understood than for remaining ecosystems. Changes in precipitation can be considered of **ecosystem significance** if, for example, they exacerbate the impact of higher growing season temperature (e.g., drought years leading to tree mortality, insect outbreaks, and fires) or on the contrary slow transition from tundra or peatlands to forest.

Indicator(s): Snow cover duration [F09, A09, W09, S09]
Phenomenon: Shorter season with snow cover [PF09, PA09, PW09, PS09]
Ecosystem characteristic: Abiotic factors
In the given definition of the reference condition for this assessment (Ch. 2), the reference climate is defined as a climate corresponding to the 1961–1990 normal period. This means that under the reference condition, each of the climate variables is within the range of variability observed during the period 1961–1990.

The most important anthropogenic driver of change in this indicator is climate change. On a local scale, grazing pressure can influence this indicator through vegetation structure (bushes/trees; te Beest et al. 2016). The links to these drivers are assessed as certain. The duration and timing of melt of snow cover is a key indicator of change in northern ecosystems, both through its effects on local ecosystem, and its importance for energy feedbacks to the climate system via surface reflectance (Euskirchen et al 2007). The persistence and depth of the snow cover is one of the most important factors determining alpine tundra vegetation characteristics (Niittynen et al. 2020b, Niittynen et al. 2018, 2020a, Wipf et al. 2009). For all northern terrestrial ecosystems a reduced snow cover period can alter the thermal regime in the soil, including the risk of frost drought on vegetation (Malmer et al. 2005, Bjerke et al. 2017) and influence biogeochemical processes in the top soil/peat layers including carbon exchange in forest (Yi et al. 2015). Duration of snow cover as well as snow depth are also related to duration and intensity of soil frost which may affect tree growth (Repo et al. 2021) and methane emission from boreal peatlands (Zhao et al. 2016). The understanding of the importance of changes in duration of snow cover is assessed as good for all ecosystems.

Changes in the duration of snow cover can be considered of ecosystem significance if, for example, i) they result in shrinkage of areas with snowbed vegetation in alpine ecosystems, ii) increased frost damages on vegetation or changes in duration and intensity of soil frost, with consequences for tree growth, iii) changes in predator-prey interactions that depend on snow cover, such as camouflage mismatch for ptarmigan and mountain hare (Henden et al. 2020, Zimova et al. 2020), and voles/lemmings-predators (Hansson and Henttonen 1985).

Indicator(s): Soil water content during growing season [W14]
Phenomenon: Decreasing soil water content or increasing number of days with low soil water content (dry days) [PW10]
Ecosystem characteristic: Abiotic conditions
In the given definition of the reference condition for this assessment (Ch. 2), the reference climate is defined as a climate corresponding to the 1961–1990 normal period. This means that under the reference condition, we would expect also the hydrological variables to be within the range of variability observed during the period 1961–1990. Since the climatic and hydrological data records cover the entire climatic reference period, deviations from this reference condition can be assessed directly.

The most important anthropogenic driver of change in this indicator is climate change and drainage on organic soils/wetlands. The link to these drivers is assessed as certain. While summer precipitation is expected to increase, snow melt will occur earlier, and evaporation will increase both in spring and summer (Norsk klimaservicesenter). There is therefore a risk for longer periods with low ground water levels and larger soil water deficits. This indicator should be viewed in concert with the indicators *Ground water condition during the growing season*, *Growing season precipitation*, *Snow cover duration*, as well as indicators on growing season temperatures (*July mean temperature, Growing degree days*). Reduced soil water content will in principle affect all ecosystems, but in particular wetlands where vegetation and micro- and mesofauna are adapted to a high-water table during the entire growing season.

The understanding of the importance of changes in soil water content during the growing season is assessed as good. Wetlands are particularly sensitive to reduced soil water content. Drought causes oxygen penetration to increase in wet soils, leading to an increase in oxidation of organic matter and reduced inorganic species (e.g., sulfides), which again can lead to soil acidification, metal mobilization and reduced water quality (Stirling et al. 2020). Lower soil water content will instigate transitions towards more drought-tolerant species assemblies in various taxa, for example bryophytes (Minkkinen et al. 1998, Renou-Wilson et al. 2019), vascular plants (Laine et al. 1995, Sperle and Bruelheide 2021), microorganisms (Potter et al. 2017, Seward et al. 2020), mushrooms (Laine et al. 1995), and soil fauna (Juan-Ovejero et al. 2019, Sławski et al. 2022). In particular, with increasing drought stress, the most hygrophilous species may suffer major declines at a regional level. For example, peatmosses (*Sphagnum*) may be completely replaced by forest mosses and other more drought-tolerant mosses that do not produce new peat in the same extent has peatmosses do (Minkkinen et al. 1998). The drying mires will become more suitable for shrub and tree growth, especially at mire margins (Laine et al. 2019, Nowakowska et al. 2021). In this region, where many wetlands already are affected by an extensive network of trenched drainage channels, additional decreasing soil content will convert wetlands to other vegetation types, particularly forest and heath. Decreasing soil water content or increasing number of dry days, can be considered of **ecosystem significance** if, for example, it leads to negative impacts on mire specialist species, of which many already are on the Norwegian Red List of threatened species, or negative impacts on already threatened wetland habitat types where these are converted to other habitats.

Indicator(s): Ground water condition during growing season [W15]
Phenomenon: Increasing number of days with low ground water level (dry days) [PW12]
Ecosystem characteristic: Abiotic conditions
In the given definition of the reference condition for this assessment (Ch. 2), the reference climate is defined as a climate corresponding to the 1961–1990 normal period. This means that under the reference condition, we would also expect the hydrological variables to be within the range of variability observed during the period 1961–1990. Since the climatic and hydrological data records cover the entire climatic reference period, deviations from this reference condition can be assessed directly. The water-table depth is a critical abiotic factor in wetlands which, apart from responding to rainfall patterns, is determined by the level of physical interventions (drainage). A reference state for wetlands, is a wetland system where the hydrological dynamics has not been disturbed by drainage or damming). Water-table depth can vary significantly between wetlands drained for crop and fodder production, and wetlands managed for conservation (Evans et al. 2016). Mean water-table depth has an over-riding influence on the rate of organic matter (including peat) decomposition rates, and primary productivity.

The most important anthropogenic driver of change in this indicator is climate change. The link to these drivers is assessed as certain. While summer precipitation is expected to increase, snow melt will occur earlier and evaporation will increase both in spring and summer (Norsk klimaservicesenter, https://klimaservicesenter.no/). There is therefore a risk for longer periods with low ground water levels and larger soil water deficits. This indicator should be viewed in concert with the indicators *Soil water content during the growing season*, *Growing season precipitation*, *Snow cover duration*, as well as indicators on growing season temperatures (*July mean temperature, Growing degree days*). Reduced ground water will have negative impacts on ecosystems adapted to high water tables during the growing season, in particular swamp forests and alluvial forests where tree roots are particularly sensitive to reduced water availability (e.g., Hacke and Sauter 1996, Doffo et al. 2017). Intact peatlands are generally considered as resilient to summer drought stress because of negative ecohydrological feedbacks that generally maintain a wet peat surface (Morris and Waddington 2011; Waddington et al. 2015). However, it has been shown that shallow mires (peat < 40 cm deep) suffer greater moisture stress than deeper mires (Moore et al. 2021). In Trøndelag, where peat accumulation has been hampered through a long history of traditional land use, i.e., scything, cattle grazing and active removal of hummocks, peat depth can be quite low. Hence, it is likely that these shallow mires will experience enhanced peat decomposition and moss moisture stress with increasing summer water deficits (Helbig et al. 2020, Moore et al. 2021). Generally, the understanding of the effects of increased number of days with low ground water level for wetland ecosystem condition is assessed as good. Increasing number of days with low ground water level in wetland ecosystems can be considered of ecosystem significance if, for example, the overall Green House Gases balance (uptake and emissions) show strong relationship with mean water table, with peatlands becoming large net emissions sources when sites were drained or inundated (Evans et al. 2016).

Indicator(s): Trenching [F13, W13]
Phenomenon: Large or increasing area affected by historical or present-day trenching [PF26, PW16]
Ecosystem characteristic: Abiotic factors
Under the reference condition wetland ecosystems are essentially unaffected by trenching activities and maintain the natural hydrological regime.

Trenching has been a common practice to change the hydrological regime and drain wetlands, to improve soil aeration conditions for agriculture, fodder production and forestry, and trenching activities have received varying levels of financial subsidies though the years (PEFC Norge 2015, Landbruksdirektoratet 2021). The only drivers of change behind this indicator are hence human activities and policy incentives, and the link to drivers is hence assessed as certain. Trenching in wetlands enhances water drainage which in turn affects the depth of the water table in trenched wetlands and has profound effects on wetland hydrology determining ecological processes such as primary productivity and organic matter decomposition. There is a high level of agreement in the literature that drainage significantly affects the ecological properties of wetland ecosystems (e.g. Evans et al. 2016). The understanding of the importance of change in this indicator on local scale processes (both abiotic and biotic) is hence considered good.

However, knowledge of the consequences of changes in water table dynamics on specific ecosystem processes is less good. Water table levels interact with other abiotic factors such as soil pH and nutrient content in determining the kind of organic matter decomposition process involved (i.e. aerobic and anaerobic decomposition) (Barthelmes et al. 2015), the kind of carbon gases produced (CO_2 vs CH_4 gases) (Evans et al. 2016) and the balance between carbon gases uptake and emissions (Bárcena et al. 2016, Humpenöder et al. 2020). Specifically, net atmospheric gas removals and emissions are highly context dependent, including the wetland type (Evans et al. 2016), so the knowledge about the consequences of water-table dynamics and other management practices, such as fertilization, re-wetting, and tree planting is also in this case, less good.

In the case of wetland trenching for agricultural purposes, the measure is part of a package of different practices that lead to land conversion from wetland to agricultural land which includes drainage with closed ditches, channels (*profilering*), excavation of the mineral soil mass, and supply of mineral soil on top of the peatland (Bárcena et al. 2015). These practices lead to a loss of peatland area through land conversion rather than a degradation of wetland condition *per se*. However, there is large uncertainty about the proportion of arable land in Norway that is based on organic soil, but estimates indicate that conversion from wetland to arable land has been higher than the conversion to other land-uses. Approximately 90 % of cultivated peatland is used for grass production for livestock feed. The conversion leads to **significant changes** in the carbon balance of the ecosystem (carbon uptake and emissions) (Bárcena et al. 2015). Hence, the overall assessment of the understanding of the importance of a high or increasing area affected by historical or present-day trenching is less good.

High or increasing levels of trenching in wetland areas can be considered of **ecosystem significance** if, for example, i) average water-table levels of drained wetlands are maintained consistently below those of non-drained ones, ii) trenching activities adversely affects biodiversity associated with wetland (Norwegian Environment Agency 2018).

6 Ecosystem characteristics

This section briefly summarizes, in a tabular format, the seven ecosystem characteristics for each ecosystem, and reflect on the overall role that the combined set of indicators and their phenomena should play in the assessment of the ecosystem characteristic to which they are assigned (see also **Box 2**).

Weaknesses in the set of indicators are not addressed here, but in the Assessment of the knowledge base (see Chapter 7.1.1). Any non-included indicators, which are recommended for future inclusion, are addressed in Recommendations for monitoring and research (Chapter 7.7). Specific details as to how included indicators may by improved and developed further, are presented in Supplementary information on indicators (**Appendix 1**).

Climate change is altering the abiotic conditions which are fundamental for the structure, functioning, and productivity of cold adapted northern ecosystems. Top: Ground ice caused by mild spells in winter can restrict the access to food plant for herbivores (photo: Jan Erik Knutsen, UiT). Bottom: Warmer temperatures may permit shrubs and trees to encroach on alpine habitats. Since they protrude above the snow in winter, this alters the surface reflectance/albedo (photo: Eeva Soininen, UiT).

***Table 6.1a**. Description of the indicator set per ecosystem characteristic for forest ecosystems.*

Ecosystem characteristic	Indicator set [indicator ID]	The role of the indicator set in the assessment of the ecosystem characteristic
Primary productivity	Maximum greenness [F10] Onset of greening [F11] Tree volume [F22]	The three indicators for *Primary productivity* are under the reference condition mainly influenced by growing season temperatures, local site conditions, and natural forest disturbance and successional dynamics. Complex vertical layers in forest ecosystems makes it challenging to measure this indicator directly. Remote sensing estimates for vegetation greenness (here EVI) and standing tree biomass are therefore used as a surrogate for primary production. In the assessment of the ecosystem characteristic *Primary productivity*, the indicator *Maximum greenness* serves to document regional (large-scale) trends in plant biomass / productivity ('greening' / 'browning'), while the indicator *Onset of greening* serves to document phenological changes, especially in relation to trophic match / mismatch relationship between plants and herbivores. The indicator *Tree volume* serves to document whether satellite based regional estimates are supported by changes in standing volume relative to dominant tree species, harvest classes, site condition (productive/unproductive forest).
Biomass distribution among trophic levels	ROS species versus moose [F18] Bilberry versus deer and moose [F24] Ungulates versus carnivorous vertebrates [F25]	The three indicators for *Biomass distribution among trophic levels* in forest ecosystems all involve ungulate biomass in relation to either key plant groups (bilberry or ROS species) or carnivores. Under the reference condition, tri-trophic interactions occur, with ungulate biomass determined in part by forage availability and in part by the top-down control from carnivores. ROS species and bilberry are all key forage species for ungulates, and are important also for forest biodiversity (see *Functionally important species*). Anthropogenic impacts can be on any of the three trophic levels here. Forest management practices alter the availability of ROS species in the stand. Directed hunting management drives ungulate population dynamics, especially when carnivores are functionally absent. The indicator of biomass distribution *ROS species versus moose* thus documents the changes in both ROS species and ungulate management. The *ungulate versus carnivorous vertebrates* indicator documents the degree of natural top-down control of ungulate populations. The *bilberry versus red deer* indicator relates to the impact of managed ungulate populations on a functionally important species.
Functional groups within trophic levels	Plant growth forms: deciduous proportion [F27] Herbivorous vertebrates: browsers versus grazers [F19]	The dominant plant growth form among trees is a defining characteristic of forest ecosystem structure and function and a characteristic highly influenced by anthropogenic drivers. In the reference condition, the proportion of deciduous trees in boreal forest in Scandinavia ranges from total dominance in sub-alpine mountain birch forest to a relatively small proportion in lowland coniferous forests. Intensive forestry in naturally conifer dominated forests acts to reduce the proportion of deciduous trees and thereby also the ecological function of the tree-layer. Hence, the deciduous proportion is an indicator of changes in the functionality of the tree-layer mainly resulting from forestry. Herbivorous vertebrates (ungulates) have, depending on their diets and relative abundance a potential capacity to induce shifts in composition/structure in the tree and understorey vegetation of forest ecosystem. While the Scandinavian forest ecosystem in a pristine state would be dominated by wild, mainly browsing moose and deer populations, grazing livestock (domestic goats, sheep and cattle) is a form of land use that has been present and contributed to shaping functionality of herbivory in these forests for centuries. Management of wild (hunting regulations) and domestic ungulates (agriculture) is expected to be the main determinant of the relative abundance of these two functional groups of herbivores, and thereby the main determinant of relative impacts of grazing and browsing in forest ecosystems.

Table 6.1a *(cont.)*

Ecosystem characteristic	Indicator set [indicator ID]	The role of the indicator set in the assessment of the ecosystem characteristic
Functionally important species and biophysical structures	Bark beetle abundance [F14] Wild ungulate density [F16] Domestic ungulate density [F17] Dead wood volume [F21] ROS volume [F28] Bilberry coverage [F20] Large predator abundance [F23]	There are seven indicators describing *Functionally important species and biophysical structures* in forests. These indicators are grouped under this ecosystem characteristics because it is assumed that a change in their state compared to the reference condition will have a disproportionately large effect on the ecosystem as a whole. The indicator set includes species that are often referred to as ecosystem engineers because of their ability to singlehandedly influence ecosystem functioning and habitat availability/suitability for other species. *Dead wood volume* is the only one of the seven indicators that represents purely a biophysical structure. This indicator represents habitat availability for numerous species of insects and fungi especially. In the reference condition, wood is not removed from the ecosystem so that the dead wood volume is in equilibrium with decay rates and tree mortality. The other indicators are related to specific species and their abundance. These species fulfil important functional roles in the ecosystem. A reduction in their relative biomass as compared to a reference state would imply these important functions do not occur (e.g. prey regulation by predators). Conversely, an increase in their relative abundance may lead to a type or size of ecosystem disturbance which will negatively impact the ecosystem, such as over-browsing.
Landscape ecological patterns	Area free of major infrastructure [F12]	Forest ecosystems are under the reference condition only marginally affected by major technical infrastructure. The indicator *Area free of major infrastructure* is a simple calculation, based on official statistics, of how much of the ecosystem's area is unaffected (defined as > 1 km away from) by major technical infrastructure. The indicator thus has its greatest relevance in ecosystems that are strongly affected by human development and major technical infrastructure, and should ideally be supplemented by more specific metrics of habitat fragmentation and connectivity, which are key landscape-ecological patterns.
Biological diversity	Forest bird communities [F15]	Forest birds are sensitive indicators of forest structure, including stand-scale vertical structuring of vegetation layers, landscape-scale composition of successional stages and in particular, forestry-induced areal reduction and fragmentation of late successional stages. Some bird species are dependent on dead wood or stands of deciduous trees. In the refence condition, the forest bird communities should include habitat specialists, especially species that require large stands of late successional stages, naturally rare habitats and patchily distributed food resources. Boreal bird species are expected to be sensitive to climate warming (nemoralisation) and ground breeding birds are sensitive omnivores and generalized predators that facilitated by anthropogenic lands use and infrastructure. Avian biological diversity is also a functional significance as birds play key roles in temperate forests as seed dispersers, cavity-nesters that excavated live and dead trees, and prey for many predators.
Abiotic factors	Annual mean temperature [F01] January mean temperature [F02] July mean temperature [F03] Winter days above 0°C [F04] Degree days [F05] Growing degree days [F06] Annual precipitation [F07] Growing season precipitation [F08] Snow cover duration [F09] Trenching [F13]	Climatic conditions are fundamental for the structure, functioning, and productivity of all ecosystems. The set of indicators for the ecosystem characteristic *Abiotic factors* serves to document changes in key characteristics of the seasonal climate relative to the reference period 1961–1990, in the form of general indicators of annual, mid-winter and mid-summer temperatures, annual and growing season precipitation, as well as more specific indicators related to growing season length (*Degree days*), growing season heat accumulation (*Growing degree days*), the propensity of mild spells in winter (*Winter days > 0°C*) and *Snow cover duration*. For forest ecosystems, summer temperatures (including growing season length and heat accumulation) and precipitation are defining for tree growth and tree species composition, as well as for the occurrence of forest damage through drought, and insect pests. Trenching is an activity which serves to lower the soil water content and adversely affect ecological conditions in wet forest. National statistics on the area affected by trenching through subsidized schemes is included as a very rough proxy of change in new trenching activities over time.

Table 6.1b*. Description of the indicator set per ecosystem characteristic for alpine ecosystems.*

Ecosystem characteristic	Indicator set [indicator ID]	The role of the indicator set in the assessment of the ecosystem characteristic
Primary productivity	Maximum greenness [A10] Onset of greening [A11]	The two indicators for *Primary productivity* are under the reference condition mainly influenced by growing season temperatures and local site conditions. Complex vertical layers of certain alpine types make it challenging to measure this indicator directly. Remote sensing estimates for vegetation greenness (here EVI) are therefore used as a surrogate for primary production. In the assessment of the ecosystem characteristic *Primary productivity*, the indicator *Maximum greenness* serves to document regional (large-scale) trends in plant biomass / productivity ('greening' / 'browning'), while the indicator *Onset of growing season* serves to document phenological changes, especially in relation to trophic match / mismatch relationship between plants and herbivores.
Biomass distribution among trophic levels	Ungulates versus carnivorous vertebrates [A24]	The indicator for *Biomass distribution among trophic levels* in the alpine ecosystem, is under the reference condition, determined by the population dynamics and trophic interactions between these groups. Under the reference condition ungulates in alpine ecosystems are influenced by predation and behavioural changes induced by carnivores. The indicator biomass distribution between *ungulates versus carnivorous vertebrates* thus documents deviations in this trophic interaction.
Functional groups within trophic levels	Herbivorous vertebrates: reindeer:moose/deer [A22] Carnivorous vertebrates: arctic versus red fox [A21]	A typical feature of alpine ecosystem under the reference condition is that some species or species groups can be dominant within a trophic level, and thus be basis for central ecosystem functions. An expectation under climate change is that the dominance of such alpine species (and their associated functions) decreases in favour of more boreal species (and thereby other functions). The two alpine indicators for the ecosystem characteristic *Functional groups within trophic levels* therefore serve to document such borealisation in terms of changes in the relative abundances of large herbivorous vertebrates (*reindeer vs. moose*) and mammalian meso-carnivores (*arctic fox vs. red fox*) that respectively may be indicative of shifts in functions towards more browsing and generalized predation in alpine ecosystems.
Functionally important species and biophysical structures	Wild ungulate density [A17] Semi-domestic reindeer density [A13] Domestic ungulate density [A16] Large predator abundance [A14] Red fox camera index [A14] Lemming abundance [A18]	There are six indicators describing *Functionally important species and biophysical structures* in alpine ecosystems. All six indicators are referring to named species and their abundances, and no indicators reflect a biophysical structure *per se*. These indicators are grouped under this ecosystem characteristics because it is assumed that a change in their state compared to the reference condition will have a disproportionately large effect on the ecosystem as a whole. The indicator set includes species that are often referred to as ecosystem engineers because of their ability to singlehandedly influence ecosystem functioning and habitat availability/suitability for other species. There are four indicators based on herbivorous species. For all of these there is a possibility for increased ecosystem disturbance (e.g. over-grazing/browsing) if population sizes are too high. However, in the case of *lemming abundance*, this indicator is more geared towards depicting lemming availability as a prey species to predatory species, as the lemming cycle is the most important pulse in the alpine food web. The last two indicators are based on predator species. In an intact alpine ecosystem, viable populations of large predators are expected to play important functional roles, regulating larger mammalian prey species, and scavenging carcasses. In addition, large predators influence the behaviour patterns of their prey, and in the absence of this "fear of predation" prey species may behave differently than in the reference condition. The low density of wolverines in alpine ecosystems is a result of a management strategy that prioritises semi-domestic and domestic herbivores over these large predators. The indicator *Large predator abundance* documents changes in this red-listed species. Alpine habitats constitute, under the reference condition a marginal habitat for red foxes, which are effective boreal meso/generalist predators and scavengers. Increasing red fox populations are a sign of increasing borealisation of alpine ecosystems, and are expected to have significant effects on alpine species of ground nesting birds, and increasing competition for the Arctic fox.

***Table 6.1b**. (cont.)*

Ecosystem characteristic	Indicator set [indicator ID]	The role of the indicator set in the assessment of the ecosystem characteristic
Landscape ecological patterns	Area free of major infra-structure [A12]	Alpine ecosystems are under the reference condition only marginally affected by major technical infra-structure. The indicator *Area free of major infrastructure* is a simple calculation, based on official statistics of how much of the ecosystem's area is unaffected (defined as > 1 km away from) by major technical infrastructure. The indicator thus has its greatest relevance in ecosystems that are strongly affect-ed by human development and major technical infrastructure, and should ideally be supplemented by more specific metrics of habitat fragmentation and connectivity, which are key landscape-ecological patterns.
Biological diversity	Alpine bird communities [A23] Arctic fox abundance [A19] Arctic fox litter size [A20]	Bird communities are key indicators of the condition of an ecosystem. Under the reference condition, *Alpine bird communities* are dominated by species that select open habitats, are adapted to short summer seasons and cyclic variation in nesting success associ-ated with rodent population cycles. This indicator serves to document changes towards a borealisation of alpine ecosystem under climate change. The Arctic fox is a characteristic Arctic species at the top of the food web when the alpine ecosystem is under the reference condi-tion. Viable population sizes resulting from sufficient production (number of litters and litter sizes) depend on regular lemming cy-cles and a moderate level of interspecific competition from expanding boreal red foxes. The Arctic fox has been chosen as climate change flagship species by IUCN. In the Fennoscandian alpine tundra, the species is endangered and is at present subject to inten-sive management actions. In the assessment of the ecosystem characteristic *Biological diversity*, the Arctic fox is a key indicator of "trophic collapse" due to changes in lower trophic levels (especially more irregular and/or dampened lemming dynamics) or due to competition and predation from invasive boreal species (in particular the red fox). The Arctic fox indicators serve to document the effects of ongoing management actions.
Abiotic factors	Annual mean temperature [A01] January mean temperature [A02] July mean temperature [A03] Winter days above 0°C [A04] Degree days [A05] Growing degree days [A06] Annual precipitation [A07] Growing season precipita-tion [A08] Snow cover duration [A09]	Climatic conditions are fundamental for the structure, functioning, and productivity of all ecosystems. The set of indicators for the ecosystem characteristic *Abiotic factors* serves to document changes in key characteristics of the seasonal climate relative to the reference period 1961–1990, in the form of general indicators of annual, mid-winter and mid-summer temperatures, annual and growing season precipitation, as well as more specific indicators related to growing season length (*Degree days*), growing season heat accumulation (*Growing degree days*), the propensity of mild spells in winter (*Winter days > 0°C*) and *Snow cover duration*. For alpine ecosystems, summer temperatures and growing season length are defining for vegetation zonation (including tree and shrub encroachment), while the duration, depth, and vertical structure of the snow cover constitutes an important niche dimension for focal species and habitats, such as small rodents and snow beds.

Table 6.1c. *Description of the indicator set per ecosystem characteristic for wetland ecosystems.*

Ecosystem characteristic	Indicator set [indicator ID]	The role of the indicator set in the assessment of the ecosystem characteristic
Primary productivity	Maximum greenness [W10] Onset of greening [W11]	The two indicators for *Primary productivity* are under the reference condition mainly influenced by growing season temperature and local site conditions including hydrological conditions. Complex vertical layers in certain wetland types make it challenging to measure this indicator directly. Remote sensing estimates for vegetation greenness (here EVI) are therefore used as a surrogate for primary production. In the assessment of the ecosystem characteristic *Pri-mary productivity*, the indicator *Maximum greenness* serves to document regional (large-scale) trends in plant biomass / productivity ('greening' / 'browning'), while the indicator *Onset of growing season* serves to document phenological changes, especially in relation to trophic match / mismatch relationship between plants and herbivores.
Biomass distribution among trophic levels	*No indicators available for this characteristic due to poor data availability*	
Functional groups within trophic levels	*No indicators available for this characteristic due to poor data availability*	
Functionally im-portant species	*No indicators available for this characteristic due to poor data availability*	
Landscape ecological patterns	Area free of major infrastructure [W12]	Wetland ecosystems are under the reference condition only marginally affected by major technical infra-structure. The indicator *Area free of major infrastructure* is a simple calculation, based on official statis-tics, of how much of the eco-system's area is unaffected (defined as > 1 km away from) by major technical infrastructure. The indicator thus has its greatest relevance in ecosystems that are strongly affected by human development and major technical infrastructure, and should ideally be supplemented by more specific metrics of habitat fragmentation and connectivity, which are key landscape-ecological patterns.
Biological diversity	Wetland bird communities [W16]	Wetland birds are highly responsive to the environmental conditions in mires and lakes and thus serves as sensitive indicators of deteriorated wetland ecosystems. The community includes species with very different habitat require-ments, diets and feeding modes. Therefore, this indicator reflects a broad spectrum of ecological conditions in wetland ecosystems. The community also includes harvested species of waterfowl and migratory species of conservation con-cern.

***Table 6.1c**. (cont.)*

Ecosystem characteristic	Indicator set [indicator ID]	The role of the indicator set in the assessment of the ecosystem characteristic
Abiotic factors	Annual mean temperature [W01] January mean temperature [W02] July mean temperature [W03] Winter days above 0°C [W04] Degree days [W05] Growing degree days [W06] Annual precipitation [W07] Growing season precipitation [W08] Snow cover duration [W09] Soil water content during growing season [W14] Ground water condition during growing season [W15] Trenching [W13]	Climatic conditions are fundamental for the structure, functioning, and productivity of all ecosystems. The set of indicators for the ecosystem characteristic *Abiotic factors* serves to document changes in key characteristics of the seasonal climate relative to the reference period 1961–1990, in the form of general indicators of annual, mid-winter and mid-summer temperatures, annual and growing season precipitation, as well as more specific indicators related to growing season length (*Degree days*), growing season heat accumulation (*Growing degree days*), the propensity of mild spells in winter (*Winter days > 0°C*) and *Snow cover duration*. For wetland ecosystems, two additional indicators are included (*Soil water content during growing season* and *Ground water condition during growing season*) which serve to document regional (large-scale) trends in hydrological conditions and the occurrence of dry spells during the growing season (days with low soil water content or ground water levels) which are both influential for wetland conditions. Trenching is an activity which serves to lower the soil water content and adversely affect wetland condition. National statistics on the area affected by trenching through subsidized schemes is included as a very rough proxy of change in new trenching activities over time.

***Table 6.1d**. Description of the indicator set per ecosystem characteristic for open lowland ecosystems.*

Ecosystem characteristic	Indicator set [indicator ID]	The role of the indicator set in the assessment of the ecosystem characteristic
Primary productivity	Maximum greenness [S10] Onset of greening [S11]	The two indicators for *Primary productivity* are, under the reference condition mainly influenced by growing season temperatures, and local site conditions including hydrological conditions. Complex vertical layers in certain wetland types makes it challenging to measure this indicator directly. Remote sensing estimates for vegetation greenness (here EVI) are therefore used as a surrogate for primary production. In the assessment of the ecosystem characteristic *Primary productivity*, the indicator *Maximum greenness* serves to document regional (large-scale) trends in plant biomass / productivity ('greening' / 'browning'), while the indicator *Onset of growing season* serves to document phenological changes, especially in relation to trophic match / mismatch relationship between plants and herbivores.
Biomass distribution among trophic levels	*No indicators available for this characteristic due to poor data availability*	
Functional groups within trophic levels	*No indicators available for this characteristic due to poor data availability*	

***Table 6.1d**. (cont.)*

Ecosystem characteristic	Indicator set [indicator ID]	The role of the indicator set in the assessment of the ecosystem characteristic
Functionally important species	Wild ungulate density [S14] Domestic ungulate density [S13] Bumblebee abundance and species richness [S17]	There are three indicators describing *Functionally important species and biophysical structures* in open lowland ecosystems. All three indicators are referring to named species or species groups and their abundances, and no indicators reflect a biophysical structure *per se*. These indicators are grouped under this ecosystem characteristics because it is assumed that a change in their state compared to the reference condition will have a disproportionately large effect on the ecosystem as a whole. The indicator set includes species that are often referred to as ecosystem engineers because of their ability to singlehandedly influence ecosystem functioning and habitat availability/suitability for other species. There are two indicators on herbivorous species. Herbivory is a defining phenomenon for this ecosystem type and herbivores have an important role in continuously maintaining a treeless nature type. Therefore, a change in herbivore pressure is considered a deviation from the reference state. For these indicators there is a possibility for increased ecosystem disturbance (e.g. over-grazing/browsing) if population sizes are too high. However, a reduction is grazing pressure is more commonly observed. Bumblebees are important pollinators of wild and domestic species. They are sensitive to land use change and intensification of agricultural practices. Due to a lack of trees and a high availability of light at the field layer, open lowland ecosystems are relatively rich in flowering herbs. Pollinators thus play an important role in maintaining populations of flowering plants. This is not to say that pollinators are not very important in other ecosystems as well, but data on insect abundances are mainly collected from semi-natural ecosystems.
Landscape ecological patterns	*No indicators available for this characteristics due to poor data availability*	
Biological diversity	Farmland bird communities [S16] Butterfly abundance and diversity [S15]	Communities of farmland birds and butterflies are particularly sensitive to land use changes. Under the reference condition, the bird community is dominated by species that select open habitats. This indicator is thus sensitive to abandonment of agriculture that for cause encroachment of forest on open land. The bird community indicator is also sensitive to intensified agriculture by means of large monocultures and use of pesticides as well as increasing urbanization of rural areas. Butterflies have several of the same sensitivities as farmland birds, but also reflect changes in the plant communities and in particular the abundance of pollen and nectar resources in open lowland ecosystems. Butterflies contribute significantly to pollination of both wild plants and some crops.
Abiotic factors	Annual mean temperature [S01] January mean temperature [S02] July mean temperature [S03] Winter days above 0°C [S04] Degree days [S05] Growing degree days [S06] Annual precipitation [S07] Growing season precipitation [S08] Snow cover duration [S09]	Climatic conditions are fundamental for the structure, functioning, and productivity of all ecosystems. The set of indicators for the ecosystem characteristic *Abiotic factors* serves to document changes in key characteristics of the seasonal climate relative to the reference period 1961–1990, in the form of general indicators of annual, mid-winter and mid-summer temperatures, annual and growing season precipitation, as well as more specific indicators related to growing season length (*Degree days*), growing season heat accumulation (*Growing degree days*), the propensity of mild spells in winter (*Winter days > 0°C*) and *Snow cover duration*.

7 Assessments

According to the PAEC protocol, the overall assessment of ecosystem condition comprises three subsections: an assessment of the knowledge base, an assessment of the phenomena, followed by an assessment of the condition of the ecosystem characteristics and the ecosystem as a whole. Since this methodological pilot addresses four ecosystems, we first summarize the content and the categories used in each level of the assessment (Chapter 7.1), before we assess the condition of each ecosystem separately (Chapters 7.2-7.5).

7.1 The PAEC assessment categories

7.1.1 Categories for the assessment of the knowledge base

The assessment of the knowledge base reflects the degree to which the data underlying each indicator has a coverage in space and time which is sufficient, and relevant <u>relative to the scope of this assessment</u>. It is not an assessment of *data quality* per se. Even data of excellent quality may score low in the assessment of the knowledge base if they, for instance, are collected with an entirely different purpose and scope in mind. The assessment of the knowledge base also address the indicator coverage behind each ecosystem characteristic. The indicator coverage reflects the extent to which the set of indicators underlying the assessment of each characteristic, can be considered adequate.

The overall assessment of the knowledge base is presented in a tabular format. The assessment is colour coded according to the predefined categories in PAEC (**Figure 7.1.1**). In accordance with the PAEC protocol, the knowledge base is assessed at three levels: *Data level*, *indicator level*, and *ecosystem characteristics level*.

1. At a data level, we summarize the spatial (SR) and temporal (TR) representativity of the datasets behind each indicator.
    a. The spatial representativity (*SR*) of *each dataset* relative to the target ecosystem (Chapter 3) is determined by the sampling design employed (design-based, model-based; Wang et al. 2012). A design-based sampling is evaluated based on three criteria: 1) whether or not the entire population has the possibility of being included in the sampling (*SRd1*), 2) whether or not sampling is based on randomisation (*SRd2*), and 3) whether or not there is a known probability of including each sampling unit (*SRd3*). A model-based sampling (*SRm*) is evaluated based on just one criterium; whether or not sampling is based on a model (i.e. a sampling design) that is relevant for the indicator or phenomenon in question.
    b. The temporal representativity (*TR*) of *each dataset* relative to any temporally defined reference condition. A temporally defined reference condition includes explicit definitions (e.g. the reference condition equals the condition of the ecosystem at a particular point in time), and implicit definitions (e.g. the reference condition equals the condition of the ecosystem under, for instance, a preindustrial climate). Temporal representativity is evaluated based on two criteria: 1) With respect to years (*TRyr*; the length of the time series relative to relevant dynamics and any temporally defined reference conditions), and 2) with respect to seasonality (*TRse*; whether or not relevant seasonality is taken into account in the sampling or not).
2. At an *indicator level* we assess the indicator's total data coverage based on the overall assessment of spatial (SRtotal) and temporal (TRtotal) representativity of each dataset included.
3. At an *ecosystem characteristic level,* we assess indicator coverage for the entire *characteristic*.

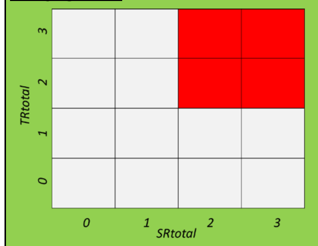
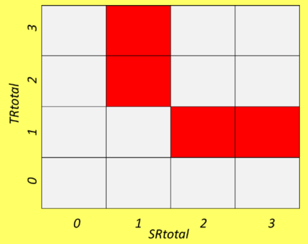
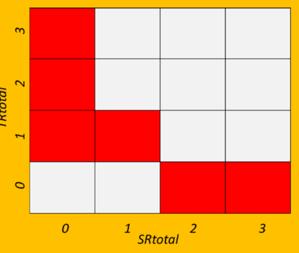
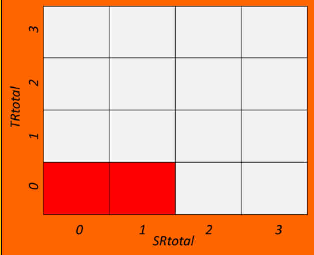
		Categories			
Spatial Representativity (SR)	SRd1	**Fulfilled**: Design-based sampling where the entire sampling population has a possibility of being included		**Not fulfilled**: Design-based sampling where only a SUBSET of the sampling population has a possibility of being included	
	SRd2	**Fulfilled**: Design-based sampling based on randomization		**Not fulfilled**: Design-based sampling NOT based on randomization	
	SRd3	**Fulfilled**: Design-based sampling, with known probability of including each sampling unit		**Not fulfilled:** Design-based sampling, with UNKNOWN probability of including each sampling unit	
	SRm	**Fulfilled**: Model-based sampling based on a model that is relevant for the indicator and the phenomenon in question		**Not fulfilled**: Model-based sampling based on a model that is NOT relevant for the indicator and the phenomenon in question	
	SRtotal	**Category 3**: *SRm* fulfilled with an adequate sample size OR *SRd1-SRd3* all fulfilled	**Category 2**: *SRm* fulfilled with a limited sample size OR two of *SRd1-SRd3* fulfilled	**Category 1**: *SRm* not fulfilled, one of *SRd1-SRd3* fulfilled	**Category 0**: *SRm* not fulfilled, none of *SRd1-SRd3* fulfilled
Temporal Representativity (TR)	TRyr	**Adequate:** A long time series relative to relevant dynamics. In case of a temporally defined reference condition, time series is partly or fully overlapping with the reference period	**Partially adequate:** A long time series relative to relevant dynamics. In case of a temporally defined reference condition, time series are NOT overlapping with the reference period		**Inadequate:** A short time series relative to relevant dynamics
	TRse	**Adequate**: Seasonal variability is relevant and taken into account in the sampling OR seasonal variability is not relevant		**Inadequate**: Seasonal variability is relevant, but not, or to a very limited degree taken into account in the sampling	
	TRtotal	**Category 3:** Both *TRyr* and *TRse* are Adequate	**Category 2**: *TRyr* Adequate and *TRse* Inadequate OR *TRyr* Partially adequate and *TRse* Adequate	**Category 1**: *TRyr* Inadequate and *TRse* Adequate OR *TRyr* Partially adequate and *TRse* Inadequate	**Category 0**: Both *TRyr* and *TRse* Inadequate
Data coverage	DC	**Very good:** 	**Good:** 	**Intermediate:** 	**Poor:** 
Indicator coverage	IC	**Adequate:** The set of indicators represent the major aspects of the ecosystem characteristic with no obvious shortcomings	**Partially adequate:** The set of indicators has certain shortcomings which might limit our ability to assess the condition of the ecosystem characteristic		**Inadequate:** The set of indicators has severe shortcomings which will definitely limit our ability to assess the condition of the ecosystem characteristic

***Figure 7.1.1** The criteria and colour coding used in the assessment of the knowledge base in Chapters 7.2-7.5.*

7.1.2 Categories for the assessment of the phenomena

The overall assessment of the phenomena consists of two parts, the validity of each phenomenon (VP) and the evidence for each phenomenon (EP). The validity of each phenomenon builds directly on the Scientific evidence base (Chapter 5.1), and expresses the "quality" of each phenomenon. A phenomenon of high validity implies certain links to relevant (anthropogenic) drivers, and a good understanding of the implications of change in indicator values for the condition of the ecosystem (**Figure 7.1.2**). An assessment of condition based on phenomena of high validity is hence more certain than one based on phenomena of lower validity. The evidence for each phenomenon builds on the statistical analysis of each indicator (**Appendix 1**). EP expresses the level of evidence for change in the indicator (**Figure 7.1.2**). If there is a high level of evidence for change, EP further distinguishes whether it is considered of high or limited ecosystem significance. In the Assessment of ecosystem condition (Chapters 7.2-7.5), VP and EP are given for each phenomenon, and form the basis for assessing the condition at the level of ecosystem characteristics and the ecosystem as a whole.

Validity of Phenomenon (VP)	Evidence for Phenomenon (EP)
High: A CERTAIN link to relevant drivers, and a GOOD understanding of the role of the indicator in the ecosystem.	**High**: High level of evidence that the expected changes in the indicator have occurred. High (expected or observed) ecosystem significance of observed changes.
Intermediate: A LESS CERTAIN link to relevant drivers, and a GOOD understanding of the role of the indicator in the ecosystem OR A CERTAIN link to relevant drivers, and a LESS GOOD understanding of the role of the indicator in the ecosystem.	**Intermediate**: High level of evidence that the expected changes in the indicator have occurred. Limited (expected or observed) ecosystem significance of observed changes.
	Low: Low level of evidence that the expected changes in the indicator have occurred. Low or no (expected or observed) ecosystem significance of observed changes.
Low: A LESS CERTAIN link to relevant drivers, and a LESS GOOD understanding of the role of the indicator in the ecosystem.	**None**: No evidence that the expected changes in the indicator have occurred (sufficient data)
	Insufficient: No evidence that the expected changes in the indicator have occurred (insufficient data)

Figure 7.1.2 *The criteria and colour coding used in the assessment of the phenomena shown in Chapters 7.2-7.5**.***

7.1.3 Categories for the assessment of ecosystem condition

During the assessment, each ecosystem characteristic is assigned one of three categories depending on the degree of deviation from the reference condition (**Box 7.3**). This choice is then addressed in the written assessment which consists of three parts: first, the assessment category which has been assigned, second, a justification for the choice of assessment category, and third, the primary uncertainties related to the choice of assessment category.

This structured assessment made by the scientific panel, is supported by 1) **Appendix 1**, which supplies plots and trend analysis of indicator values, and background data, and 2) the PAEC assessment diagrams (**Figures 7.2.1, 7.3.1, 7.4.1, 7.5.1**). These provide the panel with an overview of all phenomena, over all ecosystem characteristics with respect to their validity (VP) and evidence (EP).

Box 7.3. *The Definitions of the assessment categories (based on Jepsen et al. 2020).*

No deviation from the reference condition

Based on the current set of indicators, an ecosystem characteristic assigned to this category shows no or very limited deviations from the reference condition. According to the definition of the reference condition, the ecosystem characteristic can still be considered in an overall intact condition.

- Most or all of the phenomena should be in the green cells in the PAEC assessment diagram.
- Most or all phenomena should have either no evidence (EP=None), or low evidence (EP=Low) in combination with a low validity (VP=Low).
- Given adequate indicator coverage, this category can usually be assigned with high confidence, since there is no evidence that changes of ecosystem significance have occurred. In such cases uncertain links to drivers or a poor understanding of the implications of changes is less of a concern.
- If any phenomena are in the orange or red cells, the choice of category *No deviations from the reference condition* should be justified in the textual assessment.

Limited deviation from the reference condition

Based on the current set of indicators, an ecosystem characteristic assigned to this category shows limited deviations from the reference condition. According to the definition of the reference condition, the ecosystem characteristic can still be considered in an overall intact condition, however, individual indicators show changes in a direction towards a less intact condition which requires attention.

- Most or all of the phenomena should be in the orange cells in the PAEC assessment diagram.
- Most or all phenomena should have either low evidence (EP=Low) or intermediate evidence (EP=Intermediate) in combination with a low-intermediate validity (VP=Low or Intermediate)
- Even given adequate indicator coverage, this category is often assigned with lower confidence than the other two categories, since it can include phenomena which both have low-intermediate validity and a high level of evidence for change. These are the most uncertain phenomena to assess.
- If any phenomena are in the green or red cells, the choice of category *Limited deviation from the reference condition* should be justified in the textual assessment.

Substantial deviation from the reference condition

Based on the current set of indicators, an ecosystem characteristic assigned to this category shows substantial deviations from the reference condition. According to the definition of the reference condition, the ecosystem characteristic can NOT be considered in an intact condition.

- Most or all of the phenomena should be in the red cells in PAEC assessment diagram.
- Most or all phenomena should have intermediate – high evidence (EP=Intermediate or High) in combination with intermediate – high validity (VP=Intermediate or High).
- Given adequate indicator coverage, this category can usually be assigned with high confidence, since most phenomena have high validity, and a high level of evidence.
- If any phenomena are in the green or orange cells, the choice of category *Substantial deviation from the reference condition* should be justified in the textual assessment.

General considerations for this assessment:
The choice of assessment category for an ecosystem characteristic is hence guided by the centre of gravity of the set of phenomena representing the characteristic, as outlined in the definition of the categories above. This can be challenging when the characteristic is represented by set of indicators that are assessed as "inadequate", or when phenomena are spread across several or all categories. In such cases, the choice of assessment category is supported by a justification that highlights why more emphasis has been placed on certain phenomena. This can include better data coverage, higher validity, or an understanding that certain phenomena are of higher relevance (e.g. terms of ecological significance) than others for the condition of the ecosystem characteristic as a whole. Similarly, the assessment of the ecosystem as a whole has been guided by an understanding of the relative importance of the different characteristics for the condition and/or integrity of the ecosystem as a whole.

7.2 Forest
7.2.1 Assessment of the knowledge base

The overall assessment of the knowledge base for the forest ecosystem is presented in **Table 7.2.1**. The assessment is colour coded according to the predefined categories in PAEC (**Figure 7.1.1**). In accordance with the PAEC protocol, the knowledge base is assessed at three levels: *Data level*, *indicator level*, and *ecosystem characteristics level*. For an operational assessment, it is recommended in the PAEC protocol that each cell in **Tables 7.2.1** should link to an endnote describing why a given category was chosen, to enhance transparency (see Pedersen et al. 2021a, Table 7.1a, b). Such records are important, in particular when operational assessments are repeated after a certain time period. Since this is a pilot assessment, a written justification of each individual choice of category was left out.

Open deciduous forest habitat, Trøndelag. Photo: Juliet Landrø, NINA.

Table 7.2.1. *Assessment of the knowledge base for the datasets, indicators and ecosystem characteristics for forest ecosystems.*

DATA									INDICATOR		ECOSYSTEM CHARACTERISTIC	
Data set ID	**Spatial representativity (SR)**					**Temporal representativity (TR)**			**Indicator [indicator ID]**	**Data coverage**	**Characteristic**	**Indicator coverage**
	SRd1	SRd2	SRd3	SRm	**SRtotal**	TRyr	TRse	**TRtotal**		**DC**		**IC**
D04	ful-filled	fulfilled	fulfilled	fulfilled	**3**	part. adeq.	adeq.	**2**	Maximum greenness [F10]	**very good**	Primary productiv-ity	**partially adequate**
D04	ful-filled	fulfilled	fulfilled	fulfilled	**3**	part. adeq.	adeq.	**2**	Onset of greening [F11]	**very good**		
D05	not fulf.	fulfilled	fulfilled	not fulf.	**2**	inadeq.	adeq.	**1**	Tree volume [F22]	**good**		
D05, D11, D24	not fulf.	not fulf.	fulfilled	not fulf.	**1**	inadeq.	adeq.	**1**	ROS species versus moose [F18]	**intermediate**	Biomass distribu-tion among trophic levels	**partially adequate**
D05, D11	not fulf.	not fulf.	fulfilled	not fulf.	**1**	inadeq.	adeq.	**1**	Bilberry versus deer and moose [F24]	**intermediate**		
D11, D08	not fulf.	not fulf.	not fulf.	not fulf.	**0**	inadeq.	adeq.	**1**	Ungulates versus carnivo-rous vertebrates [F25]	**intermediate**		
D05	not fulf.	fulfilled	fulfilled	not fulf.	**2**	inadeq.	adeq.	**1**	Plant growth forms: de-ciduous proportion [F27]	**good**	Functional groups within trophic lev-els	**partially adequate**
D11	ful-filled	not fulf.	fulfilled	fulfilled	**3**	adeq.	adeq.	**3**	Herbivorous vertebrates: browsers versus grazers [F19]	**very good**		
D12	not fulf.	not fulf.	not fulf.	fulfilled (limited)	**2**	adeq.	adeq.	**3**	Bark beetle abundance [F14]	**very good**	Functionally im-portant species	**partially adequate**
D11	ful-filled	not fulf.	fulfilled	fulfilled	**3**	adeq.	adeq.	**3**	Wild ungulate density [F16]	**very good**		
D11	ful-filled	not fulf.	fulfilled	fulfilled	**3**	adeq.	adeq.	**3**	Domestic ungulate den-sity [F17]	**very good**		

Table 7.2.1. *(cont.)*

DATA									INDICATOR		ECOSYSTEM CHARACTERISTIC	
Data set ID	**Spatial representativity (SR)**					**Temporal representativity (TR)**			**Indicator [indicator ID]**	**Data coverage**	**Characteristic**	**Indicator coverage**
	SRd1	SRd2	SRd3	SRm	**SRtotal**	TRyr	TRse	**TRtotal**		**DC**		**IC**
D05	not fulf.	fulfilled	fulfilled	not fulf.	**2**	inadeq.	adeq.	**1**	Dead wood volume [F21]	**good**	Functionally important species (cont.)	
D05	not fulf.	fulfilled	fulfilled	not fulf.	**2**	inadeq.	adeq.	**1**	ROS volume [F28]	**good**		
D08	fulfilled	not fulf.	not fulf.	not fulf.	**1**	part. adeq.	adeq.	**2**	Large predator abundance [F23]	**good**		
D05	not fulf.	fulfilled	fulfilled	not fulf.	**2**	inadeq.	adeq.	**1**	Bilberry coverage [F20]	**good**		
D06	fulfilled	not fulf.	fulfilled	not fulf.	**2**	part. adeq.	adeq.	**2**	Areas free of major infrastructure [F12]	**very good**	Landscape ecological patterns	**inadequate**
D13	not fulf.	fulfilled	fulfilled	not fulf.	**2**	inadeq.	adeq.	**1**	Forest bird communities [F15]	**good**	Biological diversity	**inadequate**
D14	fulfilled	not fulf.	not fulf.	not fulf.	**1**	inadeq.	adeq.	**1**	Trenching [F13]	**intermediate**	Abiotic factors	**partially adequate**
D01	fulfilled	not fulf.	fulfilled	fulfilled	**3**	adeq.	adeq.	**3**	Annual mean temperature [F01]	**very good**		
D01	fulfilled	not fulf.	fulfilled	fulfilled	**3**	adeq.	adeq.	**3**	January mean temperature [F02]	**very good**		
D01	fulfilled	not fulf.	fulfilled	fulfilled	**3**	adeq.	adeq.	**3**	July mean temperature [F03]	**very good**		
D01	fulfilled	not fulf.	fulfilled	fulfilled	**3**	adeq.	adeq.	**3**	Winter days above 0°C [F04]	**very good**		
D01	fulfilled	not fulf.	fulfilled	fulfilled	**3**	adeq.	adeq.	**3**	Degree days [F05]	**very good**		
D01	fulfilled	not fulf.	fulfilled	fulfilled	**3**	adeq.	adeq.	**3**	Growing degree days [F06]	**very good**		

Table 7.2.1. *(cont.)*

DATA									INDICATOR		ECOSYSTEM CHARACTERISTIC	
Data set ID	**Spatial representativity (SR)**					**Temporal representativity (TR)**			**Indicator [indicator ID]**	**Data coverage**	**Characteristic**	**Indicator coverage**
	SRd1	SRd2	SRd3	SRm	**SRtotal**	TRyr	TRse	**TRtotal**		**DC**		**IC**
D02	fulfilled	not fulf.	fulfilled	fulfilled	**3**	adeq.	adeq.	**3**	Annual precipitation [F07]	**very good**	Abiotic factors (cont.)	
D02	fulfilled	not fulf.	fulfilled	fulfilled	**3**	adeq.	adeq.	**3**	Growing season precipitation [F08]	**very good**		
D03	fulfilled	not fulf.	fulfilled	fulfilled	**3**	adeq.	adeq.	**3**	Snow cover duration [F09]	**very good**		

7.2.2 Assessment of the phenomena

The overall assessment of all phenomena underlying the assessment of the forest ecosystem is presented in **Table 7.2.2**. The assessment is colour coded according to the predefined categories in PAEC (**Figure 7.1.2**).

Bilberry is a key food source for many herbivores, among these moose and deer, and an important indicator both as a functionally important species, and as part of trophic relationships under the ecosystem characteristic Biomass distribution among trophic levels*. Photo: Rolf A. Ims (top) and COAT automatic wildlife camera (www.coat.no, bottom).*

Table 7.2.2. *Assessment of the validity (VP) and evidence (EP) for each phenomenon for the forest ecosystem. For definitions of categories, see* ***Figure 7.1.2.*** *The main anthropogenic drivers for each indicator are summarized in* ***Table 5.1.***

Ecosystem characteristic	Phenomenon [ID]	Indicator [ID]	VP	EP	Comments to EP
Primary productivity	Changes in maximum greenness [PF28]	Maximum greenness	high	low	There is a general increasing trend in Maximum greenness, but the rate of change is low. However, it integrates spatially contrasting trends (greening/browning) which may be locally significant.
Primary productivity	Earlier onset of greening [PF29]	Onset of greening	high	none	--
Primary productivity	Changes in tree volume [PF30]	Tree volume	low	intermediate	There is strong evidence that tree volume is increasing both in mature harvest classes in productive forest and in unproductive forest. The ecosystem significance is assessed as limited.
Biomass distribution among trophic levels	High or increasing biomass of moose relative to ROS species [PF13]	ROS species versus moose	high	high	Both the volume of ROS species and the density of moose in forest municipalities are increasing. The lack of temporal correspondence between the datasets means that a log ratio for this trophic relationship cannot be calculated directly. However, ROS volumes (in the order of 1.5-2.5 m^3/ha) can be considered low, despite the observed increase. Browsing data supports this, and suggests that the increase in moose is outpacing the increase in ROS volume. Overall therefore, there is high evidence for an increasing biomass of moose relative to ROS species and this is considered of ecosystem significance.
Biomass distribution among trophic levels	Changes in the relative density of bilberry and deer [PF14]	Bilberry versus deer and moose	high	insufficient	There is no change in bilberry coverage over the monitoring period, but the data is considered insufficient to detect changes in this trophic relationship (2 rotations)

Table 7.2.2. *(cont.)*

Ecosystem characteristic	Phenomenon [ID]	Indicator [ID]	VP	EP	Comments to EP
Biomass distribution among trophic levels	High or increasing density of ungulates relative to large carnivores [PF15]	Ungulates versus carnivorous vertebrates	high	high	There is strong evidence that the relative density of ungulates and large carnivores is strongly biased towards ungulates, due to absence or very low number of large carnivores. This is of ecosystem significance since it means that large ungulates are under very limited top-down control.
Functional groups within trophic levels	Low or decreasing deciduous proportion [PF16]	Plant growth forms: deciduous proportion	Intermediate	low	There is low evidence of a reduction in deciduous proportion over time and between harvest classes for productive spruce forest.
Functional groups within trophic levels	Changes in the composition of functional groups within the herbivore vertebrate community [PF17]	Herbivorous vertebrates: browsers versus grazers	high	high	There is high evidence of an increasing proportion of browsers relative to grazers in forest municipalities due to increasing abundances of wild ungulates, mainly moose. This has caused a shift in the functional composition which as of ecosystem significance.
Functionally important species	Increasing abundances of bark beetles resulting in increasing frequency or severity of outbreak episodes [PF18]	Bark beetle abundance	high	none	--
Functionally important species	Changes in density of wild ungulates [PF19]	Wild ungulate density	high	high	There is strong evidence of increasing densities of wild ungulates mainly driven by increasing moose populations. Browsing data (see *ROS species versus moose*) suggests that this increase is of ecosystem significance
Functionally important species	High or increasing density of domestic ungulates [PF20]	Domestic ungulate density	intermediate	low	There is no evidence of increasing densities of domestic ungulates in forest municipalities. Current densities are not considered high and are of low ecosystem significance

Table 7.2.2. *(cont.)*

Ecosystem characteristic	Phenomenon [ID]	Indicator [ID]	VP	EP	Comments to EP
Functionally important species	Low or decreasing dead wood volume [PF21]	Dead wood volume	high	high	The volume of dead wood, both in total and the fraction which is coarse dead wood, is low in all forest types. This is a substantial deviation from an intact condition and is of ecosystem significance.
Functionally important species	Low or decreasing ROS volume [PF22]	ROS volume	high	low	The volume of ROS species is increasing but still considered low, despite the observed increase.
Functionally important species	Low or decreasing large predator abundance [PF23]	Large predator abundance	high	high	Wolf is extirpated, and the numbers of breeding females of brown bear and lynx are low in accordance with governmental policy. This is a substantial deviation from an intact condition and is of ecosystem significance.
Functionally important species	Low or decreasing bilberry coverage [PF24]	Bilberry coverage	high	insufficient	There is no change in bilberry coverage over the monitoring period, but the data is considered insufficient to detect change (2 rotations)
Landscape ecological patterns	Low or decreasing area free of major infrastructure [PF25]	Areas free of major infrastructure	intermediate	high	The forest area free of major infrastructure development is greatly reduced relative to the reference condition (to < 25% of total area) and is of ecosystem significance. Recent changes correspond to a loss of ~3% (from 22.7% to 19.9% over the monitoring period 1988 – 2018).
Biological diversity	Decreasing abundances and/or species diversity within the community of forest birds [PF12]	Forest bird communities	high	none	--
Abiotic factors	Large or increasing area affected by historical or present-day trenching [PF26]	Trenching	intermediate	low	There is low evidence in the national statistics that subsidized trenching is high or increasing in forest areas. However, the limited time span of the statistics excludes trenching prior to the late 1960's.

Table 7.2.2. (cont.)

Ecosystem characteristic	Phenomenon [ID]	Indicator [ID]	VP	EP	Comments to EP
Abiotic factors	Increasing annual temperature [PF01]	Annual mean temperature	high	high	There is strong evidence that annual mean temperatures are increasing (~0.6°C/decade relative to 1961-1990 mean). Changes are considered of high ecosystem significance for forest ecosystems.
Abiotic factors	Increasing January temperature [PF02]	January mean temperature	high	high	There is strong evidence that January mean temperatures are increasing (~1.1°C/decade relative to 1961-1990 mean). Changes are considered of high ecosystem significance for forest ecosystems.
Abiotic factors	Increasing July temperature [PF03]	July mean temperature	high	high	There is strong evidence that July mean temperatures are increasing (~0.8°C/decade relative to 1961-1990 mean). Changes are considered of high ecosystem significance for forest ecosystems.
Abiotic factors	Increasing number of winter days above 0°C [PF04]	Winter days above 0°C	high	high	The number of winter days > 0° is increasing (~1.4%/yr or ~7 days/decade). Changes are considered of high ecosystem significance for forest ecosystems.
Abiotic factors	Increasing number of degree days [PF05]	Degree days	high	high	There is strong evidence that the number of degree days is increasing (~0.3%/yr or ~7 days/decade). Changes are considered of high ecosystem significance for forest ecosystems.
Abiotic factors	Increasing growing degree day sum during the growing season [PF06]	Growing degree days	high	high	There is strong evidence that the number of growing degree days is increasing (~70 GDD/decade). Changes are considered of high ecosystem significance for forest ecosystems.
Abiotic factors	Changes in annual precipitation [PF07]	Annual precipitation	high	none	--
Abiotic factors	Changes in precipitation during the growing season [PF08]	Growing season precipitation	high	none	--
Abiotic factors	Shorter season with snow cover [PF09]	Snow cover duration	high	intermediate	There is strong evidence that the snow cover duration is decreasing (~0.6%/yr or ~11 days/decade). Changes have been assessed as of limited ecosystem significance so far.

7.2.3 Assessment of ecosystem condition

Following the PAEC protocol the assessment of ecosystem condition for the forest ecosystem consists of two sections: an assessment of each ecosystem characteristics based on all associated phenomena (Chapter 7.2.3.1), and an assessment of the ecosystem as a whole (Chapter 7.2.3.2). The assessment categories used are according to **Box 7.3.**

7.2.3.1 Assessment of the condition of ecosystem characteristics

Forest – Primary productivity
Assessment category:
Based on the set of indicators, this ecosystem characteristic is assessed as having **limited deviation from the reference condition**. This means that the ecosystem characteristic can still be considered in an intact ecological condition, but that some indicators show changes which warrant attention. There is some uncertainty regarding the choice of category.

Justification for choice of assessment category: The assessment is based on three indicators with three associated phenomena (PF28-PF30). Two of these are of high validity (VP; PF28 *Maximum greenness*, PF29 *Onset of greening*), implying certain links to drivers and a good understanding of the role of the indicators in the forest ecosystem. The last phenomenon (PF30 *Tree volume*) has less certain links to drivers other than forest management, and a less good understanding, and is hence of low validity. Forested areas in Trøndelag show a weak greening trend overall, but with substantial spatial contrasts in trends. This is concurrent with increasing tree volume in both productive and unproductive forests during the same period. Both these phenomena are hence located in the 'limited deviation' section of the diagram (**Figure 7.2.1**). The indicator *Onset of greening* shows no evidence of change over the two decades covered by the remote sensing data and is hence located in the 'no deviation' section of the diagram.

Uncertainties related to the choice of assessment category: There is some uncertainty regarding the choice of category. The indicator coverage for the ecosystem characteristic *Primary productivity* is assessed as 'partially adequate', mostly due to a lack of indicators which capture changes in primary productivity and/ or vegetation biomass in the shrub and field layer. All included indicators have 'good' – 'very good' data coverage. The temporal structure of the NFI data underlying the indicator on *Tree volume* (5-yr rotations), limits the options for estimating rates of change in tree volume over shorter time spans.

Forest – Biomass distribution among trophic levels
Assessment category:
Based on the set of indicators, this ecosystem characteristic is assessed as having **substantial deviation from the reference condition**. Changes in biomass distribution between moose and ROS species, and between ungulates and carnivores are large. Moose densities are at historically high levels and limit the regeneration of ROS species. At the same time, carnivores are functionally absent as top-down regulators of ungulate populations. These both represent substantial deviations from an intact forest ecosystem. There is some uncertainty regarding the choice of category.

Justification for choice of assessment category: The assessment of biomass distribution across trophic levels in forest ecosystems is based upon three indicators. All three of these are assessed as having high validity (VP) due to certain links to anthropogenic drivers and a good scientific basis to the understanding of the role in the ecosystem. Two of these (ungulates versus carnivorous vertebrates and moose versus ROS species) are assessed as having high evidence for changes which are likely to be of ecosystem significance. These are located in the 'substantial deviation' section of the diagram (**Figure 7.2.1**). The levels of observed browsing intensities on ROS species (30-40%) exceed those (20%) at which ROS species can underdo net height growth. For the third indicator (deer versus bilberry), there is no evidence for change due to insufficient data availability detailing bilberry biomass at relevant temporal and spatial scales.

Uncertainties related to the choice of assessment category: There is some uncertainty regarding the choice of category. The overall indicator coverage for this category is considered ‘partially adequate’ as it only includes indicators of plants, large herbivores and large predators. While these are keystone species or functional groups within these trophic levels, indicators at other trophic levels (e.g. decomposers) and other functional groups within plants (e.g. conifers), herbivores (hares, rodents, granivorous birds) and carnivores (mustelids, foxes) are missing. Furthermore, data coverage was assessed as ‘intermediate’ for all three included indicators. This was because time series were too short and poorly overlapping between the trophic levels, and because of spatial limitations for the bilberry, ROS and carnivore datasets.

Forest – Functional groups within trophic levels
Assessment category: Based on the set of indicators this ecosystem characteristic is assessed as having **substantial deviation from the reference condition**. There has been a profound change in the ratio of browsing versus grazing herbivores that is expected to have cascading effects in other ecosystem characteristics of the forest. There is substantial uncertainty related to the choice of category.

Justification for choice of assessment category: This assessment is based on two indicators - with two associated phenomena (PF 16 and 17) - that have high intermediate-validity (VP) with certain links to relevant anthropogenic drivers and good understanding of their impacts on ecosystem function (e.g. ecological significance). The phenomenon related to the herbivorous vertebrates (PF17) scores ‘high’ on the Evidence for the Phenomenon (EP) owing to a substantial increase in browsing wild ungulates, while the phenomenon related to plant growth form (proportion deciduous volume) (PF16) scores ‘low’ with respect to EP. Hence, the two indicators are placed in different sections of the diagram; i.e. plant growth forms with ‘limited deviation’ and herbivorous vertebrates with ‘substantial deviation’ (**Figure 7.2.1**). The overall assessment category of the ecosystem characteristics (i.e. substantial deviation) is justified by the pervasive effects of increasing browsing pressures on successional pathways and vegetation structure in forest ecosystems. It should be noted that that the herbivorous vertebrate indicator overlaps with the wild and domestic ungulate density indicators under the ecosystem characteristic *Functionally important species and biophysical structures*, and the ROS vs moose indicator under the ecosystem characteristic *Biomass distribution among trophic levels*.

Uncertainties related to the choice of assessment category: There is substantial uncertainty related to the choice of category. The data coverage is ‘good’ for the plant growth form indicator, while very good for herbivorous vertebrates. However, most importantly the indicator coverage of this ecosystem characteristics is only ‘partially adequate’ (bordering on ‘inadequate’), due to no indicators on plant growth form other than trees (i.e. understory plants) and other influential herbivores functional groups than ungulates (i.e. insects and rodents). Moreover, indicators for different functional groups of saprothropic organisms (e.g. fungi, invertebrates) and carnivores/predators are missing altogether.

Forest – Functionally important species and biophysical structures
Assessment category: Based on the set of indicators, this ecosystem characteristic is assessed as having **substantial deviation from the reference condition**. The changes in some of the indicators for functionally important species and biophysical structures are large, and three key indicators far exceed the levels associated with an intact forest ecosystem. There is no major uncertainty related to the choice of category.

Justification for choice of assessment category: The assessment is based on seven indicators with associated phenomena (PF18-PF24), where all but one has high validity, implying certain links to anthropogenic drivers and a relatively good understanding of their role in forest ecosystems. Three of the seven indicators are assessed as having high evidence for change expected to be of ecosystem significance, and hence are located in the ‘substantial deviation’ section of the assessment diagrams (**Figure 7.2.1**). These are phenomena related to the low volume of dead wood and low abundance of large predators, in addition to high densities of wild ungulates.

This deviation from the reference condition, will have large cascading effects on the forest ecosystem, for example by reducing habitat availability for wood-living fungi and insects, altering behavioural patterns in mammalian prey species, and causing over-browsing. Two phenomena, one related to the abundance of three highly palatable deciduous species and one on the abundance of domestic ungulates, show ‘limited deviation’ from the reference condition. A phenomenon related to the abundance of bark beetles shows no evidence for change and is therefore assessed as having no deviation from the reference condition. Finally, one phenomenon related to the coverage of bilberry, was considered to be of high validity, but, due to poor data quality, the lack of evidence in the data could not be attributed to support a hypothesis of lack of change, and so this phenomenon is not included in the total assessment of the condition of this ecosystem characteristic.

Uncertainties related to the choice of assessment category: There is no major uncertainty related to the choice of category. The data coverage of the indicators included is assessed as ‘very good’. The indicator coverage of the ecosystem characteristic is ‘partially adequate’. This is partly due to an absence or severe deficiency of indicators that characterize vegetation, such as bilberry and tree species composition, as well as ecologically important vertebrates such as woodpeckers. There are also several functionally important microbial and invertebrate species or species groups, such as decomposers or parasites, for which we have no available data to say anything about their abundance.

Forest – Landscape ecological patterns

Assessment category: Based on the single available indicator, this ecosystem characteristic is assessed as having **substantial deviation from the reference condition**. The high proportion of the total forest area that is within 1 km from major human infrastructures suggests that most of the forest in Trøndelag deviates from the reference state of low impact of infrastructure. There is substantial uncertainty related to the choice of category.

Justification for choice of assessment category: The assessment is based on only one indicator with one associated phenomenon (PF25) with intermediate validity, due to a less good understanding of how proximity to infrastructure has direct effects on species or ecosystem functions. The indicator has high evidence for change and is hence placed in the ‘substantial deviation’ section of the diagram (**Figure 7.2.1**). As it is based on human infrastructure it is evident that the driver of change is human caused. The main effect of proximity to infrastructure is thus related to increased human activities.

Uncertainties related to the choice of assessment category: There is substantial uncertainty related to the choice of category. The assessment is based on just one indicator, with very good data coverage. The data underlying this indicator probably represents an under-estimation of the proportion of forest affected by human infrastructure, as only major infrastructure is included. Smaller forest roads, cabins, antennas etc. are not included. The data of the indicator and spatial distribution of the ecosystem in Trøndelag cannot be used to do a proper evaluation of important landscape-ecological characteristics. Indicators such as changes in level of fragmentation, isolation or the size of isolated forest fragment, provide measures that are better supported as being important ecosystem characteristics, both from ecological theories and empirical studies. Further, in forest ecosystems the landscape ecological patterns have a third dimension, i.e. the vertical structure of the forest. Based on these shortcomings, the indicator coverage of the ecosystem characteristic as a whole is ’inadequate’.

Forest – Biological diversity

Assessment category:

Based on one indicator, this ecosystem characteristic is assessed as having **no deviation from the reference condition**. This means that the ecosystem characteristic can be considered in an intact ecological condition based on the single available indicator. There is substantial uncertainty related to the choice of category.

Justification for choice of assessment category: The assessment is based only on indicator/phenomenon (F15, PF12) - that has high validity (VP) and scores 'none' with respect to evidence (EP). For the forest bird community indicator, there is no change in the community level composite index or in the trend curves for the individual species.

Uncertainties related to the choice of assessment category: There is substantial uncertainty related to the choice of category. The data coverage for the bird community indicator is good but many relatively uncommon species are not included in the composite index. The indicator coverage is assessed as inadequate as indicators within major biological taxa (e.g. plants, fungi, invertebrates) are lacking.

Forest – Abiotic factors

Assessment category:

Based on the set of indicators, this ecosystem characteristic is assessed as having **substantial deviation from the reference condition**. The changes in abiotic indicators related to snow cover and temperature are large and relatively consistent across the assessed area. Several of the climatically derived indicators are close to, or exceed, the historically observed variation during the climatic reference period, in other words, values which during the 1961-1990 period were considered extreme are now within the expected norm. There is no major uncertainty related to the choice of category.

Justification for choice of assessment category: The assessment is based on ten indicators with associated phenomena (PF01-PF09, PF26), nine of which have high validity (VP), implying certain links to anthropogenic drivers and a relatively good understanding of their role in forest ecosystems. The last phenomenon, (PF26), has lower validity due to a poor understanding of how the national statistics underlying the indicator (the area subject to subsidized trenching) relates to the condition of forest ecosystems in general. All phenomena related to temperature and snow cover show high evidence of changes which are expected to be of some level of ecosystem significance and are hence located in the 'substantial deviation' section of the assessment diagrams (**Figure 7.2.1**). Phenomena related to precipitation, both total precipitation (PF07) and growing season precipitation (PF08), are exceptions and show no evidence of change relative to the climatic reference period. They are hence located in the 'no deviation' section of the diagram. However, for forest ecosystems, the two phenomena related to precipitation are considered of somewhat less relevance than the phenomena related to changes in seasonal temperatures, and more emphasis is hence placed on the latter in the assessment. The changes in snow cover duration (PF09) are considered of somewhat less ecosystem significance for forest than for alpine ecosystems. The observed changes in temperature and snow cover are in part substantial e.g. snow cover duration (PF09) has decreased by about one month relative to the mean observed during the climatic reference period. Annual mean temperatures (PF01) have increased by a rate similar to that observed for alpine areas (~0.6°C/decade).

Uncertainties related to the choice of assessment category: There is no major uncertainty related to the choice of category. The data coverage of the indicators included is assessed as 'very good' although the coarse resolution of gridded climate data does not permit the capture of small-scale contrast/gradients in the rates of change. The indicator coverage of the ecosystem characteristic is considered partially adequate despite a large set of indicators. This is due to an absence of indicators that characterize regional snow quality, including snow structure, basal ice and rain-on snow events which would allow closer causal links to be made between abiotic conditions and biotic ecosystem characteristics such as trophic relationships. Further, albedo, which represents the reflective qualities of the surface in late winter/spring, is another important indicator not included in this pilot assessment. Inclusion would allow closer causal links between land surface changes (tree cover, forest structure tree species composition), abiotic conditions (snow cover, snowmelt) and regional climate feedbacks to be established.

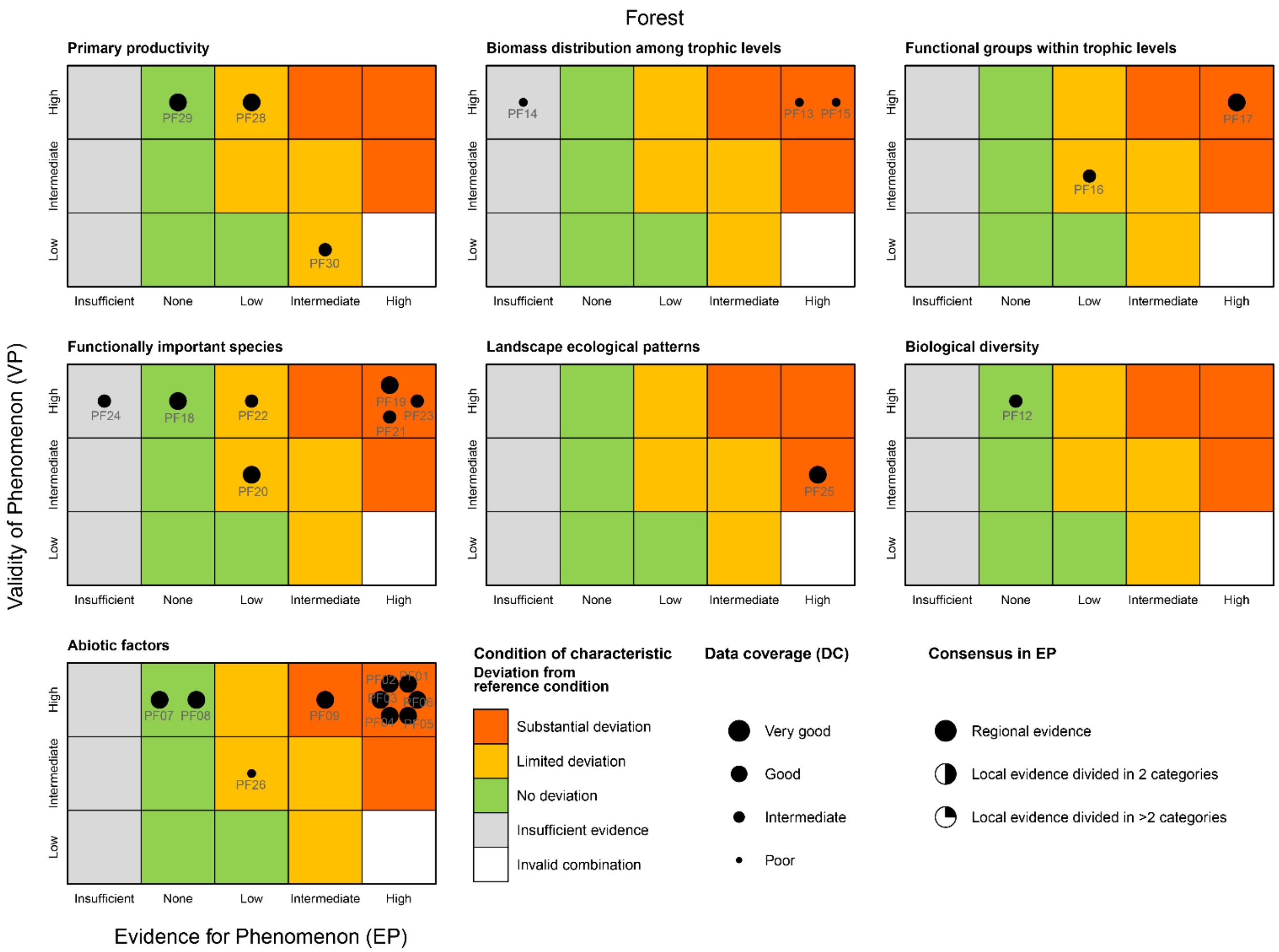


Figure 7.2.1. *The PAEC assessment diagram for forest ecosystems. The diagram provides an overview of all phenomena for all ecosystem characteristics and their placement along the validity (VP) and Evidence (EP) axis and are intended as an aid for the panel when making their assessment. Each dot represents the assessment of a phenomenon with ID (from* ***Table 5.1****). The size of the dot represents data coverage (from* ***Table 7.2.1****).*

7.2.3.2 Assessment of the condition of the ecosystem as a whole

The assessment of this ecosystem is based on an indicator set which is considered inadequate for two of the seven ecosystem characteristics (*Biological diversity* and *Landscape ecological patterns*), and partially adequate for the remaining five. All ecosystem characteristics have one or more indicators and can hence be assessed within the limits given by this set of indicators. Of the 27 indicators developed during this pilot, 10 are related to the abiotic environment in forests (temperature, precipitation, snow and trenching), while seven are related to *Functionally important species and biophysical structures* in forest ecosystems. The remaining address *Primary productivity* (three indicators), *Biomass distribution among trophic levels* (three indicators), *Landscape ecological patterns* (one indicator) and *Biological diversity* (one indicator). Two indicators have insufficient evidence to conclude their condition. Based on this limited set of indicators and the overall assessment of the seven ecosystem characteristics, the scientific panel concludes that forest ecosystems in Trøndelag show **substantial deviation** from the reference condition, with fundamental structures and functions being altered. No deviation from the reference state is evident in the ecosystem's biological diversity. However, only bird communities have been assessed and the assessment of important and diverse groups such as plants, insects, fungi and lichens are not included (**Table 7.7**). There are considerable uncertainties associated with assessment of most of the biotic ecosystem characteristics, and thus the ecosystem as a whole, due to substantial deficiencies in data and/or indicator coverage.

Current state of knowledge of the reference condition

According to the normative description of the reference condition (Framstad and Sverdrup-Thygeson 2017), forest ecosystem in an intact ecological condition is characterised by structures and functions that are shaped by natural forest dynamics such as disturbances followed by natural successions, characteristic to the climatic and soil conditions, terrain and naturally occurring tree species. The natural dynamics shape the forest structure, productivity, presence of microhabitats, and associated ecosystem processes. The reference state of the forest ecosystem can be described as natural or near-natural forest. In the reference state, there is natural variation in the structures and processes over time, but human impact on the structure or function of the ecosystem is minimal. Human utilization of the forest ecosystem changes the dynamics of the forest and drastically changes the successional stages and forest structures. In the late 1800s, the forest in Norway was more extensively logged, and starting in the 1940s, clear-cutting became the predominant form of logging (Storaunet and Rolstad 2020). Forest in an intact ecological condition (i.e. corresponding to the reference condition) can probably only be found in stands not previously subjected to clear-cutting (approximately 30% of the productive forest). It should, however, be noted that most of these stands have been subjected to more or less intensive selective loggings. Because forests have been extensively managed since the late 1800s, short term changes (years or a few decades) in indicators are less relevant for assessing the ecological condition today.

Main drivers of change

Natural dynamics in forest ecosystems provide the foundation for forest species, communities and their ecological functions through creating a diversity of habitats and structures. Forest management is expected to be the main driver of ecosystem changes in forests. Particularly, forest management reduces the compositional and vertical structural diversity of the forest, and creates even-aged, typically also single-species stands. At the landscape scale, the share of young and middle-aged stands increases while that of old stands decreases. Forest habitat transformation reduces both the spatial (connectivity) and temporal (continuity) availability of the habitat for an abundance of forest species, and leads ultimately to habitat loss (Nordén et al. 2013, 2018, Jacobsen et al. 2020). In addition, forestry reduces the amount of *Functional important species and biophysical structures,* e.g. amount of coarse woody debris and ROS volumes. The ecosystem characteristics *Functional important species and biophysical structures*, *Landscape ecological patterns*, and *Functional groups* also act as drivers on biotic indicators of biological diversity and biomass distribution. Forest management has substantially influenced forest ecosystems in Trøndelag at least from the 1800s, and in a more intensive, systematic manner (clear-cutting practice) since the 1940s. Since 1990s, biodiversity-oriented management (incl. for instance small set-asides, retention trees) has gained ground, partly through the adoption of forest certification standards. Second, climate change is another important driver of change, of increasing importance, in forest ecosystems that can influence *Biological diversity* directly but also other biotic indicators such as bark beetle abundance. Third, recent increases of large herbivores such as moose, reed deer and roe deer, are also found to modify forest ecosystems due to especially selective browsing on deciduous species such as rowan, willow and aspen.

Observed deviations from the reference condition
The set of indicators describing the ecosystem characteristics *Abiotic factors, Biomass distribution among trophic levels, Functional groups, Functional important species and biophysical structures* and *Landscape ecological patterns* substantially deviate from the reference condition. For the abiotic factors, all temperature related indicators as well as snow cover duration substantially deviate from the reference condition. High or increasing density of moose, red deer and roe deer, relative to low density of carnivores, has affected the *Biomass distribution among trophic levels* for these two trophic groups as well as that for ROS species and moose. Moreover, the high and increasing density of browsing relative to grazing herbivores was assessed as have substantially changed the ecosystem characteristic *Functional groups within trophic levels*. The indicators within *Functional important species and biophysical structures* varied across all four condition categories but was overall assessed as substantial deviation from reference conditions, especially due to low dead wood volumes, low large predator abundances and high or increasing wild ungulate densities. Major infrastructure development has contributed to habitat loss and fragmentation for forest species. Biological diversity did not deviate from the reference state. However, the indicator coverage for this ecosystem characteristic was inadequate. Further, important groups of forest biodiversity, e.g. fungi, lichens and insects have not been assessed in this pilot. The main anthropogenic drivers causing the changes include land-use intensification, wildlife and resource management, and climate change.

Figure 7.2.2. *A graphical summary of the assessment of ecological condition of forest ecosystems. The outer ring shows the assessment of ecological condition at the level of the individual indicators with associated phenomena ID in square brackets. Indicators which the scientific panel have recommended for inclusion (**Table 7.7**), but which are not included in the pilot assessment, are shown in white to illustrate the perceived most important deficiencies in the current indicator set. The middle ring shows the assessment at the level of ecosystem characteristics, indicating deviation from the reference condition, and the innermost circle shows the quality of indicator coverage. Assessment based on inadequate indicator coverage is further highlighted by paler shading in ecological characteristics and their corresponding indicators.*

7.3 Alpine

7.3.1 Assessment of the knowledge base

The overall assessment of the knowledge base for the alpine ecosystem is presented in **Table 7.3.1**. The assessment is colour coded according to the predefined categories in PAEC (**Figure 7.1.1**). In accordance with the PAEC protocol, the knowledge base is assessed at three levels: *Data level*, *indicator level*, and *ecosystem characteristics level*. For an operational assessment, it is recommended in the PAEC protocol that each cell in **Tables 7.3.1** should link to an endnote describing why a given category was chosen, to enhance transparency (see Pedersen et al. 2021a, Table 7.1a, b). Such records are important, in particular when operational assessments are repeated after a certain time period. Since this is a pilot assessment, a written justification of each individual choice of category was left out.

Alpine habitat in Børgefjell, Trøndelag. Photo: Rolf A. Ims.

Table 7.3.1. *Assessment of the knowledge base for the datasets, indicators and ecosystem characteristics for alpine ecosystems.*

DATA									INDICATOR		ECOSYSTEM CHARACTERISTIC	
Data set ID	**Spatial representativity (SR)**					**Temporal representativity (TR)**			**Indicator [indicator ID]**	**Data coverage**	**Characteristic**	**Indicator coverage**
	SRd1	SRd2	SRd3	SRm	**SRtotal**	TRyr	TRse	**TRtotal**		**DC**		**IC**
D01	fulfilled	fulfilled	fulfilled	fulfilled	**3**	part. adeq.	adeq.	**2**	Maximum greenness [A10]	**very good**	Primary productivity	**partially adequate**
D01	fulfilled	fulfilled	fulfilled	fulfilled	**3**	part. adeq.	adeq.	**2**	Onset of greening [A11]	**very good**		
D11, D08	fulfilled	not fulf.	not fulf.	not fulf.	**1**	inadeq	adeq.	**1**	Ungulates versus carnivorous vertebrates [A24]	**intermediate**	Biomass distribution among trophic levels	**inadequate**
D11	fulfilled	not fulf.	fulfilled	fulfilled	**3**	adeq.	adeq.	**2**	Herbivorous vertebrates: reindeer:moose/deer [A22]	**very good**	Functional groups within trophic levels	**inadequate**
D09	not fulf.	not fulf.	not fulfilled	fulfilled	**3**	part. adeq.	inadeq.	**1**	Carnivorous vertebrates: arctic versus red fox [A21]	**good**		
D11	fulfilled	not fulf.	fulfilled	fulfilled	**3**	adeq.	adeq.	**3**	Domestic ungulate density [A16]	**very good**	Functionally important species	**partially adequate**
D11	fulfilled	not fulf.	fulfilled	fulfilled	**3**	adeq.	adeq.	**3**	Semi-domestic reindeer density [A13]	**very good**		
D11	fulfilled	not fulf.	fulfilled	fulfilled	**3**	adeq.	adeq.	**3**	Wild ungulate density [A17]	**very good**		
D08	fulfilled	not fulf.	not fulfilled	not fulfilled	**1**	part. adeq.	adeq.	**2**	Large predator abundance [A15]	**good**		
D09	not fulf.	not fulf.	not fulfilled	fulfilled	**3**	inadeq.	inadeq.	**0**	Red fox camera index [A14]	**intermediate**		
D25	not fulf.	not fulf.	not fulfilled	Fulfilled (limited)	**2**	inadeq.	inadeq.	**0**	Lemming abundance [A18]	**intermediate**		

Table 7.3.1. (cont.)

DATA									INDICATOR		ECOSYSTEM CHARACTERISTIC	
Data set ID	**Spatial representativity (SR)**					**Temporal representativity (TR)**			**Indicator [indicator ID]**	**Data coverage**	**Characteristic**	**Indicator coverage**
	SRd1	SRd2	SRd3	SRm	**SRtotal**	TRyr	TRse	**TRtotal**		**DC**		**IC**
D06	fulfilled	not fulf.	fulfilled	not fulfilled	**2**	part. adeq.	adeq.	**2**	Areas free of major infrastructure [A12]	**very good**	Landscape ecological patterns	**inadequate**
D13	not fulf.	fulfilled	fulfilled	not fulfilled	**2**	inadeq.	adeq.	**1**	Alpine bird communities [A23]	**good**	Biological diversity	**inadequate**
D22	fulfilled	not fulf.	not fulfilled	fulfilled	**3**	inadeq.	adeq.	**1**	Arctic fox litter size [A20]	**good**		
D22	fulfilled	not fulf.	not fulfilled	fulfilled	**3**	inadeq.	adeq.	**1**	Arctic fox abundance [A19]	**good**		
D01	fulfilled	not fulf.	fulfilled	fulfilled	**3**	adeq.	adeq.	**3**	Annual mean temperature [A01]	**very good**	Abiotic factors	**partially adequate**
D01	fulfilled	not fulf.	fulfilled	fulfilled	**3**	adeq.	adeq.	**3**	January mean temperature [A02]	**very good**		
D01	fulfilled	not fulf.	fulfilled	fulfilled	**3**	adeq.	adeq.	**3**	July mean temperature [A03]	**very good**		
D01	fulfilled	not fulf.	fulfilled	fulfilled	**3**	adeq.	adeq.	**3**	Winter days above 0°C [A04]	**very good**		
D01	fulfilled	not fulf.	fulfilled	fulfilled	**3**	adeq.	adeq.	**3**	Degree days [A05]	**very good**		
D01	fulfilled	not fulf.	fulfilled	fulfilled	**3**	adeq.	adeq.	**3**	Growing degree days [A06]	**very good**		
D02	fulfilled	not fulf.	fulfilled	fulfilled	**3**	adeq.	adeq.	**3**	Annual precipitation [A07]	**very good**		
D02	fulfilled	not fulf.	fulfilled	fulfilled	**3**	adeq.	adeq.	**3**	Growing season precipitation [A08]	**very good**		
D03	fulfilled	not fulf.	fulfilled	fulfilled	**3**	adeq.	adeq.	**3**	Snow cover duration [A09]	**very good**		

7.3.2 Assessment of the phenomena

The overall assessment of all phenomena underlying the assessment of the alpine ecosystem is presented in **Table 7.2.2**. The assessment is colour coded according to the predefined categories in PAEC (**Figure 7.1.2**).

Semi-domestic reindeer are functionally important in alpine ecosystem in Trøndelag and included as an indicator for the ecosystem characteristic Functionally important species and biophysical structures*. Photo: Manuel Ballesteros, NINA.*

Table 7.3.2. *Assessment of the validity (VP) and evidence (EP) for each phenomenon for the alpine ecosystem. For definitions of categories, see* ***Figure 7.1.2.*** *The main anthropogenic drivers for each indicator are summarized in* ***Table 5.1****.*

Ecosystem characteristic	Phenomenon [ID]	Indicator [ID]	VP	EP	Comments to EP
Primary productivity	Changes in maximum greenness [PA21]	Maximum greenness	high	low	There is a general increasing trend in Maximum greenness, but the rate of change is low. However, it integrates spatially contrasting trends (greening/browning) which may be locally significant.
Primary productivity	Earlier onset of greening [PA22]	Onset of greening	high	none	--
Biomass distribution among trophic levels	High or increasing density of ungulates relative to large carnivores [PA13]	Ungulates versus carnivorous vertebrates	high	insufficient	There is no change in the ratio between ungulates (wild and semidomestic reindeer) and large carnivores over the monitoring period, but the data is considered insufficient to detect changes in this trophic relationship. It is likely though that the ratio is high relative to the reference condition due to the low abundance/absence of large predators (see also indicator Large predator abundance).
Functional groups within trophic levels	Changes in the composition of functional groups within the herbivore vertebrate community [PA15]	Herbivorous vertebrates: reindeer:moose/deer	intermediate	intermediate	There is strong evidence of a change in the ungulate community caused by an increase in the density of the more boreal ungulates moose, and red deer relative to the more alpine ungulates wild and semi-domestic reindeer. This is considered of limited ecosystem significance, hence EP is intermediate.
Functional groups within trophic levels	Decreasing occurrence of arctic fox relative to red fox [PA14]	Carnivorous vertebrates: arctic versus red fox	high	low	There is evidence for a decreasing occurrence of arctic fox relative to red fox in one of three monitoring areas, and a stable dominance of red fox in another. Overall, the evidence for a shift in the relative occurrence of the two fox species is low, but the time series are very short.
Functionally important species	High or increasing density of domestic ungulates [PA16]	Domestic ungulate density	high	low	There is low evidence that the density of domestic ungulates (sheep) in alpine municipalities is increasing or sufficiently high to be of ecosystem significance.

Table 7.3.2. *(cont.)*

Ecosystem characteristic	Phenomenon [ID]	Indicator [ID]	VP	EP	Comments to EP
Functionally important species	Changes in density of semi-domestic reindeer [PA25]	Semi-domestic reindeer density	high	low	Densities of semi-domestic reindeer is highly variable between alpine municipalities. There is some evidence of change towards higher densities over the monitoring period.
Functionally important species	Changes in density of wild ungulates [PA10]	Wild ungulate density	high	none	--
Functionally important species	Low or decreasing abundance of large predators [PA18]	Large predator abundance	high	high	The number of reproducing wolverines is kept low and stable in accordance with governmental policy. This is a substantial deviation from an intact condition which is of ecosystem significance.
Functionally important species	Increasing or high proportion of days with red fox captures by camera traps [PA19]	Red fox camera index	high	low	There is some evidence of increasing occurrence of red foxes on camera traps in one of three monitoring areas.
Functionally important species	Less frequent, less distinct peaks in the lemming cycle [PA12]	Lemming abundance	high	low	There is some evidence for less frequent and/or less distinct peaks in lemming abundance, in particular in southern Trøndelag and over the last decade also in northern Trøndelag.
Landscape ecological patterns	Low or decreasing area free of major infrastructure [PA20]	Areas free of major infrastructure	intermediate	intermediate	The alpine area free of major infrastructure development is reduced relative to a reference condition (to < 90% of total area). Recent changes correspond to a loss of ~2% (from 88.7% to 86.9% over the monitoring period 1988 – 2018).
Biological diversity	Decreasing abundances and/or species diversity within the community of alpine birds [PA11]	Alpine bird communities	intermediate	intermediate	There is evidence of declines in alpine bird communities, partly consistent with trends observed at a national and international level. However, there are strong differences between individual species, and most species have an insufficient site coverage to be representative at a county level.
Biological diversity	Small or decreasing litter size [PA24]	Arctic fox litter size	high	high	There is strong evidence that minimum litter sizes have been declining over the monitoring period.
Biological diversity	Absence of sustained increase in Arctic fox abundance despite conservation efforts [PA23]	Arctic fox abundance	high	low	Arctic fox populations have increased in response to management actions. It is too early to judge whether this increase can be considered sustained over time, and densities must still be considered low.

Table 7.3.2. (cont.)

Ecosystem characteristic	Phenomenon [ID]	Indicator [ID]	VP	EP	Comments to EP
Abiotic factors	Increasing annual temperature [PA01]	Annual mean temperature	high	high	There is strong evidence that annual mean temperatures are increasing (~0.6°C/decade relative to 1961-1990 mean). Changes are considered of high ecosystem significance.
Abiotic factors	Increasing January temperature [PA02]	January mean temperature	high	high	There is strong evidence that January mean temperatures are increasing (~1.2°C/decade relative to 1961-1990 mean). Changes are considered of high ecosystem.
Abiotic factors	Increasing July temperature [PA03]	July mean temperature	high	high	There is strong evidence that July mean temperatures are increasing (~0.8°C/decade relative to 1961-1990 mean). Changes are considered of high ecosystem significance.
Abiotic factors	Increasing number of winter days above 0°C [PA04]	Winter days above 0°C	high	high	The number of winter days > 0° is increasing (~1.9%/yr or ~5 days/decade). Changes are considered of high ecosystem significance.
Abiotic factors	Increasing number of degree days [PA05]	Degree days	high	high	There is strong evidence that the number of degree days is increasing (~0.5%/yr or ~5 days/decade). Changes are considered of high ecosystem significance.
Abiotic factors	Increasing growing degree day sum during the growing season [PA06]	Growing degree days	high	high	There is strong evidence that the number of growing degree days is increasing (~46 GDD/decade). Changes are considered of high ecosystem significance.
Abiotic factors	Changes in annual precipitation [PA07]	Annual precipitation	high	none	--
Abiotic factors	Changes in precipitation during the growing season [PA08]	Growing season precipitation	high	none	--
Abiotic factors	Shorter season with snow cover [PA09]	Snow cover duration	high	high	There is strong evidence that the snow cover duration is decreasing (~0.3%/yr or ~10 days/decade). Changes are considered of high ecosystem significance.

7.3.3 Assessment of ecosystem condition

Following the PAEC protocol the assessment of ecosystem condition for the alpine ecosystem consists of the following sections: An assessment of each ecosystem characteristics based on all associated phenomena (Chapter 7.3.3.1), an assessment of the ecosystem as a whole (Chapter 7.3.3.2).

7.3.3.1 Assessment of the condition of ecosystem characteristics

Alpine – Primary productivity

Assessment category: Based on the set of indicators, this ecosystem characteristic is assessed as having **limited deviation from the reference condition**. This means that the ecosystem characteristic can still be considered in an intact ecological condition. There is evidence of greening (e.g. a change towards a more productive state), but it is assessed as having an overall limited impact on ecological condition. There is some uncertainty regarding the choice of category.

Justification for choice of assessment category: The assessment is based on two indicators (*Maximum greenness* and *Onset of greening*) with two associated phenomena (PA21-PA22), both of high validity, implying certain links to drivers and a good understanding of the role of the indicators in the alpine ecosystem. Alpine areas in Trøndelag show a weak greening trend overall, but with substantial spatial contrasts in trends. For this reason, the phenomenon is considered having a low level of evidence for change, and is hence located in the 'limited deviation' section of the diagram (**Figure 7.3.1**). The indicator *Onset of greening* shows no evidence of change over the two decades covered by the remote sensing data, and is hence located in the 'no deviation' section of the diagram.

Uncertainties related to the choice of assessment category: There is some uncertainty regarding the choice of category, as the two phenomena are located in two different sections within the diagram. Both indicators have very good data coverage. The observed trends are in line with expectations based on observed trends in other alpine and arctic regions. The indicator coverage for the ecosystem characteristic *Primary productivity* is assessed as 'partially adequate', mostly due to a lack of indicators which capture changes in primary productivity and/ or vegetation biomass in key vegetation strata linked to regional greening/ browning (for instance alpine shrubs).

Alpine – Biomass distribution among trophic levels

Assessment category: This ecosystem characteristic is assessed as having insufficient evidence for an assessment of deviation from the reference state.

Justification for choice of assessment category: Only one indicator (log ratio between reindeer and carnivores) with one associated phenomenon (PA13), was available for biomass distribution among trophic levels in alpine ecosystems. The phenomenon has high validity, implying certain links to anthropogenic drivers and a relatively good understanding of the implications of change in this trophic relationship for alpine ecosystems. Over the time period covered by data on both levels, there is no evidence of change in the relative density of the two levels. It is likely though that the ratio is high (e.g. biased towards the ungulate level) relative to the reference condition due to the low abundance/absence of large predators. However, due to the short time span covered, and high interannual variation, the evidence is assessed as 'insufficient' (EP is 'none, insufficient evidence').

Uncertainties related to the choice of assessment category: The single indicator which is included is insufficient as it is a short time series relative to relevant dynamics (changes in trophic ratios between long lived mammals) and has high interannual variation. The data overlap between the two trophic levels is not sufficient to conclude. In addition, there are a number of potential indicators of biomass distribution among trophic levels in alpine ecosystems that could not be included in the assessment. Key trophic ratios which are omitted include alpine plants and ungulates, alpine plants and alpine rodents, and alpine rodents and small carnivores.

Alpine – Functional groups within trophic levels
Assessment category: Based on the set of indicators this ecosystem characteristic is assessed as having **limited deviation from the reference condition**. This means that the ecosystem characteristic can be considered to be in an intact ecological condition. There is evidence of changes towards a worsened condition with stronger boreal influence due to increasing abundance of browsing moose, but the magnitude of this change is such that it is assessed to have overall limited impact on ecological condition. There is substantial uncertainty related to the choice of category.

Justification for choice of assessment category: This assessment is based on two indicators - with two associated phenomena - that are of intermediate (PA15) and high (PA14) validity (VP) with certain links to relevant anthropogenic drivers and intermediate (PA15) and good understanding (PA15) of their ecological significance. The phenomenon related to carnivorous vertebrates (PA14) scores 'low' on the Evidence for the Phenomenon (EP), while the phenomenon related to herbivorous vertebrates (PA15) scores 'intermediate' with respect to EP. Overall, both indicators are located in the 'limited deviation' section of the diagram (**Figure 7.3.1**).

Uncertainties related to the choice of assessment category: There is substantial uncertainty related to the choice of category. The data coverage is good for the carnivore indicator, while very good for the herbivorous vertebrates. However, most importantly the indicator coverage of this ecosystem characteristics is *inadequate*, because there are no indicators for functional groups of plants, and lack of indicators for other functional groups of herbivores (e.g. within insects and rodents) and carnivores (birds of prey, corvids and mustelids).

Alpine – Functionally important species and biophysical structures
Assessment category: Based on the set of indicators this ecosystem characteristic is assessed as having **limited deviation from the reference condition**. This means that the ecosystem characteristic can still be considered in an intact ecological condition. There is some, but limited, evidence that this ecosystem characteristic is in reduced condition, even though the individual phenomena range from having no - to substantial deviation from the reference state. There are some uncertainty related to the choice of category.

Justification for choice of assessment category: The assessment is based on six indicators with associated phenomena (PA10, PA12, PA16, PA18, PA19, PA25), and all were assessed as having high validity, but varying evidence. Four phenomena indicate limited deviation from the reference condition, and these were given the strongest emphasis in the total evaluation. These four phenomena are related to the densities of sheep, red fox and semi domestic reindeer which were all found to be moderately high, and lemming peaks for which there was some evidence of less regular and/or distinct peaks. Changes in wild ungulates were not observed within alpine-dominated municipalities, indicating no deviation from the reference condition, whereas the abundance of wolverine was considered as being considerably reduced compared to the reference condition.

Uncertainties related to the choice of assessment category: There is some uncertainty related to the choice of category. The data coverage of the indicators included is assessed as 'very good' for three indicators, and 'good' for one and 'intermediate' for the other two. The indicator coverage of the ecosystem characteristic is 'partially adequate'. This is due to an absence of indicators that characterize vegetation (e.g. shrub cover), avian predators, mustelids and rodents other than lemmings. There are also several functionally important microbial and invertebrate species or species groups, such as decomposers or parasites, for which we have no available data to be able to say anything about their abundance.

Alpine – Landscape ecological patterns
Assessment category: Based on a single indicator this ecosystem characteristic is assessed as having **limited deviation from the reference condition**. This means that the ecosystem characteristic can still be considered in an intact ecological condition. This is based on the one indicator which has intermediate evidence and intermediate validity of the phenomenon. There is substantial uncertainty related to the choice of category.

Justification for choice of assessment category: The assessment of landscape ecological patterns is based on one indicator with one associated phenomenon (PA20). Although human infrastructure is known to affect ecosystems negatively, the role of the indicator itself, i.e. the proportion of area > 1 km from major infrastructure, is less clear. Therefore, the validity of the phenomenon is assessed as 'intermediate'. The last decades the reduction in the area of the alpine ecosystem that is more than 1 km away from major human infrastructure is weak. The deviation from the reference state (no areas closer than 1 km to human infrastructure) is clearer, and the assessment of the evidence of the phenomenon is therefore 'intermediate', and the phenomenon placed in the 'limited deviation' section of the diagram (**Figure 7.3.1**).

Uncertainties related to the choice of assessment category: There is substantial uncertainty related to the choice of category. The assessment is based on only one indicator with very good data coverage, and the validity of the indicator to measure important changes in landscape ecological patterns is not as clear as other metrics e.g. capturing level of fragmentation, isolation or reduction in fragment size, which are important for stability of ecosystems or meta-communities of species. To describe changes in such indicators was not possible given the available data and delineation of the alpine ecosystem. The indicator coverage for landscape ecological patterns is therefore 'inadequate'.

Alpine – Biological diversity
Assessment category: Based on the set of indicators this ecosystem characteristic is assessed as having **limited deviation from the reference condition**. This means that the ecosystem characteristic can still be considered in an intact ecological condition, but that changes have occurred which warrants attention. There is high evidence for a decline in Arctic fox litter size over the last decade, but except for one mountain area (Børgefjell), this has not led to any decrease in the abundance breeding arctic foxes. There is substantial uncertainty regarding the choice of category

Justification for choice of assessment category: The assessment is based on three indicators/phenomena - that are of 'intermediate' (PA11) and 'high' (PA23 and PA24) validity (VP). The phenomenon related to Arctic fox abundance (PA23) scores 'low' on the EP axis, due to the recent increase in number of litters - as could be expected from the intensive arctic fox conservation actions in these alpine areas. The EP for the alpine bird community (PA11) is assessed as 'intermediate', despite there is no change in the community level composite index. This assessment is justified by the trend curves for the individual species, where especially Lapland bunting is showing a significant decline. This assessment is consistent with the well documented Fennoscandian-scale negative trend in alpine birds. A sharp decline in arctic fox litter size (A20) during the last decade yield high EP for PA24, but this score is given low weight in the assessment of the ecosystem characteristics since the abundance of the arctic fox has been increasing overall in Trøndelag.

Uncertainties related to the choice of assessment category: There is substantial uncertainty regarding the choice of category. All three indicators have good data coverage. However, the bird community indicator does not include species typical of the middle and high alpine zones (e.g. Shore lark, Snow bunting, and Dotterel). The indicator coverage is assessed as 'inadequate' as indicators within major biological taxa (e.g. plants, invertebrates) are lacking.

Alpine – Abiotic factors

Assessment category: Based on the set of indicators this ecosystem characteristic is assessed as having **substantial deviation from the reference condition**. The changes in abiotic indicators related to snow cover and temperature are large and relatively consistent across the assessed area. Several of the climatically derived indicators are close to, or exceed, the historically observed variation during the climatic reference period, in other words, values which during the 1961-1990 period were considered extreme are now within the expected norm. There is no major uncertainty related to the choice of category.

Justification for choice of assessment category: The assessment is based on nine indicators with associated phenomena (PA01-PA09), which all have high validity, implying certain links to anthropogenic drivers and a relatively good understanding of their role in alpine ecosystems. All phenomena related to temperature and snow cover show high evidence of changes which are expected to be of ecosystem significance and are hence located in the 'substantial deviation' section of the assessment diagrams (**Figure 7.3.1**). Phenomena related to precipitation, both total precipitation (PA07) and growing season precipitation (PA08), are exceptions to this and show no evidence of change relative to the climatic reference period. They are hence located in the 'no deviation' section of the diagram. However, for alpine ecosystems the two phenomena related to precipitation are considered of somewhat less relevance than the phenomena related to snow cover and changes in seasonal temperatures and more emphasis is hence placed on the latter in the assessment. The observed changes in temperature and snow cover are in part substantial. For instance, annual mean temperatures (PA01) have increased by 1-2°C from a historical (1961-1990) range expected to permit the occurrence of discontinuous permafrost, to an above-zero range where discontinuous permafrost cannot be expected to be sustained over time. The annual number of days with above-zero temperatures in winter (PA04) has increased by about three weeks, suggesting an increased risk of ice formation and rain-on-snow events. The length of the snow-covered season has decreased similarly.

Uncertainties related to the choice of assessment category: There are no major uncertainty related to the choice of category. The data coverage of the indicators included is assessed as 'very good' although the coarse resolution of gridded climate data does not permit the capture of small-scale contrast/gradients in the rates of change. The indicator coverage of the ecosystem characteristic is considered 'partially adequate' despite a large set of indicators. This is due to an absence of indicators that characterize regional snow quality, including snow structure, basal ice and 'rain-on snow' events which would allow closer causal links to be made between abiotic conditions and biotic ecosystem characteristics such as trophic relationships. Further, albedo, which represents the reflective qualities of the surface in late winter/spring, in another important indicator not included in this pilot assessment, which would allow closer causal links between land surface changes (shrub encroachment in alpine habitats), abiotic conditions (snow cover, snow melt) and regional climate feedbacks to be established

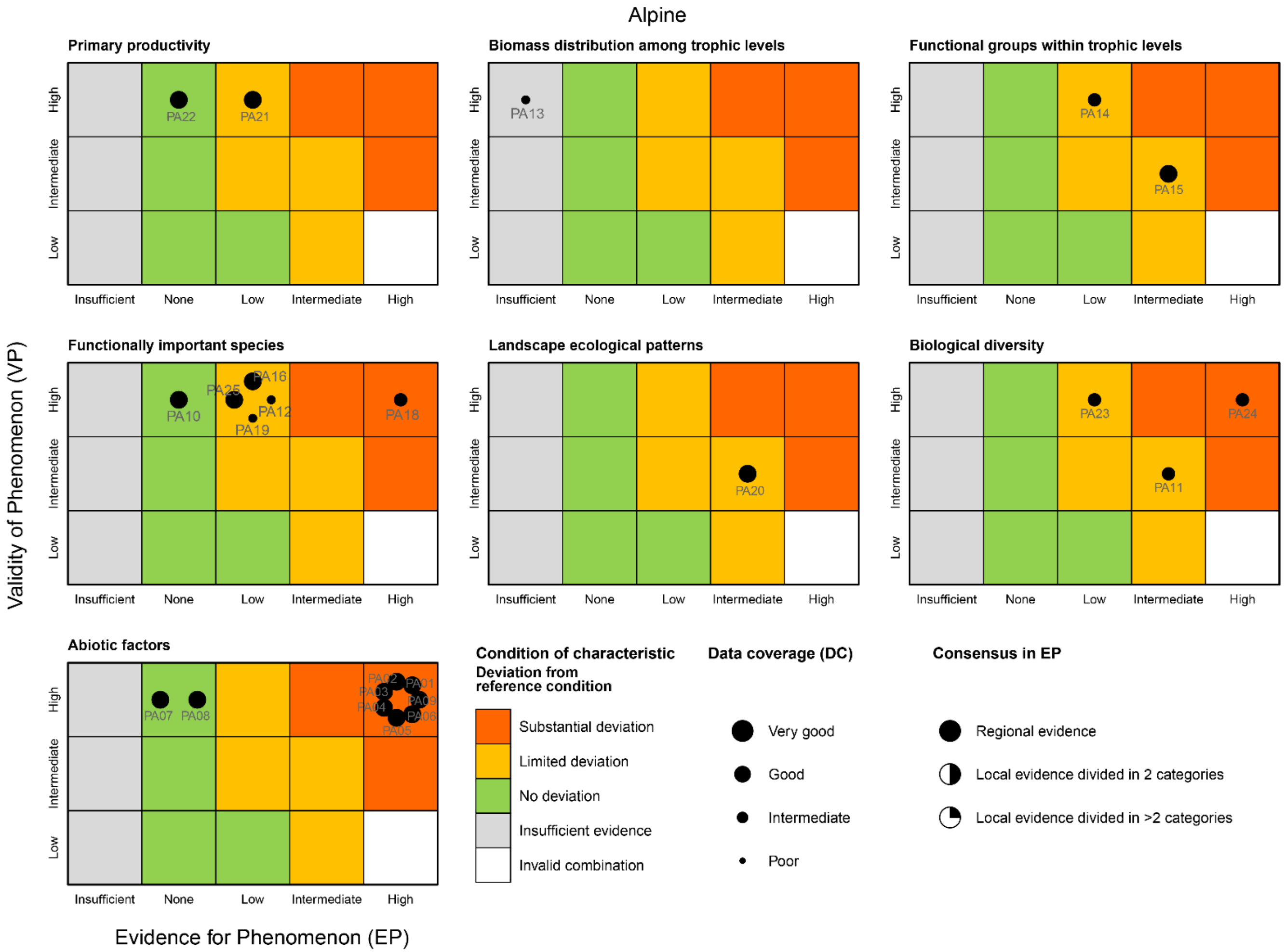


Figure 7.3.1. *The PAEC assessment diagram for alpine ecosystems. The diagram provides an overview of all phenomena for all ecosystem characteristics and their placement along the validity (VP) and Evidence (EP) axis and are intended as an aid for the panel when making their assessment. Each dot represents the assessment of a phenomenon with ID (from* ***Table 5.1****). The size of the dot represents data coverage (from* ***Table 7.3.1****).*

7.3.3.2 Assessment of the condition of the ecosystem as a whole

The assessment of this ecosystem is based on an indicator set which is considered inadequate for four of the seven ecosystem characteristics, and partially adequate for the remaining three (*Abiotic factors, Primary productivity, Functionally important species*). All ecosystem characteristics have one or more indicators and can hence be assessed within the limits given by this set of indicators. Of the 24 indicators developed during this pilot, nine are related to the abiotic environment in alpine areas (temperature, precipitation, and snow), while six are related to *Functionally important species* in alpine ecosystems and important *functional groups* (two indicators). The remaining address *Primary productivity* (two indicators), *Biomass distribution among trophic levels* (one indicator), *Landscape ecological patterns* (one indicator) and *Biological diversity* (three indicators). Based on this limited set of indicators and the overall assessment of the seven ecosystem characteristics, the scientific panel concludes that alpine ecosystems in Trøndelag show **limited deviations** from the reference condition, with fundamental structures and functions mainly maintained. Substantial deviation from the reference condition is evident in the ecosystem's abiotic factors and is driven by climate change. However, none of the biotic ecosystem characteristics expected to respond to climate change exhibit more than limited deviation. There are considerable uncertainties associated with assessment of most of the biotic ecosystem characteristics, and thus the ecosystem as a whole, because of substantial deficiencies in data and/or indicator coverage.

Current state of knowledge of the reference condition

According to the normative description of the reference condition (Aarrestad et al. 2017), alpine ecosystem in an intact condition should have structures and functions, that are set by a climate that maintains the distribution of altitudinal, bio-climatic subzones (i.e. low, middle and high alpine subzones) that were present during the 1961-1990 reference period. This means that the alpine zones, and its subzones, should not be subjected to invasions and/or increasing abundance of species from adjacent bio-climatic zones (i.e. lower elevational subzones) - such as boreal species in the low alpine subzone. Overall, primary production should be higher than decomposition leading to a net build-up of carbon. All trophic levels should be dominated by functional groups which are defining for alpine ecosystems. Food web interactions should be heavily influenced by cyclic peaks of rodents (and in particular lemmings), occurring with a regularity and amplitude that maintain alpine vegetation types such as snow beds, and arctic-alpine specialist predators such as the Arctic fox. The snow cover should have a depth, structure and morphology that provides suitable conditions for functionally important alpine species and habitats. Anthropogenic land use by means of grazing domestic ungulates has been present for centuries in most mountain regions in Norway (Austrheim et al. 2015b). Such traditional land use could therefore be regarded as a component of the reference condition - provided that its impact does not significantly alter the natural ecosystem function and structure. Keeping these points in mind, the current state of knowledge of the reference condition for alpine ecosystems is good with regard to past and current climatic and land use regimes, and in particular, the climatic boundaries that define this ecosystem and the bioclimatic subzones within it. The fundamental ecosystem functions and structures, such as the identity of alpine ecological communities and their dominant biotic interactions, and how they are contingent on climate, are also relatively well known. This permits us to detect increasing abundance and influence by boreal species and impact of emergent land use forms (e.g. increased tourism). However, we lack to a large extent knowledge on the historical and current quantitative aspects of some fundamental ecosystem processes, such as the relationship between primary production and decomposition, and the relative importance of top-down and bottom-up regulation and various forms of subsidies (boreal and anthropogenic) on food web dynamics. Such knowledge is crucial, for instance for predicting the precise nature of ecosystem responses (e.g. thresholds or other sorts of non-linearities) to drivers of change. Finally, considering the large spatial extent of alpine biome in Norway, with strong gradients in both traditional land use forms (e.g. the intensity of historic dairy farming) and climate (e.g. ranging from strong oceanic influences in the south-west to profound continentality in the north-east), there are substantial challenges with regard to providing accurate definitions of reference conditions that are site-specific.

Main drivers of change
Alpine ecosystems are fundamentally contingent on the bioclimatic conditions that provide the foundation for alpine species, communities and their ecological functions. Climate change, in particularly increasing temperatures, is expected to be the main driver of ecosystem changes in alpine ecosystems (Aarrestad et al. 2017). Hence, the condition of the ecosystem characteristic *Abiotic conditions* is to a certain degree a determinant of the current or future condition of many of the defining biotic ecosystem characteristics. While abiotic indicators may act as drivers on biotic indicators, driver-response relationships may also be the other way around (feedbacks); i.e. biotic processes driving change in abiotic indicators. Browsing by large herbivores (both wild and domestic), for instance, can influence snow cover distribution and thereby spring albedo (Cohen et al. 2013) and temperature. Generally, ecosystem dynamics are to a large degree due to interactions between and within the biotic and abiotic compartments of the ecosystems, and ecosystem change is expected to be due to chain reactions (cascades) within and between these compartments resulting from driver impacts. This is in line with all the phenomena that the scientific panel has formulated and assessed for each of the indicators. At the ecosystem level, the cumulative outcome of these phenomena may lead to ecosystem state transitions between known states, e.g. between alpine tundra and boreal forest or relocations or even disappearance of elevational subzones. If such ecosystem state changes become realised, the deviation from the reference condition will be substantial and the entire ecosystem must be assessed as in a non-intact condition. Some state changes are likely to deviate from expectation of the change trajectories that are outlined in terms of the PAEC phenomena, for instance, due to a non-analogous climate, extreme weather events, and surprising disturbances and synergies from multiple drivers (e.g. climate changes and land use). Climatic abiotic conditions cannot be managed at the scale of the ecosystems, but nevertheless need to be accounted for when assessing the total loads and those drivers which are manageable, such as land use and harvesting. Such manageable ecosystem level drivers may simply add to the total load or may potentially interact synergistically with climate change. In any case, substantial or pervasive deviations in the set of indicators/ ecosystem characteristics can provide the basis for assessing the condition of the ecosystem relative to the reference condition.

Observed deviations from the reference condition
The set of indicators describing the ecosystem characteristic *Abiotic factors* substantially deviates from the reference condition. All temperature-related indicators, as well as the snow cover indicator, show substantial deviation with expected long-term consequences for species-specific life conditions and ecosystem functions. Yet, none of the biotic ecosystem characteristics have changed substantially over the period they have been monitored and just one of the 14 biotic indicators show substantial deviation that may be attributed to climatic drivers (Arctic fox litter size). Some of the ecosystem characteristics show limited deviations in the direction that could be expected from climate warming (i.e. as specified by the phenomena); for instance, a tendency of increased primary productivity (greening), decline in some alpine bird species (Lapland bunting) and increase of boreal mammals (e.g. moose). However, none of these trends are yet assessed to be of sufficient ecological significance in terms of influencing ecosystem-level structure and function. While the ecosystem therefore could be assessed as being in an overall intact condition, there are some important caveats to be aware of. First, the indicator coverage is not deemed fully adequate for any of the alpine ecosystem characteristics. Four of the biotic ecosystem characteristics are inadequately covered, because data are lacking on central functional or structural properties of the ecosystem expected to be highly responsive to climate change. Second, for most of the biotic indicators that have been assessed the temporal data coverage are not overlapping with the climate reference period. Third, central indicators of high and middle alpine subzones are lacking. Altogether, these limitations imply that there are considerable uncertainties associated with present assessment of the ecological condition of the alpine ecosystem in Trøndelag.

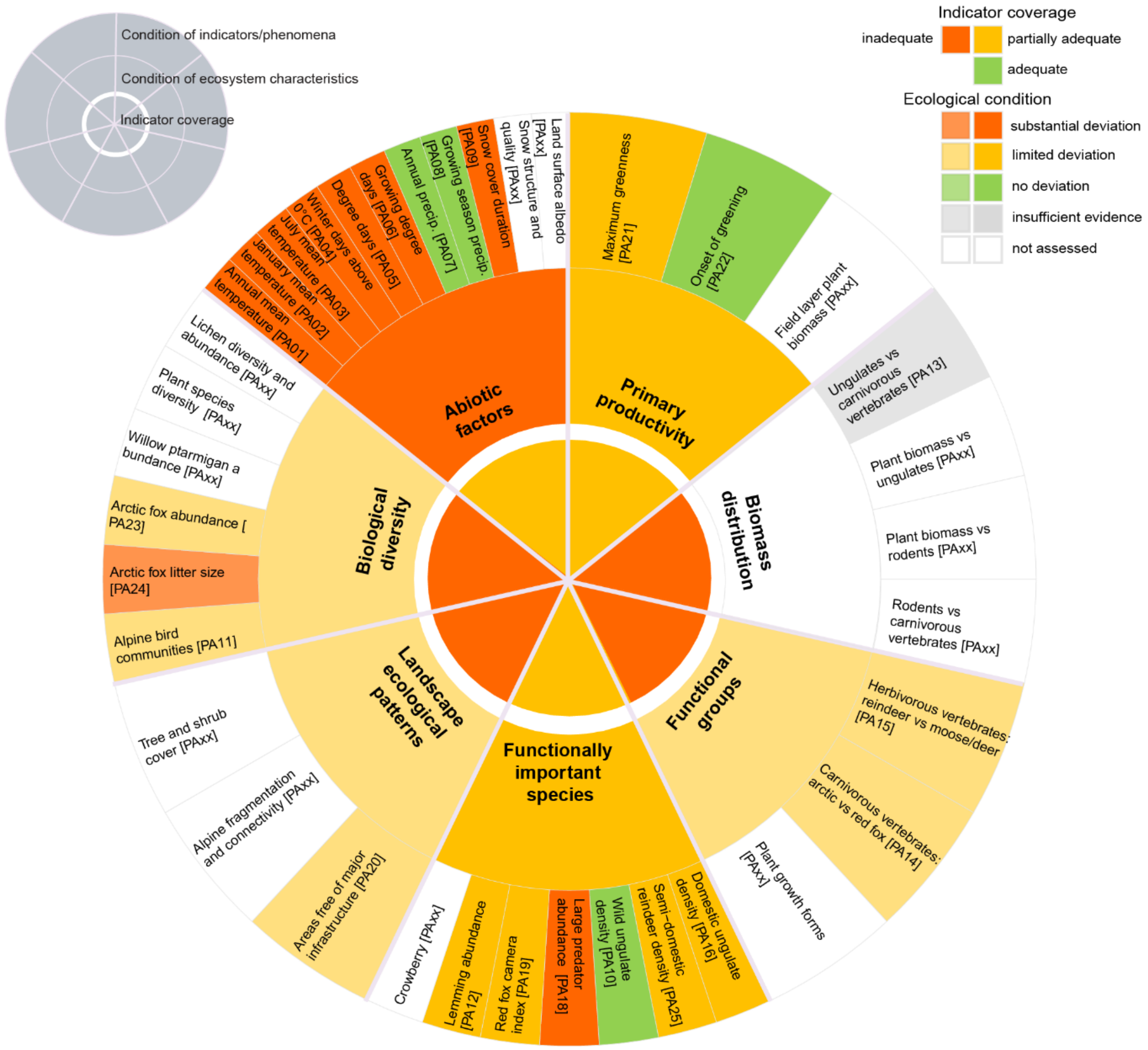


Figure 7.3.2. *A graphical summary of the assessment of ecological condition of alpine ecosystems. The outer ring shows the assessment of ecological condition at the level of the individual indicators with associated phenomena ID in square brackets. Indicators which the scientific panel have recommended for inclusion (**Table 7.7**), but which are not included in the pilot assessment, are shown in white to illustrate the perceived most important deficiencies in the current indicator set. The middle ring shows the assessment at the level of ecosystem characteristics, indicating deviation from the reference condition, and the innermost circle shows the quality of indicator coverage. Assessment based on inadequate indicator coverage is further highlighted by paler shading in ecological characteristics and their corresponding indicators.*

7.4 Wetland

7.4.1 Assessment of the knowledge base

The overall assessment of the knowledge base for the wetland ecosystem is presented in **Table 7.4.1**. The assessment is colour coded according to the predefined categories in PAEC (**Figure 7.1.1**). In accordance with the PAEC protocol, the knowledge base is assessed at three levels: *Data level*, *indicator level*, and *ecosystem characteristics level*. For an operational assessment, it is recommended in the PAEC protocol that each cell in **Tables 7.4.1** should link to an endnote describing why a given category was chosen, to enhance transparency (see Pedersen et al. 2021a, Table 7.1a, b). Such records are important, in particular when operational assessments are repeated after a certain time period. Since this is a pilot assessment, a written justification of each individual choice of category was left out.

Wetland habitat on Hitra, Trøndelag. Photo: Jutta Kapfer.

Table 7.4.1. *Assessment of the knowledge base for the datasets, indicators and ecosystem characteristics for wetland ecosystems. For the ecosystem characteristics* Biomass distribution among trophic levels, Functional groups within trophic levels *and* Functionally important species and biophysical structures, *no indicators were available. Hence only indicator coverage was assessed (and as "inadequate").*

DATA									INDICATOR		ECOSYSTEM CHARACTERISTIC	
Data set ID	**Spatial representativity (SR)**					**Temporal representativity (TR)**			**Indicator [indicator ID]**	**Data coverage**	**Characteristic**	**Indicator coverage**
	SRd1	SRd2	SRd3	SRm	**SRtotal**	TRyr	TRse	**TRtotal**		**DC**		**IC**
D01	fulfilled	fulfilled	fulfilled	fulfilled	**3**	part. adeq.	adeq.	**2**	Maximum greenness [W10]	**very good**	Primary productivity	**inadequate**
D01	fulfilled	fulfilled	fulfilled	fulfilled	**3**	part. adeq.	adeq.	**2**	Onset of greening [W11]	**very good**		
											Biomass distribution among trophic levels	**inadequate**
											Functional groups within trophic levels	**inadequate**
											Functionally im-portant species	**inadequate**
D06	fulfilled	not fulf.	fulfilled	not fulf.	**2**	part. adeq.	adeq.	**2**	Areas free of major infra-structure [W12]	**very good**	Landscape ecological patterns	**inadequate**
D13	not fulf.	fulfilled	fulfilled	not fulf.	**2**	inadeq.	adeq.	**1**	Wetland bird communi-ties [W16]	**good**	Biological diversity	**inadequate**
D01	fulfilled	not fulf.	fulfilled	fulfilled	**3**	adeq.	adeq.	**3**	Annual mean tempera-ture [W01]	**very good**	Abiotic factors	**partially adequate**
D01	fulfilled	not fulf.	fulfilled	fulfilled	**3**	adeq.	adeq.	**3**	January mean tempera-ture [W02]	**very good**		
D01	fulfilled	not fulf.	fulfilled	fulfilled	**3**	adeq.	adeq.	**3**	July mean temperature [W03]	**very good**		
D01	fulfilled	not fulf.	fulfilled	fulfilled	**3**	adeq.	adeq.	**3**	Winter days above 0°C [W04]	**very good**		

Table 7.4.1. *(cont.)*

DATA									INDICATOR		ECOSYSTEM CHARACTERISTIC	
Data set ID	**Spatial representativity (SR)**					**Temporal representativity (TR)**			**Indicator [indicator ID]**	**Data coverage**	**Characteristic**	**Indicator coverage**
	SRd1	SRd2	SRd3	SRm	**SRtotal**	TRyr	TRse	**TRtotal**		**DC**		**IC**
D01	fulfilled	not fulf.	fulfilled	fulfilled	**3**	adeq.	adeq.	**3**	Degree days [W05]	**very good**	Abiotic factors (cont.)	
D01	fulfilled	not fulf.	fulfilled	fulfilled	**3**	adeq.	adeq.	**3**	Growing degree days [W06]	**very good**		
D02	fulfilled	not fulf.	fulfilled	fulfilled	**3**	adeq.	adeq.	**3**	Annual precipitation [W07]	**very good**		
D02	fulfilled	not fulf.	fulfilled	fulfilled	**3**	adeq.	adeq.	**3**	Precipitation during growing season [W08]	**very good**		
D03	fulfilled	not fulf.	fulfilled	fulfilled	**3**	adeq.	adeq.	**3**	Snow cover duration [W09]	**very good**		
D15	not fulf.	not fulf.	not fulf.	not fulf.	**0**	adeq.	adeq.	**3**	Soil water content during growing season [W14]	**intermediate**		
D16	not fulf.	not fulf.	not fulf.	not fulf.	**0**	adeq.	adeq.	**3**	Ground water condition during growing season [W15]	**intermediate**		
D14	not fulf.	not fulf.	not fulf.	not fulf.	**0**	inadeq.	adeq.	**1**	Trenching [W13]	**intermediate**		

7.4.2 Assessment of the phenomena

The overall assessment of all phenomena underlying the assessment of the wetland ecosystem is presented in **Table 7.4.2**. The assessment is colour coded according to the predefined categories in PAEC (**Figure 7.1.2**).

*The whimbrel (*Numenius phaeopus*) is included in the wetland bird community index. The species exhibit declines in Norway and is listed as* near threatened *in the Norwegian Red List. Photo: Karl-Otto Jacobsen, NINA.*

Table 7.4.2. *Assessment of the validity (VP) and evidence (EP) for each phenomenon for the wetland ecosystem. For definitions of categories, see* ***Figure 7.1.2.*** *The main anthropogenic drivers for each indicator are summarized in* ***Table 5.1.***

Ecosystem characteristic	Phenomenon [ID]	Indicator [ID]	VP	EP	Comments to EP
Primary productivity	Changes in maximum greenness [PW17]	Maximum greenness	intermediate	low	There is a general increasing trend in Maximum greenness, but the rate of change is low. However, it integrates spatially contrasting trends (greening/browning) which may be locally significant.
Primary productivity	Earlier onset of greening [PW18]	Onset of greening	intermediate	none	--
Landscape ecological patterns	Low or decreasing area free of major infrastructure [PW15]	Areas free of major infrastructure	intermediate	intermediate	The wetland area free of major infrastructure development is greatly reduced relative to the reference condition (to < 40% of total area). Recent changes correspond to a loss of ~3.5% (from 43.3% to 39.7% over the monitoring period 1988 – 2018).
Biological diversity	Decreasing abundances and/or species diversity within the community of wetland birds [PW13]	Wetland bird communities	intermediate	low	There is low evidence of change in wetland bird communities, although several single species with good site coverage show decreasing trends over the monitoring period.
Abiotic factors	Large or increasing area affected by historical or present-day trenching [PW16]	Trenching	intermediate	low	There is low evidence in the national statistics that the wetland area subject to subsidized trenching is high or increasing. However, the limited time span of the statistics means that historical trenching prior to the late 1960's is lacking.
Abiotic factors	Increasing annual temperature [PW01]	Annual mean temperature	high	high	There is strong evidence that annual mean temperatures are increasing (~0.6°C/decade relative to 1961-1990 mean). Changes are considered of ecosystem significance.
Abiotic factors	Increasing January temperature [PW02]	January mean temperature	high	high	There is strong evidence that January mean temperatures are increasing (~1.2°C/decade relative to 1961-1990 mean). Changes are considered of ecosystem significance.
Abiotic factors	Increasing July temperature [PW03]	July mean temperature	high	high	There is strong evidence that July mean temperatures are increasing (~0.8°C/decade relative to 1961-1990 mean). Changes are considered of ecosystem significance.

Table 7.4.2. *(cont.)*

Ecosystem characteristic	Phenomenon [ID]	Indicator [ID]	VP	EP	Comments to EP
Abiotic factors	Increasing number of winter days above 0°C [PW04]	Winter days above 0°C	high	high	The number of winter days > 0° is increasing (~1.5%/yr or ~8 days/decade). Changes are considered of high ecosystem significance.
Abiotic factors	Increasing number of degree days [PW05]	Degree days	high	high	There is strong evidence that the number of degree days is increasing (~0.4%/yr or ~6 days/decade). Changes are considered of high ecosystem significance.
Abiotic factors	Increasing growing degree day sum during the growing season [PW06]	Growing degree days	high	high	There is strong evidence that the number of growing degree days is increasing (~68 GDD/decade). Changes are considered of high ecosystem significance.
Abiotic factors	Changes in annual precipitation [PW07]	Annual precipitation	high	none	--
Abiotic factors	Changes in precipitation during the growing season [PW08]	Precipitation during growing season	high	none	--
Abiotic factors	Shorter season with snow cover [PW09]	Snow cover duration	high	intermediate	There is strong evidence that the snow cover duration is decreasing (~0.5%/yr or ~7 days/decade). Changes have been assessed as of limited ecosystem significance so far.
Abiotic factors	Decreasing soil water content or increasing number of days with low soil water content [PW10]	Soil water content during growing season	high	none	--
Abiotic factors	Increasing number of days with low ground water level [PW12]	Ground water condition during growing season	high	none	--

7.4.3 Assessment of ecosystem condition

Following the PAEC protocol the assessment of ecosystem condition for the wetland ecosystem consists of the following sections: An assessment of each ecosystem characteristics based on all associated phenomena (Chapter 7.4.3.1), an assessment of the ecosystem as a whole (Chapter 7.4.3.2).

We highlight that the ecological condition for ecosystem characteristics for which no indicators are present, cannot be assessed. In this pilot assessment, this is the case of three ecosystem characteristics for wetland ecosystems.

7.4.3.1 Assessment of the condition of ecosystem characteristics

Wetland – Primary productivity

Assessment category: Based on the set of indicators this ecosystem characteristic is assessed as having **limited deviation from the reference condition**. This means that the ecosystem characteristic can still be considered in an intact ecological condition. There is evidence of greening (e.g. a change towards a more productive state), but it is assessed as having an overall limited impact on ecological condition. There are substantial uncertainty regarding the choice of category.

Justification for choice of assessment category: The assessment is based on two indicators (*Maximum greenness* and *Onset of greening*) with two associated phenomena (PW17-PW18). In contrast to forest and alpine ecosystems, where these two phenomena are considered of high validity, for wetland ecosystems they are considered of intermediate validity. This is due to a less good understanding of the implications of change in primary productivity (greening/ browning and onset of greening) for the condition of wetland ecosystems, which has received little attention in the literature relative to alpine and forest ecosystems. Wetland areas in Trøndelag show a weak greening trend overall, but with substantial spatial contrasts in trends. For this reason, the phenomenon is considered having a low level of evidence for change, and is hence located in the 'limited deviation' section of the diagram (**Figure 7.4.1**). The indicator *Onset of greening* show no evidence of change over the two decades covered by the remote sensing data, and is hence located in the 'no deviation' section of the diagram.

Uncertainties related to the choice of assessment category: There is substantial uncertainty regarding the choice of category. The two phenomena are located in two different sections within the diagram. Further, although the data coverage of both indicators is 'very good' they are both based on remote sensing data, which can be considered coarse resolution relative to the natural fragmentation of wetland ecosystems. It is hence likely that trend estimates for wetland ecosystems are influenced by the mosaic of forest and alpine areas in which wetlands exist. The indicator coverage for the ecosystem characteristic Primary productivity is assessed as 'inadequate', mostly due to a lack of indicators which capture changes in primary productivity and/or vegetation biomass in key vegetation strata linked to regional greening/browning (for instance encroachment by shrubs and trees in wetland).

Wetland – Biomass distribution among trophic levels

No indicators are available for this ecosystem characteristics due to a lack of data on relevant trophic relationships and/or food web dynamics in wetland ecosystems. The condition of this ecosystem characteristics has therefore not been assessed.

Wetland – Functional groups within trophic levels

No indicators are available for this ecosystem characteristics due to a lack of data on relevant functional groups in wetland ecosystems. The condition of this ecosystem characteristics has therefore not been assessed.

Wetland – Functionally important species and biophysical structures
No indicators are available for this ecosystem characteristics due to a lack of data on relevant functionally important species and/or biophysical structures in wetland ecosystems. The condition of this ecosystem characteristics has therefore not been assessed.

Wetland – Landscape ecological patterns
Assessment category: This ecosystem characteristic is assessed as having **limited deviation from the reference condition**. This means that the ecosystem characteristic can still be considered in an intact ecological condition based on the single available indicator. There are substantial uncertainty related to the choice of category.

Justification for choice of assessment category: The assessment is based on just one indicator, proximity to major human infrastructure, with one associated phenomenon (PW15) of intermediate validity. The knowledge base for how this indicator reflects ecosystem change is scarce, and mainly reflects direct effects of disturbance. The evidence of the phenomenon is based on both the recent change in the indicator, and the deviation from the reference state where no wetland areas are close to major human infrastructure.

Uncertainties related to the choice of assessment category: There are substantial uncertainty related to the choice of category. The assessment is based on just one indicator, with very good data coverage. The wetland ecosystem is distributed across all of Trøndelag, from the coast to the inland, and from the lowland to the high elevations. The ecosystem is by nature characterised as being fragmented and interspersed in other ecosystems such as forest and alpine. Good indicators of the landscape ecological patterns that are known to be important for such fragmented ecosystems are measures of isolation, size of fragments and number of fragments. Such measures cannot be assessed by the distance to infrastructure, but instead require detection and characterisation of each ecosystem fragment (i.e. each wetland unit). This was not feasible with the available data for the indicator or the spatial distribution of the ecosystem. In addition, large wetland areas have been transformed into forest or agricultural areas, and detecting these areas is not possible. This means that the extent of the ecosystem under the reference state (i.e. the total area of wetland in Trøndelag) is also highly uncertain. The indicator coverage for landscape ecological patterns for the wetland ecosystem is therefore 'inadequate'.

Wetland – Biological diversity
Assessment category: Based on one indicator, this ecosystem characteristic is assessed as having **limited deviation from the reference condition**. This means that the ecosystem characteristic can still be considered in an intact ecological condition. There is substantial uncertainty related to the choice of category.

Justification for choice of assessment category: The assessment is based only on one indicator/ phenomenon that is of intermediate (PW13) validity (VP) and scores low with respect to EP. There is no change in the community level composite index and the trend curves for the individual species is by-and-large consistent with a low EP.

Uncertainties related to the choice of assessment category: There is substantial uncertainty related to the choice of category as data coverage for the bird community indicator is 'intermediate' and several rare species are not included in the composite index. The indicator coverage is assessed as 'inadequate' as indicators within major biological taxa (e.g. plants, invertebrates) are lacking.

Wetland – Abiotic factors
Assessment category: Based on the set of indicators, this ecosystem characteristic is assessed as having **substantial deviation from the reference condition**. The changes in abiotic indicators related to snow cover and temperature are large and relatively consistent across the assessed area. Several of the climatically derived indicators are close to, or exceed, the historically observed variation during the climatic reference period, in other words, values which during the

1961-1990 period were considered extreme are now within the expected norm. However, indicators related to precipitation and hydrology, which are both very important for wetland condition, show no change, contributing to uncertainty in the choice of category.

Justification for choice of assessment category: The assessment is based on 12 indicators with associated phenomena (PW01-PW09, PW14-PW16), 11 of which have high validity, implying certain links to anthropogenic drivers and a relatively good understanding of their role in wetland ecosystems. The last phenomenon (PW16) has lower validity due to a poor understanding of how the national statistics underlying the indicator (the area subject to subsidized trenching) relates to the condition of wetland ecosystems in general. All phenomena related to temperature and snow cover show high evidence of changes which are expected to be of some level ecosystem significance and are hence located in the 'substantial deviation' section of the assessment diagrams (**Figure 7.4.1**). Phenomena related to precipitation, both total precipitation (PW07) and growing season precipitation (PW08), and hydrology (PW14 soil water content and PW15 ground water condition) are exceptions to this and show no evidence of change relative to the climatic reference period. They are hence located in the 'no deviation' section of the diagram. For wetland ecosystems the phenomena related to precipitation and hydrology are of high relevance. The hydrological indicators are however so far based on a very general hydrological model, resulting in a poorer data coverage, then the climatic indicators. For this reason, we place somewhat less emphasis on the hydrological phenomena in the overall assessment. The observed changes in temperature and snow cover are similar to those observed in the other ecosystems and in part substantial.

Uncertainties related to the choice of assessment category: There is some uncertainty related to the choice of category. The data coverage of the climatically derived indicators (temperature and precipitation) is assessed as 'very good' although the coarse resolution of gridded climate data does not permit the capture of small-scale contrast/gradients in the rates of change. For the hydrological indicators the data coverage is considered 'intermediate', due to the very general nature of the model these data are generated from. Both spatial coarseness, and the generality of the underlying models, means that coarse gridded data (whether on climate, hydrology or land cover) can be a poor representation of site conditions, especially for ecosystems which tend to occur in fragments, such as wetland which exists in a mosaic in between the spatially more dominating forest and alpine ecosystems. The indicator coverage of the ecosystem characteristic is considered 'partially adequate' despite a large set of indicators. This is due to an insufficient representation of seasonal and annual changes in wetland hydrology on a local scale, which would permit closer causal links to be made between abiotic conditions and biotic ecosystem characteristics. Further, albedo, which represents the reflective qualities of the surface in late winter/spring, in another important indicator not included in this pilot assessment, which would allow closer causal links between land surface changes (woody encroachment), abiotic conditions (hydrology and snow cover) and regional climate feedbacks to be established.

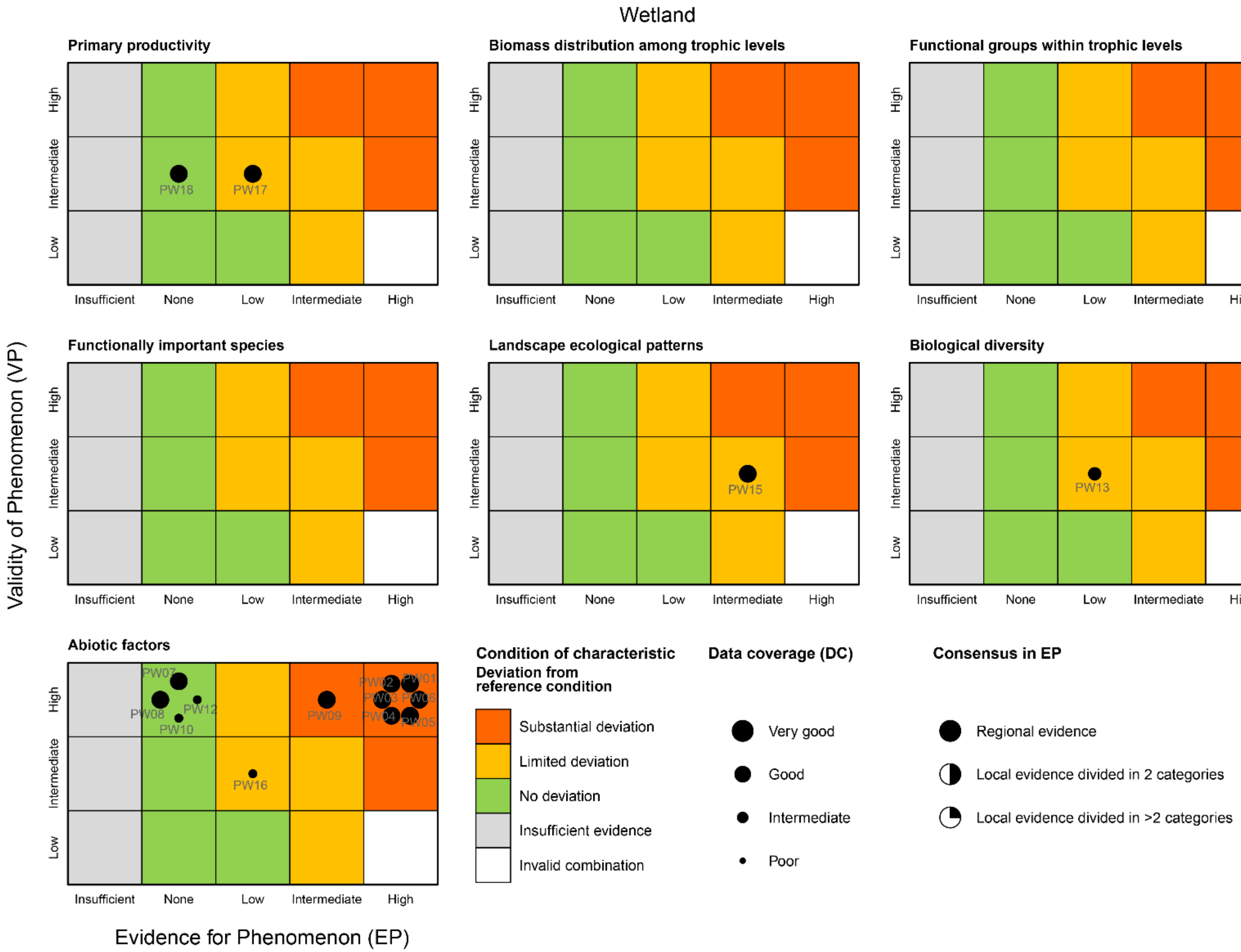


Figure 7.4.1. *The PAEC assessment diagram for wetland ecosystems. The diagram provides an overview of all phenomena for all ecosystem characteristics and their placement along the validity (VP) and Evidence (EP) axis and are intended as an aid for the panel when making their assessment. Each dot represents the assessment of a phenomenon with ID (from* ***Table 5.1****). The size of the dot represents data coverage (from* ***Table 7.4.1****).*

7.4.3.2 Assessment of the condition of the ecosystem as a whole

The assessment of this ecosystem is based on an indicator set which is considered inadequate for six of the seven ecosystem characteristics, and partially adequate for the last (*Abiotic factors*). Three ecosystem characteristics lack indicators altogether and hence cannot be assessed. Of the 16 indicators developed during this pilot, 12 are related to the abiotic environment in wetlands (temperature, precipitation, snow and hydrology), while the remaining address *Primary productivity* (two indicators), *Landscape ecological patterns* (one indicator) and *Biological diversity* (one indicator). This is not a sufficient basis for drawing a conclusion regarding the condition of the ecosystem as a whole.

Current state of knowledge of the reference condition

According to the normative description of the reference condition (Lyngstad et al. 2017), wetland in an intact condition is characterized by an intact hydrological regime which is minimally affected by anthropogenic drivers, including trenching, land conversion, and organic and inorganic pollution. The primary production should be dominated by peat mosses and moisture-tolerant or moisture-demanding vascular plants with a limited contribution from woody species. The balance between primary production and decomposition should permit the accumulation of a peat layer. The by far most important functional group is hence peat mosses. The current state of knowledge of the reference condition is thus good with respect to the abiotic conditions that wetland ecosystems are dependent upon, but much less developed when it comes to the types and strength of biotic interactions that can be expected to be in place in wetland ecosystems under the reference condition.

Main drivers of change

Wetland ecosystems are fundamentally contingent on an intact hydrological regime and a chemical regime (pH, conductivity, Ca, and the organic nutrients N, P, and K) which is not artificially enriched by fertilization, eutrophication, or water table manipulations. Both the hydrological and chemical regime is affected by all activities affecting the water table, especially trenching, industrial peat removal, tree planting, road construction, motorized transport outside of roads (ATVs), and traditional peat and hay harvesting. Much-used walking paths that cross wetlands can also affect the water table. Wetland ecosystems in Norway cover an extremely diverse set of wetland types, which are largely determined by local geomorphological and climatic conditions, and the extent of traditional use, primarily scything. Wetlands that were previously scythed maintain the floristic and morphological characteristics for a long time, often more than 100 years after cessation of traditional use, while the meter-deep pits caused by traditional peat harvesting remain for much longer (Bjerke and Tømmervik 2019). The potential impact of climate change will depend on local site conditions.

Observed deviations from the reference condition

The set of indicators describing the ecosystem characteristic *Abiotic factors* substantially deviates from the reference condition. All temperature-related indicators, as well as the snow cover indicator, show substantial deviation with expected long-term consequences for species-specific life conditions and ecosystem functions. Indicators related to hydrology and precipitation, however, show no consistent trends over the monitoring period, suggesting that, on a regional scale, hydrological conditions do not deviate from the reference condition. However, the assessment is limited by the lack of indicators which can be expected to capture changes in the hydrological regime on relevant local scales. A limited assessment could be done based on an inadequate set of indicators for three of the biotic ecosystem characteristics. These show for instance a greening trend, which is consistent with the observed change in climatic conditions, in addition to a decline in some wetland bird species. Generally, inadequate spatial delimitation and a lack of long term data to assess change, challenge the assessment of ecological condition for wetland ecosystems.

Figure 7.4.2. *A graphical summary of the assessment of ecological condition of wetland ecosystems. The outer ring shows the assessment of ecological condition at the level of the individual indicators with associated phenomena ID in square brackets. Indicators which the scientific panel have recommended for inclusion (**Table 7.7**), but which are not included in the pilot assessment, are shown in white to illustrate the perceived most important deficiencies in the current indicator set. The middle ring shows the assessment at the level of ecosystem characteristics, indicating deviation from the reference condition, and the innermost circle shows the quality of indicator coverage. Assessment based on inadequate indicator coverage is further highlighted by paler shading in ecological characteristics and their corresponding indicators.*

7.5 Open lowland

7.5.1 Assessment of the knowledge base

The overall assessment of the knowledge base for the open lowland ecosystem is presented in **Table 7.5.1**. The assessment is colour coded according to the predefined categories in PAEC (**Figure 7.1.1**). In accordance with the PAEC protocol, the knowledge base is assessed at three levels: *Data level*, *indicator level*, and *ecosystem characteristics level*. For an operational assessment, it is recommended in the PAEC protocol that each cell in **Tables 7.5.1** should link to an endnote describing why a given category was chosen, to enhance transparency (see Pedersen et al. 2021a, Table 7.1a, b). Such records are important, in particular when operational assessments are repeated after a certain time period. Since this is a pilot assessment, a written justification of each individual choice of category was left out.

Coastal heathland encroached with trees. Photo: Line Johansen, NIBIO, CC-BY 4.0. https://www.artsdatabanken.no/Pages/259194/Semi-naturlig.

Table 7.5.1. *Assessment of the knowledge base for the datasets, indicators and ecosystem characteristics for open lowland ecosystems. For the ecosystem characteristics* Biomass distribution among trophic levels*,* Functional groups within trophic levels *and* Landscape ecological patterns*, no indicators were available. Hence only indicator coverage was assessed (and as "inadequate").*

DATA									INDICATOR		ECOSYSTEM CHARACTERISTIC	
Data set ID	**Spatial representativity (SR)**					**Temporal representativity (TR)**			**Indicator [indicator ID]**	**Data coverage**	**Characteristic**	**Indicator coverage**
	SRd1	SRd2	SRd3	SRm	**SRtotal**	TRyr	TRse	**TRtotal**		**DC**		**IC**
D01	fulfilled	fulfilled	fulfilled	fulfilled	**3**	adeq.	adeq.	**3**	Maximum greenness [S10]	**very good**	Primary productivity	**inadequate**
D01	fulfilled	fulfilled	fulfilled	fulfilled	**3**	adeq.	adeq.	**3**	Onset of greening [S11]	**very good**		
											Biomass distribution among trophic levels	**inadequate**
											Functional groups within trophic levels	**inadequate**
D11	fulfilled	not fulf.	fulfilled	fulfilled	**3**	adeq.	adeq.	**3**	Domestic ungulate density [S13]	**very good**	Functionally important species	**inadequate**
D11	fulfilled	not fulf.	fulfilled	fulfilled	**3**	adeq.	adeq.	**3**	Wild ungulate density [S14]	**very good**		
D10	not fulf.	fulfilled	not fulf.	not fulf.	**1**	inadeq.	adeq.	**1**	Bumblebee abundance and species richness [S17]	**intermediate**		
											Landscape ecological patterns	**inadequate**
D10	not fulf.	fulfilled	not fulf.	not fulf.	**1**	inadeq.	adeq.	**1**	Butterfly abundance and diversity [S15]	**intermediate**	Biological diversity	**inadequate**
D13, D18	not fulf.	fulfilled	fulfilled	not fulf.	**2**	inadeq.	adeq.	**1**	Farmland bird communities [S16]	**good**		

Table 7.5.1. (cont.)

DATA									INDICATOR		ECOSYSTEM CHARACTERISTIC	
Data set ID	**Spatial representativity (SR)**					**Temporal representativity (TR)**			**Indicator [indicator ID]**	**Data coverage**	**Characteristic**	**Indicator coverage**
	SRd1	SRd2	SRd3	SRm	**SRtotal**	TRyr	TRse	**TRtotal**		**DC**		**IC**
D01	fulfilled	not fulf.	fulfilled	fulfilled	**3**	adeq.	adeq.	**3**	Annual mean tempera-ture [S01]	**very good**	Abiotic factors	**partially adequate**
D01	fulfilled	not fulf.	fulfilled	fulfilled	**3**	adeq.	adeq.	**3**	January mean tempera-ture [S02]	**very good**		
D01	fulfilled	not fulf.	fulfilled	fulfilled	**3**	adeq.	adeq.	**3**	July mean temperature [S03]	**very good**		
D01	fulfilled	not fulf.	fulfilled	fulfilled	**3**	adeq.	adeq.	**3**	Winter days above 0°C [S04]	**very good**		
D01	fulfilled	not fulf.	fulfilled	fulfilled	**3**	adeq.	adeq.	**3**	Degree days [S05]	**very good**		
D01	fulfilled	not fulf.	fulfilled	fulfilled	**3**	adeq.	adeq.	**3**	Growing degree days [S06]	**very good**		
D02	fulfilled	not fulf.	fulfilled	fulfilled	**3**	adeq.	adeq.	**3**	Annual precipitation [S07]	**very good**		
D02	fulfilled	not fulf.	fulfilled	fulfilled	**3**	adeq.	adeq.	**3**	Precipitation during growing season [S08]	**very good**		
D03	fulfilled	not fulf.	fulfilled	fulfilled	**3**	adeq.	adeq.	**3**	Snow cover duration [S09]	**very good**		

7.5.2 Assessment of the phenomena

The overall assessment of all phenomena underlying the assessment of the open lowland ecosystem is presented in **Table 7.5.2**. The assessment is colour coded according to the predefined categories in PAEC (**Figure 7.1.2**).

Butterfly communities constitute an important indicator under the ecosystem characteristic Biological diversity *in open lowland habitats, and are monitored as part of the national monitoring program for bumble bees and butterflies. Photo: Jutta Kapfer.*

Table 7.5.2. *Assessment of the validity (VP) and evidence (EP) for each phenomenon for the open lowland ecosystem. For definitions of categories, see* ***Figure 7.1.2.*** *The main anthropogenic drivers for each indicator are summarized in* ***Table 5.1.***

Ecosystem characteristic	Phenomenon [ID]	Indicator [ID]	VP	EP	Comments to EP
Primary productivity	Changes in maximum greenness [PS17]	Maximum greenness	intermediate	low	There is a general increasing trend in Maximum greenness, but the rate of change is low. However, it integrates spatially contrasting trends (greening/browning) which may be locally significant.
Primary productivity	Earlier onset of greening [PS18]	Onset of greening	intermediate	none	--
Functionally important species	Changes in density of domestic ungulates [PS12]	Domestic ungulate density	high	high	There is strong evidence for a reduction in domestic ungulates (cattle) in open lowland municipalities over the monitoring period. This reduction of domestic grazers is of ecosystem significance for seminatural habitats maintained by grazing.
Functionally important species	Changes in density of wild ungulates [PS13]	Wild ungulate density	high	intermediate	There is strong evidence for an increase in wild ungulates (red deer) in open lowland municipalities over the monitoring period. The ecosystem significance of this change should be viewed in concert with the corresponding change in domestic ungulates, and is so far assessed of limited, hence EP is intermediate.
Functionally important species	Low or decreasing bumblebee abundance or diversity [PS15]	Bumblebee abundance and species richness	high	none	There is no evidence of decreasing abundance or diversity. The evidence base does not permit an evaluation of the 2nd component of the phenomena (whether abundance and/or diversity can be considered low relative to the reference condition) thus contributing to uncertainty in the EP category
Biological diversity	Decreasing butterfly abundance or diversity [PS10]	Butterfly abundance and diversity	high	none	--

Table 7.5.2. *(cont.)*

Ecosystem characteristic	Phenomenon [ID]	Indicator [ID]	VP	EP	Comments to EP
Biological diversity	Decreasing abundances and/or species diversity within the community of farmland birds [PS11]	Farmland bird communities	high	intermediate	There is evidence of declines in farmland bird communities, consistent with trends observed at a national and international level. However, there are strong differences between individual species, and most species have an insufficient site coverage to be representative at a county level.
Abiotic factors	Increasing annual temperature [PS01]	Annual mean temperature	high	intermediate	There is strong evidence that annual mean temperatures are increasing (~0.5°C/decade relative to 1961-1990 mean). The ecosystem significance of this change is so far assessed as limited, hence EP is intermediate.
Abiotic factors	Increasing January temperature [PS02]	January mean temperature	high	intermediate	There is strong evidence that January mean temperatures are increasing (~1.1°C/decade relative to 1961-1990 mean). The ecosystem significance of this change is so far assessed as limited, hence EP is intermediate.
Abiotic factors	Increasing July temperature [PS03]	July mean temperature	high	intermediate	There is strong evidence that July mean temperatures are increasing (~1.1°C/decade relative to 1961-1990 mean). The ecosystem significance of this change is so far assessed as limited, hence EP is intermediate.
Abiotic factors	Increasing number of winter days above 0°C [PS04]	Winter days above 0°C	high	intermediate	The number of winter days > 0° is increasing (~1.2%/yr or ~8 days/decade). The ecosystem significance of this change is so far assessed as limited, hence EP is intermediate.
Abiotic factors	Increasing number of degree days [PS05]	Degree days	high	intermediate	There is strong evidence that the number of degree days is increasing (~0.4%/yr or ~7 days/decade). The ecosystem significance of this change is so far assessed as limited, hence EP is intermediate.

Table 7.5.2. *(cont.)*

Ecosystem characteristic	Phenomenon [ID]	Indicator [ID]	VP	EP	Comments to EP
Abiotic factors	Increasing growing degree day sum during the growing season [PS06]	Growing degree days	high	intermediate	There is strong evidence that the number of growing degree days is increasing (~70 GDD/decade). The ecosystem significance of this change is so far assessed as limited, hence EP= intermediate.
Abiotic factors	Changes in annual precipitation [PS07]	Annual precipitation	high	none	--
Abiotic factors	Changes in precipitation during the growing season [PS08]	Precipitation during growing season	high	none	--
Abiotic factors	Shorter season with snow cover [PS09]	Snow cover duration	high	intermediate	There is strong evidence that the snow cover duration is decreasing (~0.7%/yr or ~7 days/decade). The ecosystem significance of this change is so far assessed limited, hence EP is intermediate.

7.5.3 Assessment of ecosystem condition

Following the PAEC protocol the assessment of ecosystem condition for the open lowland ecosystem consists of the following sections: An assessment of each ecosystem characteristics based on all associated phenomena (Chapter 7.5.3.1), an assessment of the ecosystem as a whole (Chapter 7.5.3.2). We highlight that the ecological condition for ecosystem characteristics for which no indicators are present, cannot be assessed. In this pilot assessment, this is the case of three ecosystem characteristics for open lowland ecosystems.

7.5.3.1 Assessment of the condition of ecosystem characteristics

Open lowland – Primary productivity

Assessment category: Based on the set of indicators this ecosystem characteristic is assessed as having **limited deviation from the reference condition**. This means that the ecosystem characteristic can still be considered in an intact ecological condition. There is evidence of greening (e.g. a change towards a more productive state), but it is assessed as having an overall limited impact on ecological condition. There is substantial uncertainty regarding the choice of category.

Justification for choice of assessment category: The assessment is based on two indicators (*Maximum greenness* and *Onset of greening*) with two associated phenomena (PS17-PS18). In contrast to forest and alpine ecosystems, where these two phenomena are considered of high validity, for open lowland ecosystems they are considered of intermediate validity. This is due to a less good understanding of the implications of change in primary productivity (greening/ browning and onset of greening) for the condition of open lowland ecosystems, which has received little attention in the literature relative to alpine and forest ecosystems. Open lowland areas in Trøndelag show a weak greening trend overall, but with substantial spatial contrasts in trends. For this reason, the phenomenon is considered having a low level of evidence for change and is hence located in the 'limited deviation' section of the diagram (**Figure 7.5.1**). The indicator *Onset of greening* show no evidence of change over the two decades covered by the remote sensing data and is hence located in the 'no deviation' section of the diagram.

Uncertainties related to the choice of assessment category: There is substantial uncertainty regarding the choice of category. The two phenomena are located in two different sections within the diagram. Further, although the data coverage of both indicators is 'very good' they are both based on remote sensing data, which can be considered coarse resolution relative to the natural fragmentation of both natural and seminatural open habitats. It is hence likely that trend estimates for open lowland ecosystems are influenced by the mosaic of forest and alpine areas in which these areas exist. The indicator coverage for the ecosystem characteristic Primary productivity is assessed as 'inadequate', mostly due to a lack of indicators which capture changes in primary productivity and/or vegetation biomass in key vegetation strata linked to regional greening/browning (for instance herbs, grasses, shrubs and trees).

Open lowland – Biomass distribution among trophic levels

No indicators are available for this ecosystem characteristics due to a lack of data on relevant trophic relationships and/or food web dynamics in open lowland ecosystems. The condition of this ecosystem characteristics has therefore not been assessed.

Open lowland – Functional groups within trophic levels

No indicators are available for this ecosystem characteristics due to a lack of data on relevant functional groups in seminatural and open lowland ecosystems. The condition of this ecosystem characteristics has therefore not been assessed.

Open lowland – Functionally important species and biophysical structures

Assessment category: Based on the set of indicators this ecosystem characteristic is assessed as having **substantial deviation from the reference condition**. The changes in two of the indicators for functionally important species and biophysical structures are large, implying the open lowland ecosystem is not intact. There are substantial uncertainty related to the choice of category.

Justification for choice of assessment category: The assessment is based on three indicators with associated phenomena (PS12, PS13, PS15), and all were assessed as having high validity, but varying evidence. Two phenomena indicate substantial deviation from the reference condition, and these are related to the densities of domestic (cattle) and wild (red deer) ungulates, which were all found to strongly decrease and increase, respectively. Even though cattle and red deer are both species of large herbivores, this observed shift from domestic to wild herbivores is of ecosystem significance, since it is unlikely that red deer numbers can completely compensate for reduced cattle densities, because their diet preferences and ecological function is somewhat different. There was no evidence of low or decreasing abundance and diversity of bumblebees, however, this indicator was given less weight in the total assessment due to less good data coverage.

Uncertainties related to the choice of assessment category: There is substantial uncertainty related to the choice of category due to an unknown potential for ecological compensation between cattle and red deer abundance in maintaining ecological functions. There is also a clear understanding that pollinators are very important to ecosystem functioning, and therefore there is some uncertainty as to what emphasis to put on phenomenon PS15 related to bumblebee abundance. The data coverage of the indicators included is assessed as 'very good' for two ungulate related indicators, and 'intermediate' for the bumblebee. We nonetheless acknowledge the lack of information about the actual habitat use of ungulate species, as these data currently only exists at the municipality scale. The indicator coverage of the ecosystem characteristic is 'inadequate'. This is due partly to an absence of indicators related to vegetation, other grazers such as sheep, and insects other than bumblebees.

Open lowland – Landscape ecological patterns

No indicators are available for this ecosystem characteristics due to a lack of data on relevant landscape ecological patterns in open lowland ecosystems. The condition of this ecosystem characteristics has therefore not been assessed.

Open lowland – Biological diversity

Assessment category: Based on the set of indicators this ecosystem characteristic is assessed as having **limited deviation from the reference condition**. This means that the ecosystem characteristic can still be considered in an intact condition. There is substantial uncertainty related to the choice of category

Justification for choice of assessment category: The assessment is based on two indicators/phenomena – that both have high validity (VP). The butterfly indicator (S15, PS10) scores low with respect to EP as the abundance and species richness have more than doubled over the last decade - thus showing strong trends opposite of the formulated phenomenon although the butterfly species richness is low even in years with the highest richness. The composite index for the bird community indicator shows no consistent trend. However, as some of the individual species (Lapwing and Curlew) exhibit declines, the EP for this indicator is assessed as 'intermediate'. This assessment is consistent with the well documented European- scale negative trend in farmland birds.

Uncertainties related to the choice of assessment category: There is substantial uncertainty related to the choice of category due to an inadequate indicator coverage, with indicators within major biological taxa (e.g. plants, fungi, other invertebrates than butterflies) lacking. Further, the data coverage for the butterfly indicator is intermediate, and the assessment of bird community indicator is based on a few declining species.

Open lowland – Abiotic factors
Assessment category: Based on the set of indicators this ecosystem characteristic is assessed as having **substantial deviation from the reference condition**. The changes in abiotic indicators related to snow cover and temperature are large and relatively consistent across the assessed area. Several of the climatically derived indicators are close to, or exceed, the historically observed variation during the climatic reference period, in other words, values which during the 1961-1990 period were considered extreme are now within the expected norm. There is no major uncertainty related to the choice of category.

Justification for choice of assessment category: The assessment is based on nine indicators with associated phenomena (PS01-PS09), which all have high validity, implying certain links to anthropogenic drivers and a relatively good understanding of their role in the ecosystem. All phenomena related to temperature and snow cover show high evidence of changes which are expected to be of ecosystem significance and are hence located in the 'substantial deviation' section of the assessment diagram (**Figure 7.5.1**). Phenomena related to precipitation, both total precipitation (PS07) and growing season precipitation (PS08), are exceptions to this and show no evidence of change relative to the climatic reference period. They are hence located in the 'no deviation' section of the diagram. However, for both seminatural and naturally open systems the two phenomena related to precipitation are considered of somewhat less relevance than the phenomena related to snow cover and changes in seasonal temperatures and more emphasis is hence placed on the latter in the assessment.

The observed changes in temperature and snow cover are in part substantial. For instance, annual mean temperatures (PS01) have increased by 1-2°C relative to the climatic reference period. Growing season temperatures (PS03, PS06) have increased markedly and exceed the range of variation observed during the climatic reference period. The length of the snow-covered season (PS09) has decreased similarly and is on average around one month shorter now than during 1961-1990.

Uncertainties related to the choice of assessment category: There is no major uncertainty related to the choice of category. The data coverage of the indicators included is assessed as 'very good' although the coarse resolution of gridded climate data does not permit the capture of small-scale contrast/gradients in the rates of change. Both spatial coarseness, and the generality of the underlying models, means that coarse gridded data (whether on climate, hydrology, or land cover) can be a poor representation of site conditions. This is especially so for ecosystems which tend to occur in fragments, such as seminatural and open habitats which exist in a mosaic in between arable land, infrastructure and forests. The indicator coverage of the ecosystem characteristic is considered 'partially adequate' despite a large set of indicators. This is due to an absence of indicators that characterize nutrient content in soils (N and P-levels) indicative of nutrient status and fertilization from local and regional sources. Further, albedo, which represents the reflective qualities of the surface in late winter/spring, is another important indicator not included in this pilot assessment, which would allow closer causal links between land surface changes (shrub encroachment in open lowland habitats), abiotic conditions (snow cover, snow melt) and regional climate feedbacks to be established.

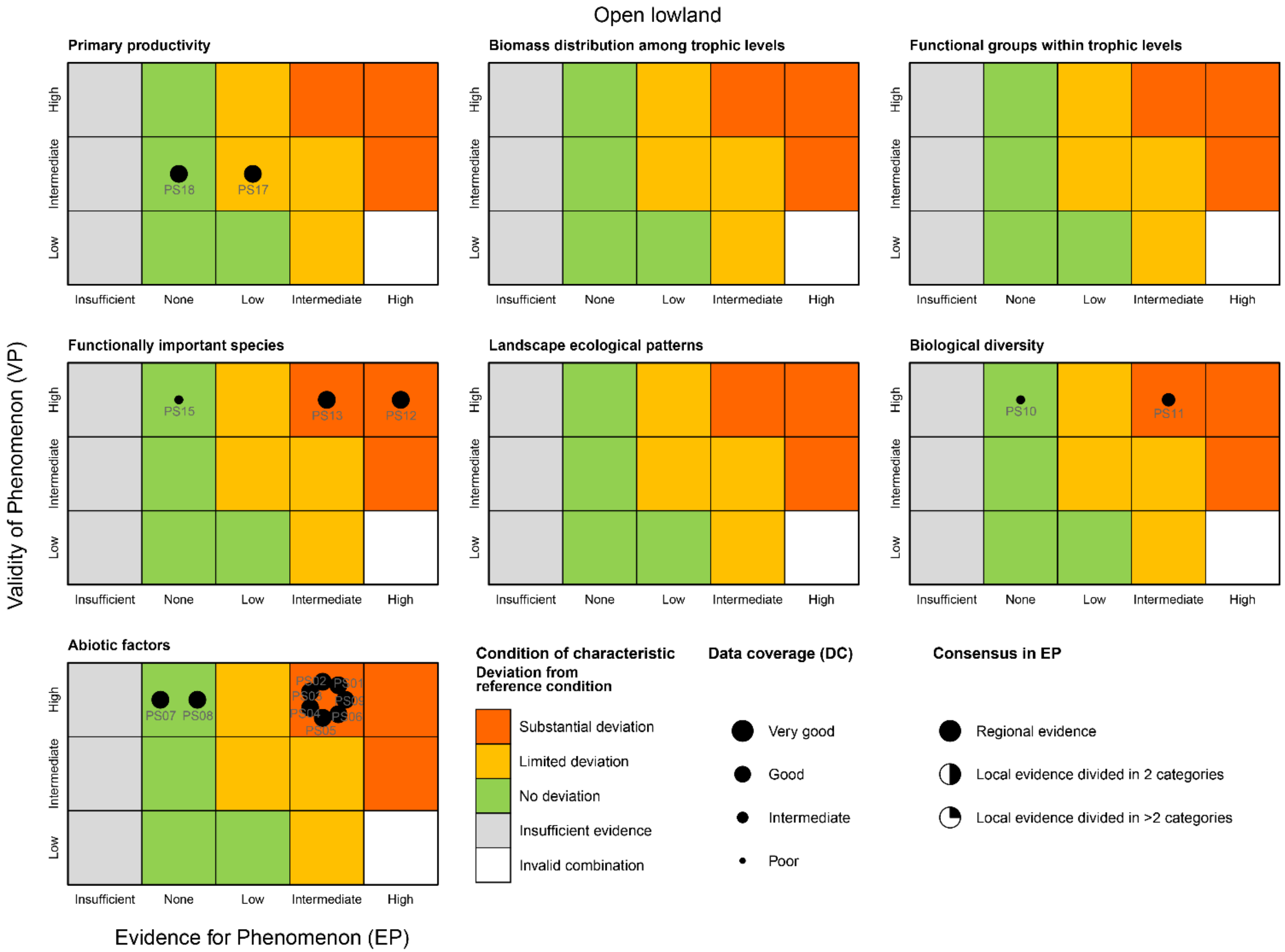


Figure 7.5.1. *The PAEC assessment diagram for open lowland ecosystems. The diagram provides an overview of all phenomena for all ecosystem characteristics and their placement along the validity (VP) and Evidence (EP) axis and are intended as an aid for the panel when making their assessment. Each dot represents the assessment of a phenomenon with ID (from* ***Table 5.1****). The size of the dot represents data coverage (from* ***Table 7.5.1****).*

7.5.3.2 Assessment of the condition of the ecosystem as a whole

The assessment of this ecosystem is based on an indicator set which is considered inadequate for six of the seven ecosystem characteristics, and partially adequate for the last (*Abiotic factors*). Three ecosystem characteristics are missing indicators altogether and hence cannot be assessed. Of the 16 indicators developed during this pilot, nine are related to the abiotic environment in open lowland (temperature, precipitation, and snow), while the remaining address *Primary productivity* (two indicators), *Functional groups* (three indicators) and *Biological diversity* (two indicators). <u>This is not sufficient basis for a conclusion regarding the condition of the ecosystem as a whole.</u>

Current state of knowledge of the reference condition

Open lowland consists for the most part of semi-natural areas which are defined and maintained by anthropogenic influence through mowing, burning and grazing by domestic herbivores (Sickel et al. 2017). The ecosystem covers a wide range of types from semi-natural meadows to coastal and boreal heathland which differ with respect to the type and intensity of anthropogenic activities required for their maintenance. The primary production should be determined by local edaphic and climatic conditions and be dominated by low growing grasses, and light demanding or light tolerant herbs with contributions from dwarf shrubs in boreal and semi-natural heathlands. The cover of tall shrubs and trees should be low. Semi-natural meadows are characterized by high vascular plant species diversity especially in on lime rich substrates and are the main habitat for many pollinating insects such as bumblebees, wild bees, hoverflies and butterflies. The current state of knowledge of the reference condition is thus good with respect to the principal anthropogenic activities which semi-natural ecosystems are dependent on. Knowledge regarding the level of historical use is however, fragmented and often incomplete, and the state of knowledge is much less developed when it comes to the types and strength of biotic interactions (e.g. plant-pollinators, plant-soil interactions including decomposers), which can be expected to be in place under the reference condition in the different ecosystem subtypes such as semi-natural grassland and heathland.

Main drivers of change

Semi-natural grasslands and heathlands are by definition human induced/modified ecosystems, and dependent on some type of continued human disturbance to maintain a an intact ecological condition. The main drivers are associated with changes in different types of land use as described by Sickel et al. (2017) and includes abandonment (and subsequent forest succession) and intensification (e.g. use of alternative means like fertilization, frequent ploughing to increase plant productivity). Low to moderate intensified used semi-natural habitats, considered to be the reference condition for this ecosystem are thus expected to be in decrease. However, the complexity of former and current land use as well as parent ecological conditions (e.g. humidity, lime, soil pH, nutrients, climate) also in interaction with climate change challenges our understanding of the driver and associated indicators in the open lowland.

Observed deviations from the reference condition

The set of indicators describing the ecosystem characteristic *Abiotic factors* substantially deviates from the reference condition. All temperature-related indicators, as well as the snow cover indicator, show substantial deviation with expected long-term consequences for species-specific life conditions and ecosystem functions. Indicators related to precipitation, however, show no consistent trends over the monitoring period, suggesting that, on a regional scale, precipitation patterns do not deviate from the reference condition. However, the assessment is strongly limited by the lack of indicators which can be expected to capture changes in abiotic conditions and land use changes on relevant local scales. A limited assessment could be done based on an inadequate set of indicators for three of the biotic ecosystem characteristics. These show for instance a greening trend, which is consistent with the observed change in climatic conditions, in addition to a decline in some farmland bird species. Among functionally important species, a shift from domestic to wild ungulates which is considered of high ecosystem significance was observed.

Generally, inadequate spatial delimitation and a lack of long-term data to assess change, challenge the assessment of ecological condition for open lowland ecosystems.

Figure 7.5.2. *A graphical summary of the assessment of ecological condition of open lowland ecosystems. The outer ring shows the assessment of ecological condition at the level of the individual indicators with associated phenomena ID in square brackets. Indicators which the scientific panel have recommended for inclusion (**Table 7.7**), but which are not included in the pilot assessment, are shown in white to illustrate the perceived most important deficiencies in the current indicator set. The middle ring shows the assessment at the level of ecosystem characteristics, indicating deviation from the reference condition, and the innermost circle shows the quality of indicator coverage. Assessment based on inadequate indicator coverage is further highlighted by paler shading in ecological characteristics and their corresponding indicators.*

7.6 Future trajectories for ecosystem condition

Chapter 7.6 Future trajectories for ecosystem condition, is not relevant for a methodological pilot assessment based on a limited set of indicators and is left out.

7.7 Recommendations for monitoring and research

The current pilot assessment of the ecosystem condition of four ecosystems within Trøndelag county is based on a set of selected indicators derived from a wide range of sources (**Table 3.1**). These include data sources based on national monitoring of climate, forest, large carnivore, large wild and domestic herbivores, bird communities in agricultural areas (3Q), birds in general (TOV-E), bark beetles, and areas without major infrastructure. Some indicators are based on regional and local monitoring of functionally important species, such as pollinators (bumble bees, butterflies), and rodents, or species subject to conservation measures such as the Arctic fox.

Several limitations in terms of spatial and temporal representativity, data coverage, and the link to the ecosystem characteristic for each indicator have an impact on how the validity and the evidence of the phenomenon could be understood. This reflects the fact that most monitoring is not developed to specifically assess the ecosystem condition in the four target ecosystems, but rather natural resources (forest, game and livestock) and their associated environmental drivers (climate, large carnivores, bark beetles) often with a narrow taxonomic focus. The *System for assessment of ecological condition* is so far aimed at providing assessments for a geographical scale corresponding to a county or region level (Nybø and Evju 2017). This pilot has made clear that several national monitoring programs have insufficient representativity to provide estimates of change on a county level, because they, at establishment, were intended to provide national-level estimates. This is true for instance for bird monitoring in TOV-E (Kålås and Husby 2002) and 3Q (Pedersen, 2020) which have too low site coverage to provide reliable estimates of change for the majority of bird species on a county level. If assessments of ecological condition are intended to operate on a county level, this would require an intensification of several of these running monitoring programs. Further, we especially highlight the scarcity of long-term ecosystem-based monitoring programs for all four ecosystems. Although we utilize data from national monitoring programs, none of these are truly ecosystem-based: i.e. designed to evaluate ecosystem conditions across functional groups and trophic levels. However, more ecosystem-based indicators could be developed within established monitoring schemes. An example is the Norwegian Forest Inventory (NFI), which during the more recent cycles have increasingly included information relevant for assessing ecosystem conditions in forest.

Another basic challenge is related to the inadequate spatial delineation of ecosystem extent for all four ecosystems: i.e. the ecosystem identity of a spatial explicit indicator is uncertain in many cases, due to lack of biotic or abiotic information, uncertain information in land use, and/or lack of land cover maps. Small and naturally fragmented habitats, such as wetlands and semi-natural habitats within open lowlands, are especially challenging to delineate which introduce a considerable, but remediable, uncertainty in the assessments of these ecosystems. This uncertainty regarding the spatial delineation places severe limitations on the use of otherwise cost-efficient data sources such as gridded environmental data, and series of aerial and satellite imagery (see also Framstad et al. 2021b). It also makes it challenging to assess the representativity of data from national monitoring programs relative to each ecosystem.

The assessment of land use as both a potentially positive and negative driver for ecosystem condition is a general challenge recognised by the expert group on ecosystem condition (Nybø and Evju 2017). Land use affecting biotic (e.g. species composition) and abiotic (e.g. hydrology) is a long-term legacy in all target ecosystems which facilitates semi-natural wetlands, forest, and alpine ecosystems in addition to semi-natural open grassland. However, it is not always clear whether a change in this legacy is, or can be assessed as, an either positive or negative trend for ecosystem condition.

The mosaic-like occurrence of naturally fragmented ecosystems such as wetlands and open lowland, render these highly challenging to delineate spatially. Photo: Ivar Herfindal.

During the assessment, the panel identified focal components of the ecosystems not covered by the current set of indicators. Indeed, none of the target ecosystems had indicator sets that scored 'adequate' for any of the ecosystem characteristics. In most cases, the indicator coverage was found to be 'inadequate' so that the condition of the ecosystem characteristics and/or the ecosystem as a whole could not be reliably assessed. There are three general shortcomings. First, there is a lack of data on vegetation (field layer plant biomass/productivity, and plant diversity) across all ecosystems. Monitoring programs (ANO, ASO) are in the establishment phase, and constitute a data source for the future, given that they acquire sufficient data coverage for the main ecosystems at the spatial scale targeted in *System for assessment of ecological condition* (region/county). There is, however, a potential for better utilization of data from short to medium term research projects through developing common standards/protocols (Austrheim et al. 2015a, Barrio et al. 2021) and improving data infrastructure and incentives for data sharing of both new and historical data (e.g. Living Norway, GBIF). This could improve opportunities for evaluating indicators relevant for understanding several of the ecosystems' characteristics (especially *Primary productivity*, *Biomass distribution among trophic levels, Biological diversity*). Second, decomposers are not included in any ecosystem (see also recommendations in Pedersen et al. 2021a). Decomposition is a central function in boreal and Arctic ecosystems for instance as a determinant of ecosystem carbon budgets (Xu and Zhang 2016). Fungi, are in addition functionally important species, which also contribute significantly to biodiversity, but we are not aware of any systematic monitoring of fungi in any of the four target ecosystems. Third, abiotic conditions are mainly described in terms of climatic variables (temperature, precipitation, snow cover) and derived variables (degree days etc.). No temporal information is available on soil/ecosystem carbon and key nutrients (e.g. N, P), and wetland hydrology is currently addressed based on coarse modelled data with unknown representativity for local wetland conditions. We suggest including a systematic monitoring across ecosystems especially on C/N relationships, but also C/P. These relationships are expected to vary due to both land use and climate and have important impacts on ecosystem conditions as well as the potential for climate mitigation (Steffen et al. 2015). Land surface albedo is another climate-related abiotic factor for which indicators could be developed across all ecosystems.

Table 7.7 provides recommendations for development and/or new data acquisition that can remedy some of the shortcomings. Overall, the number of indicators for assessing ecosystem conditions are more limited for wetlands and open lowland ecosystems as compared to the forest and alpine ecosystems. A large proportion of the suggested indicators focus on functionally important species and groups of species. First, pollinators include a broad range of invertebrates especially important for open lowland and calcareous/minerotrophic wetlands. This pilot includes data on bumble bees, and butterflies associated with semi-natural grassland, which is one of several subsystems within open lowland. Species-specific knowledge from systems including other insects, e.g. wild bees and hoverflies (especially open lowland, forest), is needed to validate the impact of land use and climate change on this functionally important group. Other invertebrates associated with dead wood and subjected to land use change in forest ecosystems (e.g. decomposers and predators) are functionally important, but also contribute significantly to biodiversity (Åström et al. 2019). Second, the understanding of several herbivore and carnivore vertebrates, which are functionally important species within trophic levels in alpine and forest ecosystems is hampered by lack of data. The dynamics of the plant-rodent-predator food web is a cornerstone for ecosystem condition in particular in alpine ecosystems, but also in boreal forest ecosystems (Boonstra et al. 2016), and is virtually missing from the assessment. Third, in wetlands, peatmoss is a functionally important species affected by both land use and climate change and could be monitored both with regard to ecosystem primary productivity and as an important biophysical structure (peat depth).

Peat mosses (left Sphagnum lindbergii*), and crowberry (right,* Empetrum nigrum*) are functionally important species in mires (peatmoss) and forests and alpine ecosystems (crowberry) and on the list of indicators recommended for development. Photo: Jutta Kapfer (left) and Jane Uhd Jepsen (right).*

This assessment also demonstrates needs for research and development in order to strengthen the knowledge base of future assessments, including priorities. It is particularly important to address how the understanding of the effects of drivers on the indicators can be improved. This in order to increase the validity of phenomena and hence the degree of confidence in the assessments. A particular challenge is the large variation of certain indicators in space and time, as also found in the PAEC for arctic tundra (Pedersen et al. 2021a). For careful consideration of the spatial and temporal resolution and data coverage of the target indicator, monitoring is needed. The PAEC protocol provides a structured rule set for this. This report shows that a lack of temporal and/or spatial correspondence between data from disparate national monitoring programs challenges our ability to assess and interpret ecosystem condition. In addition, there are challenges related to disentangling the effects of multiple drivers. An example is the interacting effects of climate on the one hand and herbivory and land use on the other hand on tree growth during the succession of post-harvested forest (Vuorinen 2020). A recent report from the scientific panel behind the PAEC assessment of Arctic tundra (Pedersen et al. 2021b), provides a detailed discussion of how attribution of driver-response relationships can be made within the framework of a PAEC assessment. This requires attention to study designs that include several drivers (e.g. climate and land use), and to more formal analyses of ecological responses using quantitative models, to understand the relative importance of multiple drivers, and through that improve the validity of a phenomenon. Strategies for including indicators on several ecosystem characteristics within common study designs, will also provide synergies and facilitate a better understanding of interactions critical for ecosystem condition.

Table 7.7. *Indicators which are not included in the pilot assessment, but recommended for development and inclusion in order to improve the indicator coverage to a level that would be considered at least partially adequate for all ecosystem characteristics and all four ecosystems. The table briefly describes the role of each indicator for the ecosystem characteristics to which the indicator is associated, and whether the indicator primarily requires development based on existing data sources (can be considered 'near operational'), or whether it requires new or improved data acquisition/monitoring. For indicators which primarily rely on development, the last column also indicates whether it is likely that the indicator can be provided on a country wide scale (e.g. can be based on data sources which are available for the whole of Norway). For indicators which rely on new data acquisition, this has not been indicated, as it will depend on the scale of new data acquisition.*

Ecosystem	Ecosystem characteristics	Indicator	Role	Requirements
Forest	Primary productivity	Field layer plant biomass	A field-based indicator on plant biomass should serve to document changes in plant biomass and associated drivers. It can further nuance and help explain patterns of change in remote sensing-based indicators of primary productivity, for instance with respect to forest pest outbreaks. Satellite-based (e.g. EVI, NDVI) estimates of vegetation productivity/greening/browning are influenced by a myriad of factors which may be unrelated to actual trends in vegetation productivity including changes in wetness/water/snow coverage (Li et al. 2021, Huemmrich et al. 2021), and inclusion of additional field-based plant indicators should be a priority. Point frequency analyses, which are applied in a few monitoring studies, can be directly translated into biomass, and is the recommended non-destructive field-based method for monitoring of biomass change. TOV targets boreal birch forest and spruce forest at selected sites, but does not, with the current design and extent have spatial representativity on a national or county level. The newly established ANO can be a data source for the future, given that it acquires sufficient representativity for forest habitats, and includes direct or indirect (e.g. point frequency) proxies of plant biomass. But this indicator (and other plant indicators suggested below) will require a certain amount of new data acquisition/monitoring. It should be a priority to arrive at a level of data acquisition which can provide data both for this indicator (plant biomass), and other forest plant indicators suggested below (key functional groups, plant diversity, key functionally important species). It should be required that such plant indicators be stratified according to forest types as well as management intensity.	Data acquisition and development
Forest	Biomass distribution among trophic levels	Plant biomass versus rodents	The plant-rodent-small carnivores is a dominant food chain in boreal forest ecosystems (Boonstra et al. 2016). To permit interpretation of the indicators it is recommended that it is addressed separately in two indicators: one on plant-rodents and one on rodents-small carnivores. This indicator will require new data acquisition in key forest types of both trophic levels. New, non-invasive, camera-based technology for rodent monitoring has been implemented for Arctic tundra and is also now adopted for forest/alpine habitats as a replacement of the snap-trapping based indices that have been employed in TOV.	Data acquisition and development

Table 7.7. *(cont.)*

Ecosystem	Ecosystem characteristics	Indicator	Role	Requirements
Forest	Biomass distribution among trophic levels	Rodents versus carnivorous vertebrates	The plant-rodent-small carnivores is a dominant food chain in boreal forest ecosystems (Boonstra et al. 2016).To permit interpretation of the indicators, it is recommended that it is addressed separately in two indicators: one on plant-rodents and one on rodents-small carnivores. These indicators will require new data acquisition in key forest types of both trophic levels. New, non-invasive, camera-based technology for rodent monitoring has been implemented for Arctic tundra and is also now adopted for forest/alpine habitats as a replacement of the snap-trapping based indices that have been employed in TOV. The camera traps also capture mustelids which are specialist rodent predators.	Data acquisition and development
Forest	Functional groups within trophic levels	Carnivorous vertebrates	The current policy of regulating large carnivores in Norway can be expected to induce profound shifts in the dominance of different guild within the community of vertebrate carnivores in forest ecosystems (e.g. Boonstra et al. 2016). In particular, meso-predators with broad diets (red fox and pine marten) may be expected to increase relative to more specialized smaller (small mustelids) and larger predators (lynx and wolves). Wildlife cameras is a cost-efficient method for monitoring such shifts in dominance among functional groups of carnivorous vertebrates (Hamel et al. 2013b).	Data acquisition and development
Forest	Functional groups within trophic levels	Plant growth forms: Field layer	The functional composition of the plant community is influenced by anthropogenic drivers and is of great significance for herbivore populations, nutrient cycling, and primary production. Currently, the assessment includes only functional groups related to the tree layer. TOV targets field layer vegetation in boreal birch forest and spruce forest at selected sites, but does not, with the current design and extent, have spatial representativity on a national or county level. The newly established ANO is a data source for the future, given that it acquires sufficient representativity for forest habitats. But this indicator will require a certain amount of new data acquisition/monitoring. It should be required that such plant indicators be stratified according to forest types as well as management intensity.	Data acquisition and development
Forest	Functional groups within trophic levels	Decomposers	Highly species-rich decomposer communities in dead wood and soil have important roles in the regulation of the ecosystem carbon and nutrient cycles, and they provide habitat, shelter and food for a range of other species. Decomposer communities on dead wood have been much affected by forestry and the associated decline in the amount of dead wood and its spatiotemporal connectivity, resulting in a large proportion of the species becoming red-listed. Decomposers in soils are also affected by forestry. Climate change is expected to change decomposer communities. Decomposers are currently not included in any monitoring program. Appropriate methodology for systematic survey and monitoring of decomposer communities exists, and includes optimally a combination of modern eDNA-based survey and a traditional survey of morphological structures such as fruiting bodies of fungi (Olsen et al. 2021).	Data acquisition and development

Table 7.7. *(cont.)*

Ecosystem	Ecosystem characteristics	Indicator	Role	Requirements
Forest	Functionally important species	Woodpeckers	Woodpeckers are ecosystem engineers because they create nesting and resting sites for many other bird species and some species of small mammals. Due to their low population densities TOV-E has presently too low site coverage for robust assessments of the state of woodpecker populations at the county scale	Data acquisition and development
Forest	Functionally important species	Crowberry	Crowberry is an abundant dominant plant species in boreal forest, representative mainly of nutrient-poor, dry forest types. Crowberry has substantial chemical properties which reduce the primary and secondary productivity and species diversity of the plant community, and is therefore a functionally important species. It is susceptible to fires, so suppression of forest fires is a likely driver of increased crowberry abundance (Nilsson and Wardle 2005). Increased dominance of crowberry also in more nutrient rich habitats may result from increased warming (e.g. drought). Some historical and resurvey data exists which may be explored, and the newly established ANO is a data source for the future given that it acquires sufficient representativity for forest habitats. But this indicator will require a certain amount of new data acquisition/monitoring.	Data acquisition and development
Forest	Landscape ecological patterns	Forest fragmentation and connectivity	Loss of forest area to infrastructure development results in increased fragmentation and loss of connectivity beyond the loss of total areas described by the indicator "Areas free of major infrastructure". Development of an indicator which captures changes in such landscape ecological metrics is recommended both for forest areas in general and for key strata within forest (e.g. subtypes such as productive versus non-productive, managed versus unmanaged land).	Development (Country wide scale)
Forest	Landscape ecological patterns	Forest vertical structure	The vertical complexity (layering) of forest influences the diversity of habitats and hence the diversity of a wide range of taxa. An indicator of forest vertical structure based on NFI should be explored.	Development (Country wide scale)
Forest	Biological diversity	Plant species diversity	The diversity of the forest plant community is influenced by anthropogenic drivers and is an important biodiversity indicator for forest ecosystems, in particular focused on the loss of diversity of native species which are sensitive to silvicultural practices. TOV targets field layer vegetation in boreal birch forest and spruce forest at selected sites, but does not, with the current design and extent, have spatial representativity on a national or county level. The newly established ANO is a data source for the future given that it acquires sufficient representativity for forest habitats. But this indicator will require a certain amount of new data acquisition/monitoring. It should be required that such plant indicators be stratified according to forest types as well as management intensity.	Data acquisition and development

Table 7.7. (cont.)

Ecosystem	Ecosystem characteristics	Indicator	Role	Requirements
Forest	Biological diversity	Insect diversity and abundance	Terrestrial monitoring of insects is rare and typically suffers from a substantial taxonomic bias towards butterflies and bumble bees. The new insect monitoring program is currently limited to a small part of the country and to agricultural/semi-natural and forest habitats (Åström et al 2021). It is a data source for the future, given that it achieves sufficient representativity for forest habitats.	Data acquisition and development
Forest	Biological diversity	Fungal diversity and abundance	Fungi have important functions in the forest ecosystem as symbionts, decomposers and pathogens. The occurrence, abundance and distribution of fungal species are much influenced by land use, climate and pollution. The Norwegian funga is known relatively well in terms taxonomy and ecology, and established methodologies exist for their survey. Best detection is achieved with a combination of modern eDNA-based and traditional fruiting body-based surveys and monitoring (Olsen et al. 2021). The former method detects a larger part of the community, but performs worse than the fruiting body survey method in detecting rare species, often species of conservation concern. Fungi are currently not included in any Norwegian monitoring program.	Data acquisition and development
Forest	Biological diversity	Lichen diversity and abundance	Lichens form a very species rich group of organisms in the forest ecosystem. Many species of lichens are sensitive to changes in light and moisture conditions, and therefore easily influenced by environmental changes, such as those caused by forestry, climate change and pollution. The lichens of Norway are relatively well known in terms taxonomy and ecology, and established methodologies exist for their survey. Expert-dependent survey of morphological structures, thalli, is the dominating survey method, but new technologies have made it possible to survey and monitor lichens using eDNA-based methodologies (Olsen et al. 2021). Tree-living epiphytic lichens are included in the TOV monitoring program.	Data acquisition and development
Forest	Abiotic factors	Carbon/Nitrogen (C/N), Carbon/Phosphorus (C/P)	C/N and C/P denotes the availability of key nutrients important for primary productivity and biodiversity. These relationships are expected to vary due to both land use and climate and have important impacts on ecosystem conditions as well as the potential for climate mitigation	Data acquisition and development
Forest	Abiotic factors	Land surface albedo	Albedo is governed by snow cover and characteristics of the vegetation cover, especially the distribution and composition of the tree layer (coniferous versus deciduous), and has an important regulating function in the climate system. Warming induced reductions in the duration and extent of spring snow cover lowers albedo because snow-free land reflects much less solar radiation than snow. Similarly, a production forest (homogenous composition, coniferous dominance) reflects less solar radiation than a more heterogenous forest with a wider species and structural diversity. It is recommended to include a regional indicator on albedo, based on remote sensing data series.	Development (Country wide scale)

Table 7.7. *(cont.)*

Ecosystem	Ecosystem characteristics	Indicator	Role	Requirements
Alpine	Primary productivity	Field layer plant biomass	A field-based indicator on plant biomass should serve to document changes in plant biomass and associated drivers. It can further nuance and help explain patterns of change in remote sensing-based indicators of primary productivity, for instance with respect to an expected shrubification of alpine habitats. Satellite-based (e.g. EVI, NDVI) estimates of vegetation productivity/greening/browning are influenced by a myriad of factors which may be unrelated to actual trends in vegetation productivity including changes in wetness/water/snow coverage (Li et al. 2021, Huemmrich et al. 2021), and inclusion of additional field-based plant indicators should be a priority. Point frequency analyses, which are applied in a few monitoring studies, can be directly translated into biomass, and is the recommended non-destructive field-based method for monitoring of biomass change. Some historical and resurvey data exists which may be explored, and the newly established ANO can a data source for the future, given that it acquires sufficient representativity for alpine habitats and includes direct or indirect (e.g. point frequency)proxies of plant biomass. But this indicator (and other plant indicators suggested below) will require a certain amount of new data acquisition/monitoring. It should be a priority to arrive at a level of data acquisition which can provide data both for this indicator (plant biomass), and other alpine plant indicators suggested below (key functional groups, plant diversity, key functionally important species). It should be required that such plant indicators be stratified according to important alpine habitats such as snow beds, heaths and meadows as well as altitudinal bio-climatic subzones.	Data acquisition and development
Alpine	Biomass distribution among trophic levels	Plant biomass versus ungulates	The current indicator coverage of *Biomass distribution among trophic levels* covers the trophic relationship between large herbivores and large carnivores. The relationship between the plant level and large herbivores is missing and should be included. The plant level will require a certain amount of new data acquisition/monitoring (see *Field layer plant biomass*).	Data acquisition and development
Alpine	Biomass distribution among trophic levels	Plant biomass versus rodents	The plant-rodent-small carnivores is a dominant food chain in alpine ecosystems. To permit interpretation of the indicators, it is recommended that it is addressed separately in two indicators: one on plant-rodents and one on rodents-small carnivores. This indicator will require new data acquisition in key vegetation types (heath, meadow, snow beds) and bioclimatic alpine sub-zones (low - and middle alpine) of both trophic levels. New, non-invasive, camera-based technology for rodent monitoring has been implemented for Arctic tundra and is also now adopted for alpine habitats as a replacement for the snap-trapping based indices that have been employed in TOV.	Data acquisition and development

Table 7.7. *(cont.)*

Ecosystem	Ecosystem characteristics	Indicator	Role	Requirements
Alpine	Biomass distribution among trophic levels	Rodents versus carnivorous vertebrates	The plant-rodent-small carnivores is a dominant food chain in alpine ecosystems. To permit interpretation of the indicators it is recommended that it is addressed separately in two indicators: one on plant-rodents and one on rodents-small carnivores. This indicator will require new data acquisition in key vegetation types (heath, meadow, snow beds) and bioclimatic alpine sub-zones (low - and middle alpine) of both trophic levels. New, non-invasive, camera-based technology for rodent monitoring has been implemented for Arctic tundra and is also now adopted for alpine habitats as a replacement for the snap-trapping based indices that have been employed in TOV. The camera traps also capture mustelids which are specialist rodent predators.	Data acquisition and development
Alpine	Functional groups within trophic levels	Plant growth forms	The functional composition of the plant community, for instance shifts between alpine and sub-alpine/non-alpine groups, are influenced by anthropogenic drivers and of great significance for herbivore populations, nutrient cycling and primary production. Some historical and resurvey data exists which may be explored, and the newly established ANO is a data source for the future given that it acquires sufficient representativity for alpine habitats. But this indicator will require a certain amount of new data acquisition/monitoring. It should be required that such plant indicators be stratified according to important alpine habitats such as snow beds, heaths and meadows as well as bio-climatic alpine subzones.	Data acquisition and development
Alpine	Functionally important species	Crowberry	Crowberry is a dominant plant species in alpine habitats, representative mainly of nutrient-poor, dry heath vegetation. Crowberry has substantial chemical properties which reduce the primary and secondary productivity and species diversity of the plant community, and is therefore a functionally important species. Increased dominance of crowberry also in more nutrient rich habitats is a likely result of increased warming. Some historical and resurvey data exists which may be explored, and the newly established ANO is a data source for the future given that it acquires sufficient representativity for alpine habitats. But this indicator will require a certain amount of new data acquisition/monitoring.	Data acquisition and development
Alpine	Landscape ecological patterns	Alpine fragmentation and connectivity	Loss of alpine area to infrastructure development results in increased fragmentation and loss of connectivity beyond the loss of total areas described by the indicator “Areas free of major infrastructure”. Development of an indicator which captures changes in such landscape ecological metrics is recommended both for alpine areas in general and for key strata within alpine (e.g. subtypes).	Development (Country wide scale)
Alpine	Landscape ecological patterns	Tree and shrub cover	Distributional shift in woody, canopy forming species in alpine habitats, in particular in the forest-low alpine ecotone are expected outcomes of both climate change and changes in grazing/browsing pressure. The resulting encroachment and increase in productivity will have a range of implications for alpine ecosystems and eventually for regional climate feedbacks. A regional indicator of the occurrence of trees and shrubs in alpine habitats based on remote sensing (satellites) supplemented by field data and/or aerial photos for validation, is recommended.	Development (Country wide scale)

Table 7.7. *(cont.)*

Ecosystem	Ecosystem characteristics	Indicator	Role	Requirements
Alpine	Biological diversity	Willow ptarmigan abundance	Willow ptarmigan are among the most important small game species in Norway, and hence an important ecosystem service. Historically it has been a functionally important species in alpine and subalpine ecosystems, and depending on prevailing densities should be considered for inclusion either under *Biological diversity* or *Functionally important species.* In this pilot, it has been considered only as one of many species in the bird community indicator, but it is recommended that a specific indicator on ptarmigan is included based on annual surveys reported from Hønsefuglportalen.	Development (Country wide scale)
Alpine	Biological diversity	Plant species diversity	The diversity of the alpine plant community is influenced by anthropogenic drivers and an important biodiversity indicator for alpine ecosystems, in particular focused on the loss of diversity of alpine species. Some historical and resurvey data exists which may be explored, and the newly established ANO is a data source for the future given that it acquires sufficient representativity for alpine habitats. But this indicator will require a certain amount of new data acquisition/monitoring. It should be required that such plant indicators be stratified according to important alpine habitats such as snow beds, heaths and meadows as well as bio-climatic alpine subzones.	Data acquisition and development
Alpine	Biological diversity	Lichen diversity and abundance	Lichens are important for the functioning and biodiversity of alpine ecosystems. They are a dominant feature of ridge communities and in addition an important resource for reindeer. The abundance of alpine lichens is negatively influenced by increased plant cover and shrubification, which in turn are driven by climate change and relaxed grazing pressure. Some historical and resurvey data exists which may be explored, and the newly established ANO can be a data source for the future given that it acquires sufficient representativity for alpine habitats. ANO includes plot level estimates of total lichen cover. But this indicator will require a certain amount of new data acquisition/monitoring. It should be required that such lichen indicators be stratified according to important alpine habitats such as snow beds, heaths and meadows as well as bio-climatic alpine subzones.	Data acquisition and development

Table 7.7. *(cont.)*

Ecosystem	Ecosystem characteristics	Indicator	Role	Requirements
Alpine	Abiotic factors	Snow structure and quality	The attributes of the snowpack are paramount to the grazing condition for ungulates in winter as well as for the survival and reproduction of rodents in winter and early spring. Especially the hardness of the snowpack, including the occurrence of iced layers caused by mild spells (rain-on-snow) is important. Adverse winter conditions due to icing are likely to increase with the observed increase in winter warming. An indicator capturing this is hence strongly recommended. It can be approached in several ways from a simple seasonal prediction of the occurrence and duration of rain-on-snow event based on existing gridded climate data, to most costly, but also more informative, estimates from dynamic snowpack models which are informed by climatic data and validated using field data on snow layering. Such models are currently developed for high Arctic tundra and can be developed also for alpine areas on the mainland.	Development. Potentially new data acquisition for validation (Country wide scale)
Alpine	Abiotic factors	Land surface albedo	Albedo is governed by snow cover and characteristics of the vegetation cover, especially distribution of shrubs and trees, and has an important regulating function in the climate system. Warming induced reductions in the duration and extent of alpine spring snow cover, lower albedo because snow-free land reflects much less solar radiation than snow. Herbivore effects, particularly ungulate grazing, can influence albedo via its effect on shrubs and trees in the forest-low alpine ecotone. It is recommended to include a regional indicator on albedo, based on remote sensing data series.	Development (Country wide scale)
Wetland	Primary productivity	Field layer plant biomass	A field-based indicator on plant biomass should serve to document changes in plant biomass and associated drivers. It can further nuance and help explain patterns of change in remote sensing-based indicators of primary productivity. Satellite-based (e.g. EVI, NDVI) estimates of trends or events of declining or increasing vegetation greenness are influenced by a myriad of factors which may be unrelated to actual trends in vegetation productivity including changes in wetness/water/snow coverage (Li et al. 2021, Huemmrich et al. 2021). Thus, inclusion of additional field- based plant indicators should be a priority. Time series of biodiversity change (see Plant species diversity”’ below) are tightly linked to productivity, especially in cases where major changes take place (for example from moss dominance to graminoid dominance). Point frequency analyses, which are applied in a few monitoring studies, can be directly translated into biomass, and is the recommended non-destructive field-based method for monitoring of biomass change. The newly established ANO can be a data source for the future given that it acquires sufficient representativity for wetland habitats and include direct or indirect (e.g. point frequency) proxies of plant biomass. But this indicator (and other plant indicators suggested below) will require a certain amount of new data acquisition/monitoring. It should be a priority to arrive at a level of data acquisition which can provide data both for this indicator (plant biomass), and other wetland plant indicators suggested below (key functional groups, plant diversity, key functionally important species).	Data acquisition and development

Table 7.7. (cont.)

Ecosystem	Ecosystem characteristics	Indicator	Role	Requirements
Wetland	Biomass distribution among trophic levels	Insects versus birds	Both insects and birds are important groups of organisms in wetlands, and insect diversity and abundance is considered to be important for birds. However, monitoring of both groups of organisms are currently limited to specific sites (Nybø and Evju 2017, Pedersen et al. 2018).	Data acquisition and development
Wetland	Functional groups within trophic levels	Plant growth form	The abundance of trees and shrubs versus field layer plants (herbs, graminiods, dwarf-shrubs) and cryptogams (bryophytes mainly) is expected to vary due to both land use and climate. The newly established ANO can be a data source for the future given that it acquires sufficient representativity for wetland habitats (see below).	Data acquisition and development
Wetland	Functionally important species	Depth of *Sphagnum* /peat/brown moss layer	Peat mosses (*Sphagnum* in ombrotrophic mires and brown mosses in minerotrophic mires) are the most important defining biophysical structures in mire and vital for C sequestration, habitat formation for other species as well as indicators of hydrological integrity (e.g. Bengtsson et al. 2021). Currently there is no monitoring in place which permit the development of indicators on changes in peat moss distribution and/or depth. The newly established ANO can be a data source for the future given that it acquires sufficient representativity for wetland habitats. It includes estimates of plot level peat cover, which could potentially serve as validation data for remote sensing-based mappings of changes peat distribution. Peat depth is currently not included.	Data acquisition and development
Wetland	Landscape ecological patterns	Wetland fragmentation and connectivity	Loss of wetland area to infrastructure development results in increased fragmentation and loss of connectivity beyond the loss of total areas described by the indicator 'Areas free of major infrastructure'. Development of an indicator which captures changes in such landscape ecological metrics is recommended both for wetland areas in general and for key wetland types.	Development (Country wide scale)
Wetland	Landscape ecological patterns	Tree and shrub cover	Distributional shift in woody, canopy forming species in wetland habitats are expected outcomes of both climate change, changes in the degree of utilization and manipulations of the hydrological conditions through drainage/trenching. The resulting encroachment and increase in productivity will have a range of implications for wetland ecosystems. A regional indicator of the occurrence of trees and shrubs (e.g. natural or facilitated encroachment) in wetland habitats based on remote sensing (satellites) supplemented by field data and/or aerial photos for validation, is recommended. This would require a reasonable level of accuracy in the spatial delineation of wetland ecosystems (see general text above this table).	Development (Country wide scale)

Table 7.7. *(cont.)*

Ecosystem	Ecosystem characteristics	Indicator	Role	Requirements
Wetland	Biological diversity	Plant species diversity	The diversity of the wetland plant community is influenced by anthropogenic drivers, and an important biodiversity indicator for wetland ecosystems focused in particular on the loss of diversity of typifying wetland species indicating changes in the hydrological regime. Time series on vegetation change of Norwegian wetlands are collected in a few monitoring projects, but none of these are at national level and very few monitoring sites are in Trøndelag (see summary in Bjerke and Tømmervik 2020). The impacts of increasing wetness are monitored on a few restored mires, including a mire in Verdal in Trøndelag, and in thawing palsa mires, including the site Leirpullan in Trøndelag. The impacts of time since scything of mires with a long history of human traditional use are monitored at Sølendet in Trøndelag. Reduced human activity may lead to increased wetness. Thus, the monitoring contributes to showing how vegetation changes are in line with changes in hydrological regime. The newly established ANO can be a data source for the future given that it acquires sufficient representativity for wetland habitats. However, this indicator (and other plant indicators suggested below) will require a certain amount of new data acquisition/monitoring.	Data acquisition and development
Wetland	Biological diversity	Insect diversity	Terrestrial monitoring of insects is rare and typically suffers from a substantial taxonomic bias towards butterflies and bumblebees. In Norway, no monitoring programs address insect diversity in wetland habitats. The new insect monitoring program is so far limited to a small part of the country and agricultural/semi-natural and forest habitats (Åström et al 2020). It should be extended to provide representativity also for wetland ecosystems.	Data acquisition and development
Wetland	Biological diversity	Anuran amphibians	Amphibians can be valuable indicators of wetland conditions due to their sensitivity to water quality, climatic fluctuations, and water table changes for instance due to drainage. Of the six species of amphibians breeding in Norway, two (*Pelophylax lessonae* and *Triturus cristatus*) are on the Norwegian redlist and subject to monitoring within their restricted distribution areas (e.g. Engemyr and Reinkind 2019, Bærum and Dervo 2019 and references therein). The remaining, and more common, anuran amphibian species are not included in monitoring in Norway. However, anuran amphibians are vocal species which can be monitored using acoustic methods during parts of their life cycle (Crump and Houlahan 2017, Gibb et al. 2019), potentially in combination with other extensive (e-DNA) or intensive (field surveys) methods.	Data acquisition and development

Table 7.7. (cont.)

Ecosystem	Ecosystem characteristics	Indicator	Role	Requirements
Wetland	Abiotic factors	Surface water	Productivity of wetlands is largely dependent on the water table level. Further, water table levels also influence greenhouse gas emissions and the balance between carbon uptake and emissions of wetland ecosystems, as well as critical habitat properties for wetland dependent biodiversity. A permanent lowering of the water table of previously inundated areas leads to a conversion from wetlands to other ecosystems, for example grasslands, shrublands, meadows, or forest depending on which vegetation change is associated with the reduced wetness. Surface water is mapped and monitored at a global scale using satellite imagery, as shown in a highly cited study published in Nature (Pekel et al. 2016), and there is continuous improvement of wetland water-table depth based on increasing availability of remote sensing data (Chen et al 2020). Using Landsat satellite images, Pekel et al. reported disappearance of surface water from an area of 90,000 km^2 from 1984 to 2015. Numerous studies have in recent years used the same method for surface water monitoring. For example, Li et al. (2021) applied MODIS satellite imagery to elucidate the causes of declining vegetation greenness (NDVI) of permafrost regions of Siberia. Their study showed that surface wetness had increased due to thawing permafrost. With the continuously growing time series of very-high-resolution Sentinel satellite imagery, it is possible to use the same method as developed by Pekel et al. (2016) for monitoring of surface wetness of even the smallest patches of Norwegian wetlands. Such monitoring should be supplemented with a field-based monitoring sites for water table depth for calibration. Sites showing major changes in surface water (from one year to another, or over a time scale of ca. 5 years) should be examined in the field to examine possible cause for the changes, if such changes cannot be explained by well-known weather events or climatic trends. Possible reasons for abrupt non-climatic changes in surface water could be related to recent human activities such as trenching or damming.	Data acquisition and development

Table 7.7. *(cont.)*

Ecosystem	Ecosystem characteristics	Indicator	Role	Requirements
Open lowland	Primary productivity	Field layer plant biomass	A field-based indicator on plant biomass should serve to document changes in plant biomass and associated drivers. It can further nuance and help explain patterns of change in remote sensing-based indicators of primary productivity. Satellite-based (e.g. EVI, NDVI) estimates of vegetation productivity/greening/browning are influenced by a myriad of factors which may be unrelated to actual trends in vegetation productivity including changes in wetness/water/snow coverage (Li et al. 2021, Huemmrich et al. 2021), and inclusion of additional field-based plant indicators should be a priority. Point frequency analyses, which are applied in a few monitoring studies, can be directly translated into biomass, and is the recommended non-destructive field-based method for monitoring of biomass change. The newly established ANO (general) or ASO (targeted at semi-natural meadows) can be data sources for the future given that they acquire sufficient representativity for open lowland habitats and include direct or indirect (e.g. point frequency) proxies of plant biomass. The 3Q monitoring program also contain records of vascular plant species composition and cover in agricultural/cultural land, but no direct or indirect estimates of plant biomass. This indicator (and other plant indicators suggested below) will require a certain amount of new data acquisition/monitoring. It should be a priority to arrive at a level of data acquisition which can provide data both for this indicator (plant biomass), and other open lowland plant indicators suggested below (key functional groups, plant diversity, key functionally important species).	Data acquisition and development
Open lowland	Biomass distribution among trophic levels	Plant biomass versus ungulates	The majority of the semi-natural open lowland ecosystems is maintained with ungulate grazing, mainly by livestock (e.g. Sickel et al. 2017). However, there is a lack of data on ungulate grazing pressure relative to plant biomass (but see Pedersen et al. 2020). Especially more details are needed on livestock grazing in outlying land (e.g. livestock species, length of grazing season, density/metabolic biomass of animals). These are data that could be included in farmers reports to agricultural statistics (https://www.ssb.no/jord-skog-jakt-og-fiskeri/artikler-og-publikasjoner/2021).	Data acquisition and development
Open lowland	Functional groups within trophic levels	Plant growth forms: Flower resources	As plant community composition in lowland habitats varies depending on both parent environmental variables (e.g. nutrients, soil, climate) and land use, monitoring of functional group composition could serve to indicate the ecological state for several ecosystem characteristics (see comments on Field layer plant biomass above). This could be proportion of plant species important for pollinating insects such as herbs (Pedersen et al. 2020, Åström et al 2020), but also plant species diversity (see indicator below) would be a relevant indicator for pollinator species richness (see Åstrøm et al. 2019).	Data acquisition and development

Table 7.7. *(cont.)*

Ecosystem	Ecosystem characteristics	Indicator	Role	Requirements
Open lowland	Functionally important species	Pollinator species	Increased scientific knowledge about trends in pollinator species is a central objective of the National Pollinator Strategy for Norway (Norwegian Ministries 2018); considered necessary to achieve the overall goal of the Strategy, i.e. to maintain the diversity of wild pollinator species in Norway. Arthropods, including pollinating insects, are declining, in some cases drastically, even in Arctic ecosystems with little anthropogenic influence other than climate change. However, terrestrial monitoring of insects is rare and typically suffers from a substantial taxonomic bias towards butterflies and bumblebees. Especially, how and where the quality of habitats that provide resources for pollinator species is poorly understood, and how they contribute to their persistence and reproduction (see Sydenham et al. 2021, 2022) In Norway, monitoring programs for these two taxonomic groups is in place and the data from these programs have also been utilized in this assessment. Other insect groups, however, have only recently been included in a monitoring program which is so far limited to a small part of the country (Åström et al 2020). This would represent is a critical data source for the future which may provide data both on pollinators beyond bumblebees and on insect biomass/diversity (see below). There are spatial data and models assessing the distribution of pollinator species richness which currently do not have a platform where to be made public (e.g. Sydenham et al. 2020, 2021, 2022).	Data acquisition and development
Open lowland	Functionally important species	Winter grazing sheep in coastal lowlands	Winter grazing sheep ("villsau") is a functionally important species in coastal heathland, which have increased greatly in numbers in many coastal municipalities. These are small breeds (ewes ~¨ 50-60 kg), with a high proportion of heather and other shrubs in their diet (Ross et al. 2016). There are currently no temporally and spatially consistent statistics on the number of winter grazing sheep, but the number of animals slaughtered probably gives a good indication of changes in densities, and could be evaluated as a potential indicator in absence of direct population estimates. On a national level the number of animals slaughtered per year has increased from just above 2300 animals from 128 producers in year 2000 to 45-55.000 animals/year from > 1200 producers during 2010-20 (https://www.animalia.no/no/kjott--egg/klassifisering/klassifisering-av-sau/)	(Data acquisition and) development (Country wide scale)
Open lowland	Landscape ecological patterns	Open lowland fragmentation and connectivity	In the current assessment, the indicator on 'areas free of major infrastructure' was not extended to include the open lowland ecosystem. This system is for a large part semi-natural and hence both close to major infrastructure such as roads and fragmented by definition. Nevertheless, the connectivity between patches of semi-natural and open habitats is important for biodiversity and species migration and dispersal on a landscape scale, and an indicator capturing patch metrics and connectivity between key open lowland types is recommended for inclusion. This would require a reasonable level of accuracy in the spatial delineation of open lowland ecosystems (see general text above this table).	Development (Country wide scale)

Table 7.7. *(cont.)*

Ecosystem	Ecosystem characteristics	Indicator	Role	Requirements
Open lowland	Landscape ecological patterns	Tree and shrub cover	Distributional shift in woody, canopy forming species in open lowland habitats are expected outcomes of both climate change, and changes in the degree of utilization, and land-use change (e.g. with afforestation). The resulting encroachment and increase in productivity will have a range of implications for open lowland ecosystems. A regional indicator of the occurrence of trees and shrubs (e.g. natural or facilitated encroachment) in open lowland habitats based on remote sensing (satellites) supplemented by field data and/or aerial photos for validation, is recommended. This would require a reasonable level of accuracy in the spatial delineation of open lowland ecosystems (see general text above this table). The ANO program could provide relevant ground-truthing data. Statistics based on area planted provide some information, but not suitable to assess cover.	Development (Country wide scale)
Open lowland	Biological diversity	Plant species diversity	The diversity of the open habitat plant community is influenced by anthropogenic drivers and an important biodiversity indicator for open lowland ecosystems, in particular focused on the loss of diversity of open habitat (light demanding) species. The newly established ANO (general) or ASO (targeted at semi-natural meadows) can be data sources for the future given that they acquire sufficient representativity for open lowland habitats. The 3Q monitoring program also contains records of vascular plant species composition and cover in agricultural/cultural land. However, this indicator will require a certain amount of new data acquisition/monitoring. It should be required that such plant indicators be stratified according to important open lowland subtypes, and management regimes.	Data acquisition and development
Open lowland	Biological diversity	Insect species diversity	Terrestrial monitoring of insects is rare and typically suffers from a substantial taxonomic bias towards butterflies and bumble bees. In Norway, monitoring programs for these two taxonomic groups is in place and the data from these programs have also been utilized in this assessment. Other insect groups, however, have only recently been included in a monitoring program which is so far limited to a small part of the country (Åström et al 2020). This is a potential data source for the future, given that it acquires sufficient representativity for open lowland habitats, which may provide data both on pollinators beyond bumble bees (see above) and on insect biomass/diversity in general.	Data acquisition and development
Open lowland	Biological diversity	Fungi species diversity and abundance	Fungi represents a large proportion of species diversity in semi-natural habitats such as grasslands, but system diversity and functionality such as decomposition varies with land use (Navrátilova et al. 2019).	Data acquisition and development
Open lowland	Abiotic factors	Carbon/Nitrogen (C/N), Carbon/Phosphorus (C/P)	C/N and C/P denotes the availability of key nutrients important for primary productivity and biodiversity. These relationships are expected to vary due to both land use and climate and have important impacts on ecosystem conditions as well as the potential for climate mitigation (Steffen et al. 2015).	Data acquisition and development

8 Appendices

8.1 Appendix 1 Supplementary information on indicators

Appendix 1 is available as an electronic supplement to this report at https://hdl.handle.net/11250/2982411.

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NINA Report

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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