

Towards understanding and managing cumulative impacts in Sápmi: approaches & collaboration

WORKSHOP REPORT WITH FOCUS ON SPATIAL
DATA, REINDEER AND REINDEER HERDING



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FOREWORD

Industrial development activities such as forestry, mining, wind power, and tourism have been growing rapidly in Sápmi, the homeland of the Sámi people, and this has accelerated with the green transition. To understand the consequences of industrial land-use beyond single projects, cumulative impacts of multiple land uses and development projects need to be assessed – and this requires better awareness of concepts, tools, and practical examples on methods for Cumulative Impact Assessment (CIA). This report aims to fill this gap by providing a popular summary and an entry point for further literature on CIA in the context of Sápmi, with focus on reindeer husbandry in Norway, Sweden and Finland.

The report draws from an expert workshop organized by the Norwegian Institute for Nature Research (NINA) and the Finnish Environment Institute (Syke) in Oslo in August 2025 as part of the project Sustainable Green Transition in the Barents Region (BAVIS), funded by the Ministry for Foreign Affairs of Finland. The workshop also received funding from the Nordic Joint Committee for Agricultural and Food Research (NKJ) through ReinCIAnet, a network to promote dialogue, tools, and practice on cumulative impacts and CIA. The workshop gathered 24 participants from Norway, Sweden, and Finland, consisting of academics, authorities, non-governmental organizations, and reindeer herders, although most of the participants were researchers. The workshop provided a fruitful arena for transboundary exchange and concluded that closer collaboration within the region is urgently needed to address current shortcomings in CIA. The report builds on the contributions of all researchers and experts involved as well as their various other projects. We would like to warmly thank everyone who made this work possible.

With this report, the authors wish to create a shared vision for future Nordic cooperation which takes critical steps towards a more robust application of CIA and land-use planning that accounts for cumulative impacts and for reindeer husbandry perspectives. The idea for the report started with discussions with Sámi advocates, and was given Free, Prior and Informed Consent (FPIC) from the Finnish Sámi Parliament on 6 November 2023. Due to the scarcity of resources, ample engagement of Sámi rightsholders regrettably remained limited. Recognizing that there are fundamental differences between scientific and Sámi knowledge systems, we hope to spark inspiration for knowledge production that is accountable and responsive to how environmental changes are lived and experienced in Sápmi.

Oslo, 30.03.2026
Bernardo Brandão Niebuhr, Aino Lipsanen and Jan Saijets

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The workshop on which this report is based received financial support from the Ministry for Foreign Affairs of Finland and the Nordic Joint Committee for Agricultural and Food Research (NKJ). The report also draws on results and experiences from various projects carried out in Norway, Sweden, and Finland over the past decades. We are grateful to the participants in these projects and to the organisations that funded them.



SUMMARY

Sápmi is inhabited by the Indigenous Sámi people and spans the northern parts of Norway, Sweden, Finland, and large parts of the Kola Peninsula in Russia. Sápmi and the reindeer herding area have been particularly impacted by the acceleration of industrial land-demanding activities such as forestry, mining for rare minerals, and hydro and wind power production, promoted by the Nordic countries towards a low-carbon economy. Together, the so-called “green transition” adds to past and present pressure on nature, contributing to changes in landscapes and affecting both people and biodiversity.

Land-use planning and impact assessments often focus on single projects on a local scale. As a result, planning processes are fragmented, with limited dialogue across sectors and insufficient consideration of cumulative impacts (CI) from past, ongoing, and future activities at relevant scales. Furthermore, Sámi rightsholders experience that their rights and perspectives are not properly understood and considered in planning processes, and in some cases even disregarded. Current research and planning on multiple anthropogenic impacts are also largely limited to local and national contexts, further reinforcing this fragmentation and constraining land-use planning across Sápmi. To assess the impacts of historic and new activities in Sápmi, there is a need for concepts, frameworks, and tools that can address the cumulative impacts of multiple activities across space, time, sectors, and borders, and a stronger knowledge base for just decision-making.

Cumulative Impact Assessment (CIA) offers a way forward, aiming to understand the combined impacts of multiple land uses and environmental changes. Here, CIA should be understood as a comprehensive approach that can be integrated into regional planning efforts, instead of as a narrow evaluation of (potential) impacts. This report summarizes concepts, tools, and examples of CIA methods (relevant to reindeer husbandry, in particular). It is based on a review of the academic literature and on a workshop held in Oslo in 2025 with experts from Norway, Sweden, and Finland.

In chapter 1, we present a synthesis of key components of CI in general and in relation to reindeer husbandry. Questions like “what is cumulative” and “what are impacts” are addressed to explain key terminology to understand the problems caused by CI. In Chapter 2, we present a synthesis of frameworks and methods used to quantify cumulative effects and impacts within and outside Sápmi. In Chapter 3, we present a short summary of needs for CIA, in terms of data, approaches, and ethical collaboration.

To offer a more hands-on pathway for CIA in practice, in Chapter 4 we present six different frameworks, through case studies, in which CIA was applied in reindeer and reindeer husbandry contexts. Each of the frameworks is described in detail, presenting the overall vision, the steps for implementation, and the needs in terms of data, tools, and skills. They also point to additional resources where more detailed information can be found. In two examples from Norway, we demonstrate how habitat and connectivity models based on reindeer and environmental data can be used for mapping and predicting CI, and how individual-based monitoring can be used to evaluate how multiple environmental changes affect reindeer populations. In two cases from Sweden, we show approaches focused on the co-production of spatial information and knowledge and on collaboration among researchers and reindeer herders to map and measure impacts. These approaches focused especially on projects in which the impacts of forestry, wind power development, and mining were evaluated. Finally, in two case studies from Fin-



land, we present a framework to measure and map reindeer resources and assess the impacts of anthropogenic, social, economic, and climatic factors on reindeer pastures and reindeer production. Based on this framework, we show a second example which highlights the accumulation of impacts of forestry through space and time.

The report calls attention to the limited integration of CIA in land-use planning in the three countries. This includes the fragmentation of data sources, data infrastructure, and impact assessment practices, and the insufficient participation of Sámi rightsholders and reindeer herding communities in impact assessment and land-use planning. Based on the workshop discussions, the report proposes needs for the future. Key suggestions include (i) stronger cross-border collaboration among researchers, authorities, and Sámi communities as a backbone for meaningful CIA and sustainable land-use planning; (ii) integration and harmonization of data across borders; (iii) inclusion of scientific and Sámi traditional knowledge into CIA, including co-production approaches; and (iv) the development of ethical CIA guidelines, following the CARE Principles of Indigenous Data Governance (Collective Benefit, Authority to Control, Responsibility, and Ethics) and the SODA principles (Sámi Ownership and Data Access).

The report calls for strategic, regional approaches to land-use planning that respect Sámi rights and livelihoods, ensure broad participation, and provide tools for assessing cumulative impacts. Importantly, the integration of CIA into decision-making might require a reorganization of institutions to integrate the regional character of CIA. The report is a step toward building collaboration, improving methods, and creating shared platforms for knowledge exchange and CIA across Sápmi.

SAMMENDRAG

Den grønne omstillingen har ført til høy etterspørsel etter sjeldne mineraler, miljøvennlig elektrisk kraft og andre naturgoder (økosystemtjenester). I Norden ser vi nå en betydelig vekst i arealkrevende næringer som berører helt eller delvis uberørte naturarealer, blant annet innen skogbruk, gruvedrift og utbygging av vann- og vindkraft. Til sammen bidrar dette til et økende arealpress på naturområder som tidligere i liten grad har vært påvirket av samfunnsutviklingen, og endrer landskap og påvirker både mennesker og biologisk mangfold. Særlig påvirker dette det samiske urfolket og deres reindrift i de nordlige delene av Norge, Sverige, Finland og store deler av Kolahalvøya i Russland.

Arealplanlegging og konsekvensutredninger blir ofte gjennomført på et prosjektspesifikt og lokalt nivå. Dermed blir gjerne planleggingsprosessene tematisk, faglig og geografisk fragmenterte, med lite dialog på tvers av profesjoner og forvaltningsnivåer, og uten at samla belastning (SB – kumulative effekter) fra tidligere, pågående og framtidige prosjekter tas tilstrekkelig med i vurderingene på riktig skala. Samtidig opplever samiske rettighetshavere at deres rettigheter og perspektiver ofte ikke blir riktig forstått og vurdert – og i noen tilfeller direkte tilsidesatt – i planleggingsprosesser. Siden samiske interesser og rettigheter strekker seg over landegrensene, kan Sápmi forstås som ett sammenhengende, transnasjonalt område. En lokalt, eller nasjonalt, avgrenset tilnærming gjør det derfor utfordrende å utvikle et inkluderende og godt kunnskapsgrunnlag, og metoder og regelverk som ivaretar helheten i arealplanleggingen.

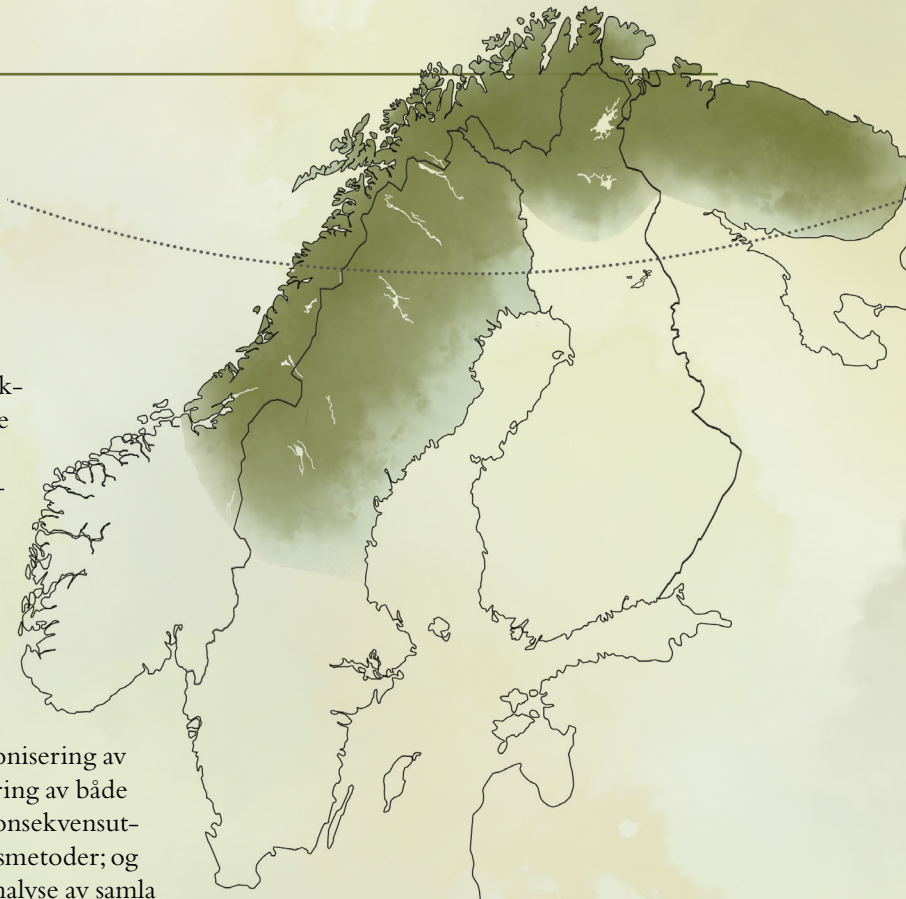
For å vurdere effektene av historiske og nye aktiviteter i samiske områder trenger vi begreper, rammeverk og verktøy for å forstå de samlede/kumulative effektene av flere aktiviteter på tvers av rom, tid, sektorer og landegrenser – og å utvikle et kunnskapsgrunnlag for helhetlige og rettferdige beslutninger.

Å inkludere analyse av samla belastning i planprosesser og konsekvensutredninger er et godt startpunkt for å utvikle dette temaet videre. Målet er å forstå de samlede påvirkningene av ulike arealbruksformer og miljøendringer. Her skal ikke analyser av samla belastning forstås som en snever evaluering av (potensielle) konsekvenser, men som en helhetlig tilnærming for å identifisere, kvantifisere og kartfeste effekter av samla belastning som kan integreres i planlegging på flere skalaer. Denne rapporten oppsummerer begreper, verktøy og eksempler på metoder for å evaluere samla belastning som er relevante for reindriften, basert på en kort gjennomgang av faglitteraturen og en workshop arrangert i Oslo i 2025 med eksperter fra Norge, Sverige og Finland.

Først presenterer rapporten en syntese av begreper og bruk av samla belastning i vitenskapelig litteratur, med vekt på nøkkelkomponenter og hvordan man kan forstå dem generelt og i reindriftskonteksten spesielt. Spørsmål som «hva er kumulativt? (SB)» og «hva er effekter?» drøftes for å forklare sentrale begreper som trengs for å forstå utfordringene samla/kumulative effekter gir.

Deretter presenterer vi en oversikt over rammeverk og metoder som brukes til å kvantifisere samla/kumulative effekter i ulike systemer, både innenfor og utenfor Sápmi. Vi gir også en kort oppsummering av behovet for data og etisk samarbeid i analyse av samla belastning.

Rapporten trekker fram den begrensede integreringen av analyse av samla belastning i arealplanleggingen i de tre landene, fragmenterte datakilder, ulik infrastruktur for



data og konsekvensutredning samt tilstrekkelige muligheter for deltakelse fra samiske rettighetshavere og reindriftsutøvere i vurderinger og planlegging. Med utgangspunkt i workshopdiskusjonene foreslår rapporten behov for framtidig innsats. Viktige anbefalinger inkluderer: (i) sterkere samarbeid på tvers av landegrenser mellom forskere, myndigheter og samiske samfunn, som grunnlag for meningsfull analyse av samla belastning og bærekraftig arealplanlegging; (ii) integrering og harmonisering av data på tvers av landegrenser; (iii) inkludering av både vitenskapelig og tradisjonell kunnskap i konsekvensutredning, blant annet gjennom samskappingsmetoder; og (iv) utvikling av etiske retningslinjer for analyse av samla belastning basert på CARE-prinsippene for urfolks datastyring (Collective Benefit, Authority to Control, Responsibility, and Ethics) og SODA-prinsippene (Sámi Ownership and Data Access).

For å gi en mer praktisk tilnærming til analyse av samla belastning presenterer rapporten seks ulike rammeverk – som case-studier – der samla belastningsanalyse er brukt i reindriftsrelaterte sammenhenger. Hvert rammeverk beskrives i detalj, med en overordnet visjon, implementeringssteg og behov når det gjelder data, verktøy og kompetanse. Det pekes også på ytterligere ressurser med mer informasjon. De ulike rammeverkene utfyller hverandre ved å belyse forskjellige sider av kumulative effekter på reindriftens sosioøkologiske system.

I to svenske eksempler viser vi metoder som vektlegger samskaping av romlig informasjon (for eksempel kartdata) og samarbeid mellom forskere og reindriftsutøvere for å kartlegge og måle effekter, særlig i prosjekter knyttet til skogsdrift, vindkraftutbygging og gruvedrift. I to norske eksempler demonstrerer vi hvordan habitat- og konnektivitetsmodeller basert på rein- og miljødata kan brukes til å kartfeste og forutsi kumulative effekter, samt hvordan individbasert overvåking kan brukes til å vurdere hvordan flere miljøendringer påvirker reinbestander. Til slutt presenterer vi to finske case-studier som viser et rammeverk for å måle og kartfeste reindriftsressurser, inkludert vurderinger av menneskeskapte, sosiale, økonomiske og klimatiske påvirkninger på reinbeiter. Eksempelene illustrerer også hvordan effektene av skogsdrift akkumuleres over tid og rom.

Rapporten etterlyser strategiske, regionale og integrerte tilnærminger til arealplanlegging som respekterer samiske rettigheter og livsgrunnlag, sikrer bred deltakelse og gir verktøy for å vurdere kumulative effekter. Rapporten er et første skritt mot å bygge samarbeid, kapasitet, forbedrede metoder og delte plattformer for kunnskapsutveksling og analyse av samla belastning i hele Sápmi.

SAMMANFATTNING

Sápmi sträcker sig över de nordliga delarna av Norge, Sverige och Finland samt Kolahalvön i Ryssland och är hemvist för urfolket samerna. Området präglas av stora naturvärden och långvariga traditioner av renskötsel. Samtidigt står Sápmi idag inför ett växande tryck från olika former av industriell exploatering. Den gröna omställningen – med ökad efterfrågan på förnybar energi och viktiga mineraler – har lett till en utökad markanvändning av skogsbruk, gruvdrift samt vatten- och vindkraft. Även om dessa satsningar syftar till att minska klimatpåverkan innebär de samtidigt nya belastningar på naturen och på de människor som lever av och med landskapet.

Rapporten beskriver hur dagens markanvändningsplanering ofta fokuserar på enskilda projekt, till exempel en vindkraftpark eller en ny gruva, utan att fullt ut ta hänsyn till hur många olika verksamheter tillsammans påverkar natur och samhällen över tid. För renskötseln kan små förändringar på flera olika platser tillsammans få stora konsekvenser. Vägar, skogsavverkning, kraftledning och gruvor kan stegvis minska tillgången till viktiga betesmarker och störa renarnas vandringar. Samiska rättighetsinnehavare upplever dessutom att deras rättigheter och perspektiv ofta inte förstås eller bedöms korrekt – och i vissa fall direkt åsidosätts – i planeringsprocesser. Samiska intressen och rättigheter sträcker sig över nationsgränser, vilket gör att Sápmi kan betraktas som ett sammanhängande transnationellt område. Ett lokalt eller nationellt avgränsat perspektiv gör det därför svårt att utveckla en inkluderande och välgrundad kunskapsbas samt metoder och regelverk som tar hänsyn till helheten i markanvändningsplaneringen.

För att kunna bedöma effekterna av historiska och nya verksamheter i samiska områden behövs begrepp, ramverk och verktyg för att förstå de samlade, kumulativa, effekterna av flera aktiviteter över tid, rum, sektorer och nationsgränser. Då kan vi utveckla kunskapsunderlag för helhetsorienterade och rättvisa beslut. För att möta dessa utmaningar presenterar rapporten olika metoder för en kumulativ konsekvensbedömning (Cumulative Impact Assessment, CIA). Rapporten bygger både på vetenskaplig forskning och på erfarenheter från en workshop som hölls i Oslo 2025 med experter från Norge, Sverige och Finland.

I rapporten presenteras flera nyckelbegrepp i en kumulativ konsekvensbedömning, både generellt och i relation till renskötsel (kapitel 2). Frågor som ”vad är kumulativt?” och ”vad är effekter?” behandlas för att förklara centrala begrepp och skapa förståelse för de problem som orsakas av kumulativa effekter. Vidare redogörs för olika ramverk och metoder som används för att kvantifiera kumulativa effekter. Vi ger också en kort sammanfattning av behovet av data och ett etiskt förhållningssätt vid analyser av samlad belastning.

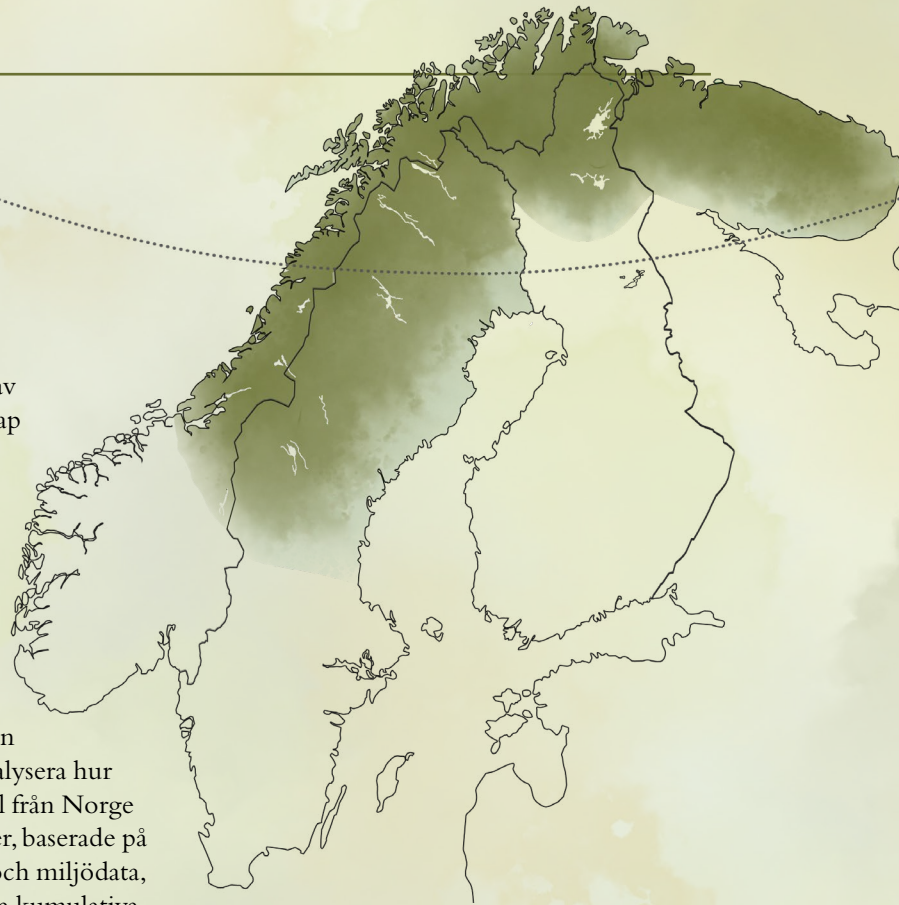
Rapporten lyfter fram att analyser av kumulativa effekter fortfarande används i begränsad utsträckning i markanvändningsplaneringen i de tre länderna. Den pekar också på problem med splittrade datakällor och olika system för data och konsekvensutredningar, och att samiska rättighetsinnehavare och renskötare har små möjligheter att delta i bedömningar och planering. Utifrån diskussionerna vid workshopen föreslår rapporten några viktiga framtida insatser. De inkluderar: (i) starkare gränsöverskridande samarbete mellan forskare, myndigheter och samiska samhällen som grund för CIA och hållbar markanvändningsplanering; (ii) integrering och harmonisering av

data över nationsgränser; (iii) inkludering av vetenskaplig och samisk traditionell kunskap i CIA, inklusive samskapande metoder; samt (iv) utveckling av etiska riktlinjer för CIA i enlighet med CARE-principerna för urfolks dataförvaltning (Collective Benefit, Authority to Control, Responsibility and Ethics) och SODA-principerna (Sámi Ownership and Data Access).

I flera exempel (kapitel 4) visar rapporten hur forskare och renskötare tillsammans kan kartlägga förändringar i landskapet och analysera hur renarnas livsmiljöer påverkas. I två exempel från Norge demonstreras först hur avancerade modeller, baserade på GPS-data från renar och olika landskaps- och miljödata, kan användas för att kartlägga och förutsäga kumulativa effekter. I det andra exemplet förklaras hur individbaserad information på renar från olika områden kan användas för att utvärdera hur flera miljöförändringar påverkar renarnas kondition och hälsa. I två exempel från Sverige visas metoder som fokuserar på samproduktion av kunskap genom samarbete mellan forskare och renskötare för att kartlägga och mäta effekter. I dessa projekt utvärderades effekterna av skogsbruk, vindkraftsutbyggnad och gruvdrift. Slutligen presenteras i två exempel från Finland, ett ramverk för att mäta och kartlägga resurser för renskötsel, bland annat hur mänskliga aktiviteter, samhällsförändringar, ekonomi och klimat påverkar renbeten och produktion i renskötseln. Utifrån detta ramverk visas ett exempel som belyser hur påverkan från skogsbruket ackumuleras över tid och rum.

Avslutningsvis lyfter rapporten behovet av långsiktiga och regionala strategier för markanvändning, som respekterar samiska rättigheter och livsvillkor, säkerställer bred delaktighet och tillhandahåller verktyg för att bedöma kumulativa effekter. Rapporten ses som ett första steg mot ökat samarbete, bättre metoder och en gemensam kunskapsplattform för att förstå och hantera kumulativa effekter i hela Sápmi.

Rapporten etterlyser strategiske, regionale og integrerte tilnærminger til arealplanlegging som respekterer samiske rettigheter og livsgrunnlag, sikrer bred deltakelse og gir verktøy for å vurdere kumulative effekter. Rapporten er et første skritt mot å bygge samarbeid, kapasitet, forbedrede metoder og delte plattformer for kunnskapsutveksling og analyse av samla belastning i hele Sápmi.





TIIVISTELMÄ

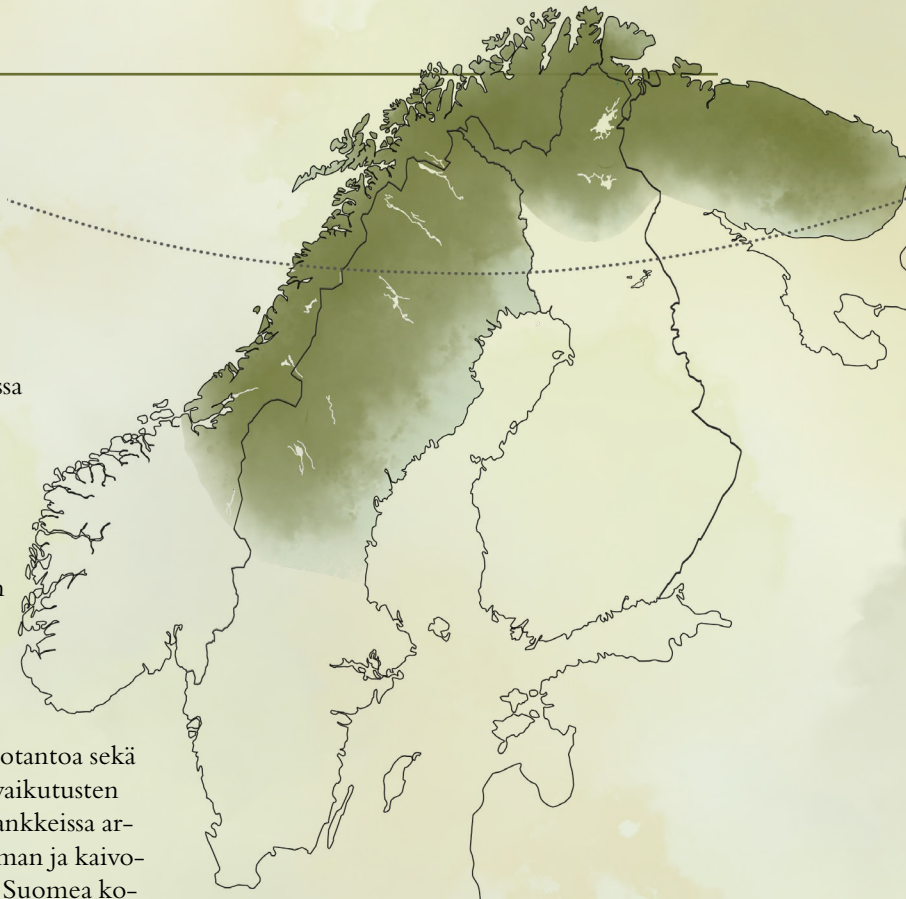
Alkuperäiskansa saamelaisten asuttama Saamenmaa (Sápmi) kattaa Norjan, Ruotsin ja Suomen pohjoisosat sekä suuren osan Kuolan niemimaasta Venäjällä. Muiden paineiden ohella Saamenmaahan ja poronhoitoalueeseen on vaikuttanut teollisen maankäytön, kuten metsätalouden, harvinaisten mineraalien louhinnan sekä vesi- ja tuulivoiman tuotannon, kiihtyminen Pohjoismaiden tavoitellessa siirtymää vähäpäästöiseen talousjärjestelmään. Tämä ”vihreä siirtymä” yhdessä muiden nykyisten ja aiempien luontoon kohdistuvien paineiden kanssa muuttaa maisemia ja vaikuttaa sekä ihmisiin että luonnon monimuotoisuuteen.

Maankäytön suunnittelu ja vaikutusten arviointi keskittyvät usein yksittäisiin hankkeisiin hyvin paikallisella tasolla. Tämän seurauksena suunnitteluprosessit ovat aihepiireittäin, ammatillisesti ja alueellisesti pirstaloituneita. Vuoropuhelu eri toimijoiden ja sektoreiden välillä on puutteellista, ja aiempien, käynnissä olevien ja tulevien hankkeiden kumulatiivisten vaikutusten käsittely eri tarkastelun tasoilla riittämätöntä. Saamelaiset oikeudenhaltijat kokevat, että suunnitteluprosesseissa heidän oikeuksiaan ja näkökulmiaan ei huomioida ja ymmärretä riittävästi, tai ne sivuutetaan kokonaan. Sekä vaikutusten arviointiin keskittyvä tutkimus että suunnittelukäytännöt rajoittuvat paikallisen tai kansallisen tason tarkasteluihin, mikä entisestään voimistaa vaikutusten arvioinnin pirstaleisuutta ja rajoittaa maankäytön suunnittelua Saamenmaan tasolla. Historiallisten ja uusien maankäyttöhankkeiden vaikutusten arvioimiseksi tarvitaan käsitteitä, menetelmiä ja työkaluja, joiden avulla voidaan eritellä niin alueellisesti ja ajallisesti kuin sektorien ja valtioiden rajojen yli kumuloituvia vaikutuksia. Näin voidaan muodostaa vahva tietopohja kokonaisvaltaisen ja oikeudenmukaisen päätöksenteon tueksi.

Kumulatiivisten vaikutusten arviointi (englanniksi Cumulative Impact Assessment, CIA) tarjoaa yhden lähestymistavan ymmärtää useiden maankäyttömuotojen ja ympäristömuutosten yhteisvaikutuksia. Kumulatiivisten vaikutusten arviointia ei tule ymmärtää kapeasti vain (mahdollisten) vaikutusten arviointina, vaan laajempana lähestymistapana, jonka avulla kumulatiiviset vaikutukset voidaan tunnistaa, mitata ja kartoittaa sekä kytkeä alueelliseen suunnitteluun. Tämä raportti kokoaa yhteen käsitteitä, työkaluja ja esimerkkejä porotalouden näkökulmasta olennaisten kumulatiivisten vaikutusten arvioinnin menetelmistä. Raportti perustuu lyhyeen katsaukseen tieteellisestä kirjallisuudesta sekä vuonna 2025 Oslossa järjestettyyn työpajaan, johon osallistui asiantuntijoita Norjasta, Ruotsista ja Suomesta.

Raportti esittää ensiksi yhteenvedon kumulatiivisten vaikutusten keskeisistä osatekijöistä yleisesti sekä erityisesti porotalouden yhteydessä. Luvussa käsitellään kysymyksiä kuten ”mikä on kumulatiivista” ja ”mitä vaikutukset ovat” keskeisen käsitteistön avaamiseksi sekä kumulatiivisten vaikutusten aiheuttamien ongelmien ymmärtämiseksi. Toiseksi raportissa esitetään yhteenveto menetelmistä, joita käytetään kumulatiivisten vaikutusten mittaamiseen erilaisissa konteksteissa sekä Saamenmaalla että sen ulkopuolella. Lisäksi esitetään lyhyt yhteenveto kumulatiivisten vaikutusten arvioinnin kannalta keskeisistä tiedonhallinnan ja eettisen yhteistyön näkökulmista.

Raportin kuusi tapaustutkimusta tarjoavat käytännönläheisiä lähestymistapoja kumulatiivisten vaikutusten soveltamiseen. Tapaustutkimuksissa menetelmiä on sovellettu erilaisissa poroihin ja poronhoitoon liittyvien vaikutusten arvioinnissa. Jokainen tapaustutkimus on esitelty yksityiskohtaisesti, sisältäen kuvauksen kokonaisvisiosta, toteutuksen vaiheista sekä tarvittavista tietolähteistä, työkaluista ja osaamisesta. Tapaustutkimukset opastavat luki-



jan myös syventävän tiedon pariin. Kahdessa Norjaa koskevassa esimerkissä osoitetaan, kuinka poro- ja ympäristötiedon pohjalta laadittuja elinympäristö- ja kytkeytyvyysmallinnuksia voidaan käyttää kumulatiivisten vaikutusten kartoittamiseen ja ennustamiseen sekä kuinka eläinyksilöihin perustuvaa seurantaa voidaan hyödyntää arvioitaessa useiden ympäristömuutosten vaikutuksia porokantoihin. Kahdessa Ruotsista peräisin olevassa esimerkissä käsitellään paikkatiedon ja tiedon yhteistuotantoa sekä tutkijoiden ja poronhoitajien yhteistyötä vaikutusten kartoittamisessa ja mittaamisessa. Näissä hankkeissa arvioitiin erityisesti metsätalouden, tuulivoiman ja kaivostoiminnan vaikutuksia. Lopuksi kahdessa Suomea koskevassa tapaustutkimuksessa esitellään menetelmiä porojen käyttämien laidunresurssien mittaamiseen ja kartoittamiseen. Esimerkeissä arvioidaan ihmistoiminnan, sosiaalisten, taloudellisten ja ilmastollisten tekijöiden vaikutuksia porolaitumiin, ja havainnollistetaan erityisesti metsätalouden vaikutusten kumuloitumista ajallisesti ja alueellisesti.

Raportti kiinnittää huomiota siihen, että kumulatiivisten vaikutusten arviointi on toistaiseksi puutteellisesti tuotu osaksi maankäytön suunnittelua kaikissa kolmessa maassa. Lisäksi raportti tuo esiin tietolähteiden, tietoinfrastruktuurin ja vaikutusten arvioinnin käytäntöjen pirstoutuneisuuden sekä saamelaisten oikeudenhaltijoiden ja poronhoitoyhteisöjen riittämättömät osallistumismahdollisuudet vaikutusten arviointiin ja maankäytön suunnitteluun. Työpajassa käytiin keskusteluihin perustuen raportissa tunnistetaan tutkimus- ja yhteistyötarpeita. Keskeisiä ehdotuksia ovat: (i) rajat ylittävän yhteistyön vahvistaminen tutkijoiden, viranomaisten ja saamelaisyhteisöjen välillä merkityksellisen kumulatiivisten vaikutusten arvioinnin ja kestävä maankäytön suunnittelun perustana; (ii) tietolähteiden yhdistäminen ja harmonisointi yli valtioiden rajojen; (iii) tieteellisen ja saamelaisten perinteisen tiedon sisällyttäminen kumulatiivisten vaikutusten arviointiin, mukaan lukien tiedon yhteistuotanto; sekä (iv) eettisten kumulatiivisten vaikutusten arvioinnin ohjeistusten kehittäminen CARE-periaatteiden (alkuperäiskansojen tiedonhallinnan periaatteet Collective Benefit, Authority to Control, Responsibility, Ethics) ja SODA-periaatteiden (Sámi Ownership and Data Access) mukaisesti.

Raportti korostaa maankäytön suunnittelussa tarvetta strategisille, alueellisille ja integroiville lähestymistavoille, jotka kunnioittavat saamelaisten oikeuksia ja elinkeinoja, varmistavat laajan osallistumisen sekä tarjoavat työkaluja kumulatiivisten vaikutusten arviointiin. Kumulatiivisten vaikutusten arvioinnin tuominen osaksi päätöksentekoa voi edellyttää myös institutionaalisia uudelleenjärjestelyjä vaikutusten arvioinnin alueellisen luonteen vuoksi. Raportti on askel kohti yhteistyön rakentamista, osaamisen vahvistamista, menetelmien kehittämistä sekä yhteisten tiedonvaihtolustojen ja kumulatiivisten vaikutusten arvioinnin käytäntöjen luomista koko Saamenmaalla.

ČOAHKKÁIGEASSU

Sámieatnamis ássá álgoálbmot sápmelaččat, eanan gokčá dan mat odne leat davvioasit Norggas, Ruotas, Suomas, ja stuora oasi Ruošša Guoládatnjárggas. Earret eará deattut lea Sápmái ja boazodullui erenoamážit čuohcan eanagáibideaddji doaimmat nugo meahccedoallu, hárvenaš minerálaid roggan, ja čáhce- ja bieggafápmobuvttadeapmi, maid Davviriikkat ovddidit vuollegis luoitinekonomiija várás. Ovttas lasiha nu gohčoduvvon “ruoná muktašeabmi” ovddeš ja dálá deattu lundui, mii dagaha rievadásaid eanadagaide ja váikkuha sihke olbmuid ja biologalaš girjáivuhtii.

Eanangeavaheami plánemis ja váikkuhusaid árvvoštallamis guovdilastet dávjá oktasaš prošeavttaid báikkálaš sturrodaga dásis. Dan dihte leat plánenproseassat temáhtalaččat, fágalaččat ja geográfalaččat sirrejuvvon, mas lea ráddjejuvvon dialoga surggiid gaskkas ja váilevaš vuhtiiváldin kumulatiiva váikkuhusaid (CI) ovddeš, joatkka- ja boahpteáiggi doaimmain relevánta dásis. Viidáseappot vásihit sámi vuoigatvuodaguoddit ahte sin vuoigatvuodát ja perspektiivvat dávjá eai riektá ipmirduvvo eage vuhtiiváldojuvvo plánaproseassain, ja muhtun áššiin vaikko vájalduvvojit.

Dálá dutkan ja plánen mánggabealat váikkuhusain lea maiddá viehka dávjá ráddjejuvvon báikkálaš ja nátionála oktavuodaide, mii ain nanne dán bidejumi ja gáržžida eanangeavaheami plánema miehtá Sámi. Jus árvvoštallat historjjálaš ja ođđa doaimmaid váikkuhusaid Sámis, de dárbbasuvvojit konseptat, rámmat, ja readdut mat sáhttet čalmmustahttit mánggabealat doaimmaid kumulatiiva váikkuhusaid areála, áiggi, surggiid ja rájiid rastá, ja nannet máhttovuodu ollislaš ja vuoiggalaš mearrádusdahkamii.

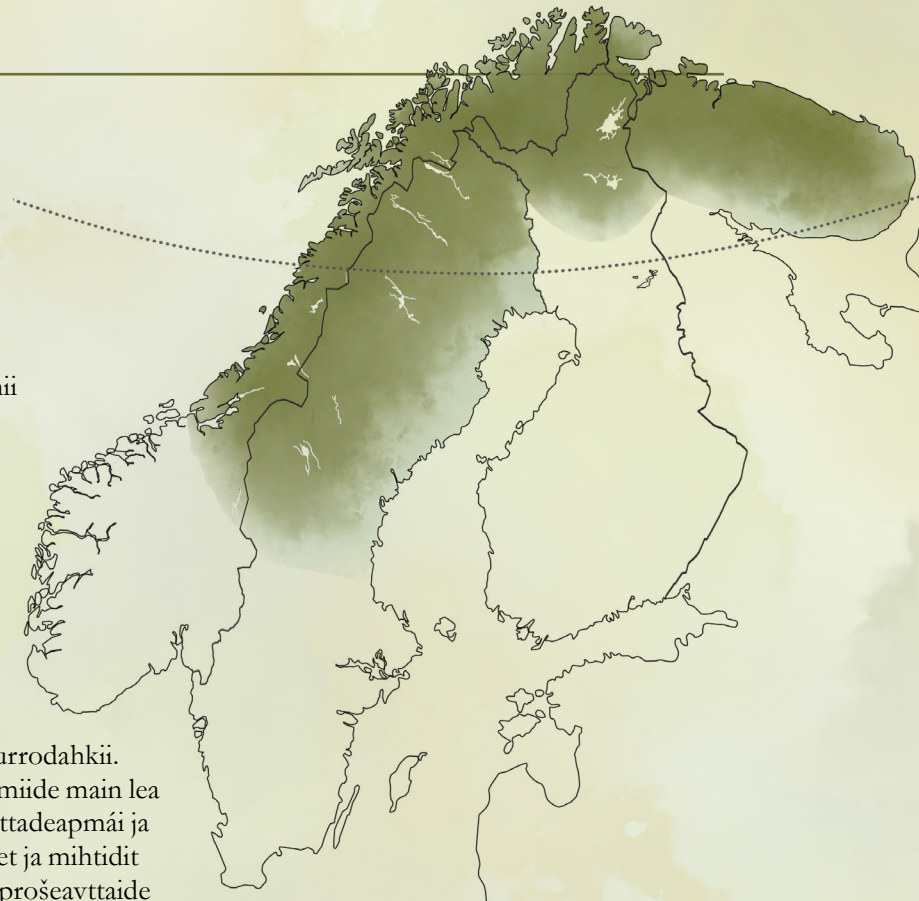
Kumulatiiva váikkuhusárvvoštallan (CIA) fállá geainnu ovddosguvlui, man ulbmil lea ipmirdit mánggalágan eanangeavaheami ja birasrievdamiid oktasaš váikkuhusaid. Dás ii galgga CIA áddejuvvot gáržžes árvvoštallamin (vejolaš) váikkuhusain, muhto ollislaš vuohkin identifiseret, kvantifiseret ja kártet kumulatiiva váikkuhusaid, maid sáhtta laktit guvllolaš plánenbargguide.

Dát raporta čeahkkáigeassá konseptiid, readduid ja ovdamearkkaid CIA-vugiin mat leat relevánttat boazodollui, ja buktá oanehis dárkkástusa fágalaš girjjálašvuođas ja bargobájis mii dollojuvvui Oslos jagis 2025:s, mas ledje áššedovdit Norggas, Ruotas ja Suomas.

Vuosttažettiin mii ovdanbuktit syntesa CI váldo komponanttain oppalaččat ja boazodoalu oktavuodas. Gažaldagat nugo “mii lea kumulatiiva” ja ”mat leat váikkuhusat” gieđahallojuvvot čilget guovddáš terminologiija vai ipmirdit váttisvuođaid maid CI dagaha. Nuppi dáfus mii ovdanbuktit syntesa rámmaide ja metodaide mat leat geavahuvvon kvantifiseret kumulatiiva váikkuhusaid siskkobealde ja olggobealde Sámi. Mii ovdanbuktit maiddá oanehis čeahkkáigeasu CIA dárbbuid birra, dieđuid ja etihkalaš ovtasbarggu ektui.

Diedáhus čujuha CIA ráddjejuvvon integreremii eanageavahanplánemis dáin golmma riikkain, diehtogálduid, diehtoinfrastruktuvrra ja váikkuhusárvvoštallamiid práksisiid bidejupmái, ja metodalaš hástalusaid mat bohtet das go sámi vuoigatvuodaguoddit ja boazodoalloservodagat oassálastet váikkuhusčielggadeamis ja eananplánemis.

Go galgá fállat eambo geavatlaš geainnu-CIA:i, de ovdanbukta raporta guhtta iešguđetlágan rámmaid, dáhpusdutkamiid bokte, mas CIA geavahuvvui boazodoallu- ja boazodoalu konteavsttas. Juohke rámma lea čilgejuvvon dárkilit, mas ovdanbuktojuvvo



ollislaš višuvdna, lávkkit implementeremii ja dárbbut dieđuid, readduid ja gelbbolašvuođa ektui. Sii čujuhit maid lassi resurssaide gos gávdná eanet dieđuid. Guovtti ovdamearkkas Norggas mii čájehit mot ealibiid- ja oktavuodamodeallat mat leat vuodđuduvvon bohcco- ja birasdieđuide sáhttet geavahuvvot CI kártemii ja einnosteapmái, ja mot indiviidavuodđuduvvon váksun sáhtta geavahuvvot árvvoštallat mot mánggalágan birasrievadásat váikkuhit boazologu sturrodahkii. Guovtti áššis Ruotas mii čájehit lahkoneamiid main lea fokus areáladieđuid ja máhtu ovddasbuvttadeapmái ja dutkiid ja boazodolliid ovtasbargui kártet ja mihtidit váikkuhusaid, erenoamážit guovdilastot prošeavttaide main boazodoalu, bieggafápmohuksema ja ruvkedoaimma váikkuhusat árvvoštallojuvvojedje. Loahpas mii ovdanbuktit guovtti áššedutkamiid Suomas rámmaeavttuid mihtidit ja kártet boazoresurssaid, earret eará antropogena, sosiála, ekonomalaš ja dálkkádatrievdama váikkuhusaid ealuid láidumiidda, ja čájehit dan ovdamearkkain mii čalmmustahtta meahccedoalu čoaččan váikkuhusaid báikki ja áiggi bokte.

Bargobáji ságastallamiid vuodul raporttas evttohuvvojit boahpteáiggi dárbbut. Guovddáš evttohusaide gullet (i) nannoseabbo rájáid rastildeaddji ovtasbargu dutkiid, eiseváldiid ja sámi servodagaid gaskkas, mat leat vuodđun mearkkašahhti CIA:i ja ceavzilis eanangeavaheami plánemii; (ii) data integrerema ja harmoniserema rájáid rastá; (iii) dieđalaš ja árbevirolaš máhtu ollái váldin CIA:i, earret eará lahkoneapmi ovtasbuvttadanvugiide; ja (iv) etihkalaš CIA rávvagiid ovddideapmi, čuovvumin CARE-prinsihpaid álgoálbmogiid data hálddašemi (Kollektiiva ávki, bearráigeahččánváldi, ovddasvástádus ja etihkka) ja SODA (Sámi oamastan- ja beassanlobi) prinsihpaid.

Diedáhus gáibida strategalaš, regionála lahkonevugiid eanangeavaheami plánemii mat váldet vuhtii sámi vuoigatvuodaid ja ealáhusaid, sihkkarastet viiddes oassálastima, ja addet readduid árvvoštallat kumulatiiva váikkuhusaid. Lea dehálaš ahte CIA ollašuhttin mearrádusdahkamii sáhtta gáibidit ášahusaid ođđasit organiserema mat integrerejit CIA guovllolaš iešvuođa. Raporta lea vuosttaš lávki hukset ovtasbarggu, kapasitehta, buoridit metodaide, ja ráhkadit oktasaš lávddiid máhttogaskkusteapmái ja CIA:i miehtá Sámi.



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1. Introduction: fragmentation of Sápmi and why we need cumulative impact assessments

During the last centuries, and intensified in the last decades, industrial development has accelerated globally, driving extensive land-use change. Land-use and environmental change can cause loss and fragmentation of habitats for species, as well as impacts for people who depend on them. Each change may seem small on its own and is often planned and managed separately, even though many activities together can have major impacts on landscapes and ecosystems. When combined across space and time – together with unpredictable and varying local effects such as climate change – the combined effects might lead to large-scale and long-term impacts on the environment, biodiversity, communities, and local livelihoods (Gillingham et al., 2016). These are known as cumulative impacts (CI), meaning the combined and interacting effects of multiple land uses or development projects (Johnson, 2016), which can be stronger and more persistent than the impacts of any single project alone.

Sápmi, the Sámi homeland, which encompasses parts of Norway, Sweden, Finland, and the Kola peninsula in Russia*, is the region where Indigenous Sámi People live and practice their culture and their traditional livelihoods, including reindeer husbandry, hunting, fishing, gathering and Sámi handicrafts (Figure 1.1). Reindeer husbandry is one of the most important livelihoods that can still

sustain Sámi reindeer herding families economically. In Fennoscandia, besides Sámi people, reindeer husbandry is also practiced by non-Sámi reindeer herders in the southern part of the reindeer herding area in Finland† and in concession reindeer-herding districts in Norway and Sweden. Reindeer husbandry refers to the livelihood of reindeer pastoralism and “encompasses the social-ecological relation between people, animals, and natural environment, as well as the economic and cultural dimension inherent in the livelihood” (Holand et al., 2022, p. 9). Within reindeer husbandry, these elements are interdependent and are continuously interacting (Figure 1.2). Reindeer roam freely most of the time across natural pastures within the borders of the reindeer herding districts. The pasture resources vary seasonally and their use by reindeer require herding and movement of the reindeer between them. Reindeer are gathered and handled during specific events, such as calf marking in summer and slaughter in autumn and winter, and they may need supplementary feeding when winter grazing conditions are bad. Reindeer husbandry both contributes to and is affected by many factors, including economic, political, environmental and climate conditions, from the local to the global level. For a comprehensive description of reindeer husbandry, we refer the reader to Horstkotte et al. (2022a) and Holand et al. (2024).

*This report focuses on the Nordic parts of Sápmi, but the methods presented in this report are of relevance both inside and outside Sápmi.

†According to the Finnish Reindeer Husbandry Act (848/1990) in Finland, citizens of the European Economic Area who have permanent residence in the reindeer management area are allowed to own reindeer if they are approved as a member by the reindeer herding co-operative.

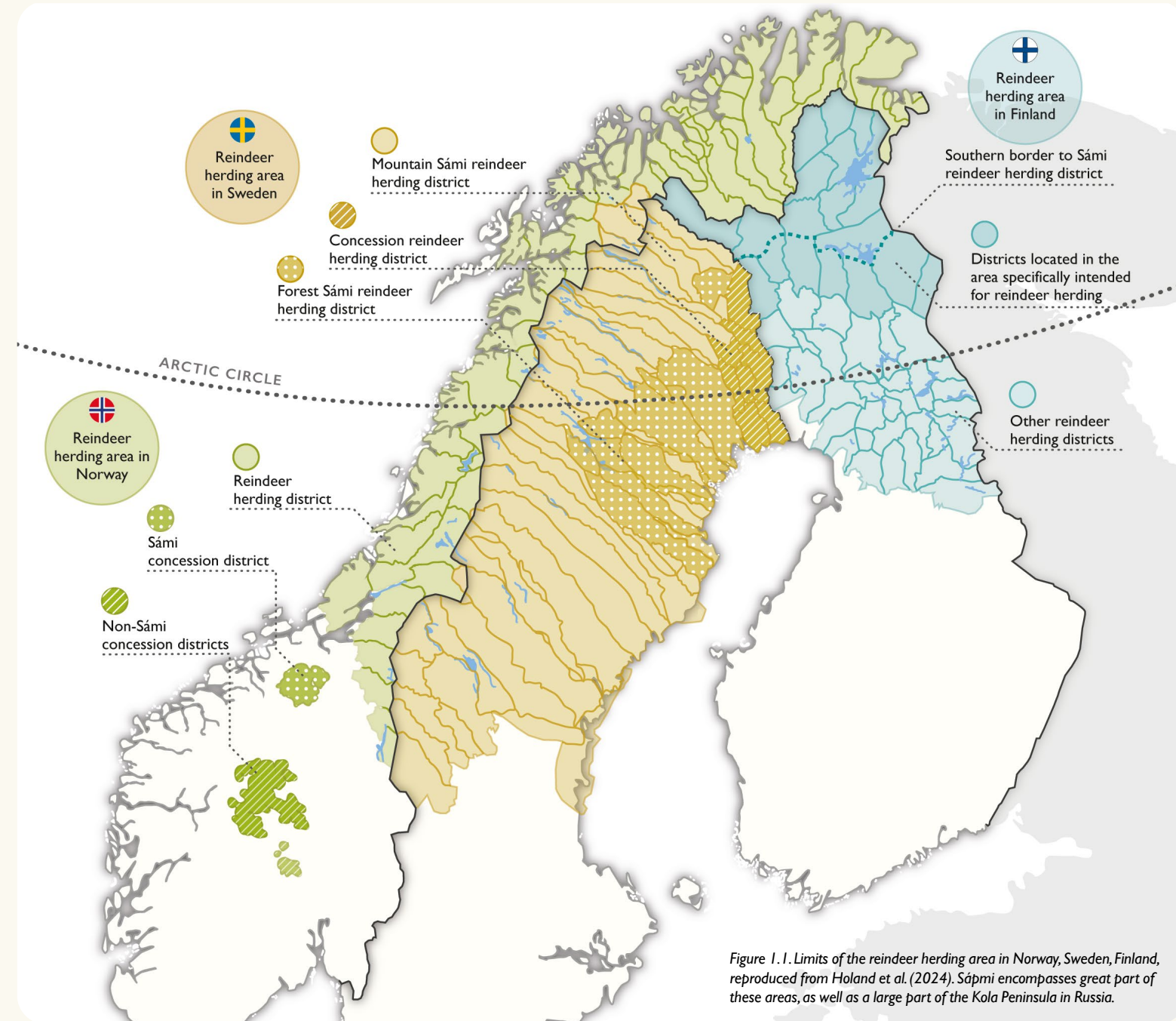


Figure 1.1. Limits of the reindeer herding area in Norway, Sweden, Finland, reproduced from Holand et al. (2024). Sápmi encompasses great part of these areas, as well as a large part of the Kola Peninsula in Russia.

In Sápmi, multiple extractive industrial activities are increasing, including forestry, mining, the use of land for hydro and wind power production, and tourism, with both public resorts and private cabins proliferating. These activities develop as piecemeal (bit-by-bit) processes, leading to a cumulative loss, fragmentation, and degradation of good pasture areas (Nellemann et al., 2003) (Fig. 1.2). Simultaneously, warmer mean temperatures, higher variation and unpredictability in weather conditions, and extreme weather events are more common, and are expected to continue in decades to come (Walsh et al., 2020). Together with anthropogenic activities and land uses, climate changes challenge the adaptation of reindeer husbandry in the use of

the pastures (Rasmus et al., 2022) (Fig. 1.2). For instance, there is an increased need for supplementary feeding due to lack of natural, accessible pastures in winter (Åhman et al., 2022). On top of that, there is a long history of colonization and the subsequent division of Sápmi into sub-divisions of nation-states, which has fragmented and localized social organization and political mobilization.

It is important to understand the combined impacts of multiple pressures on reindeer husbandry. However, assessments of impacts of industrial development are often made separately and centred on single projects, without considering other ongoing or future development projects, or the already

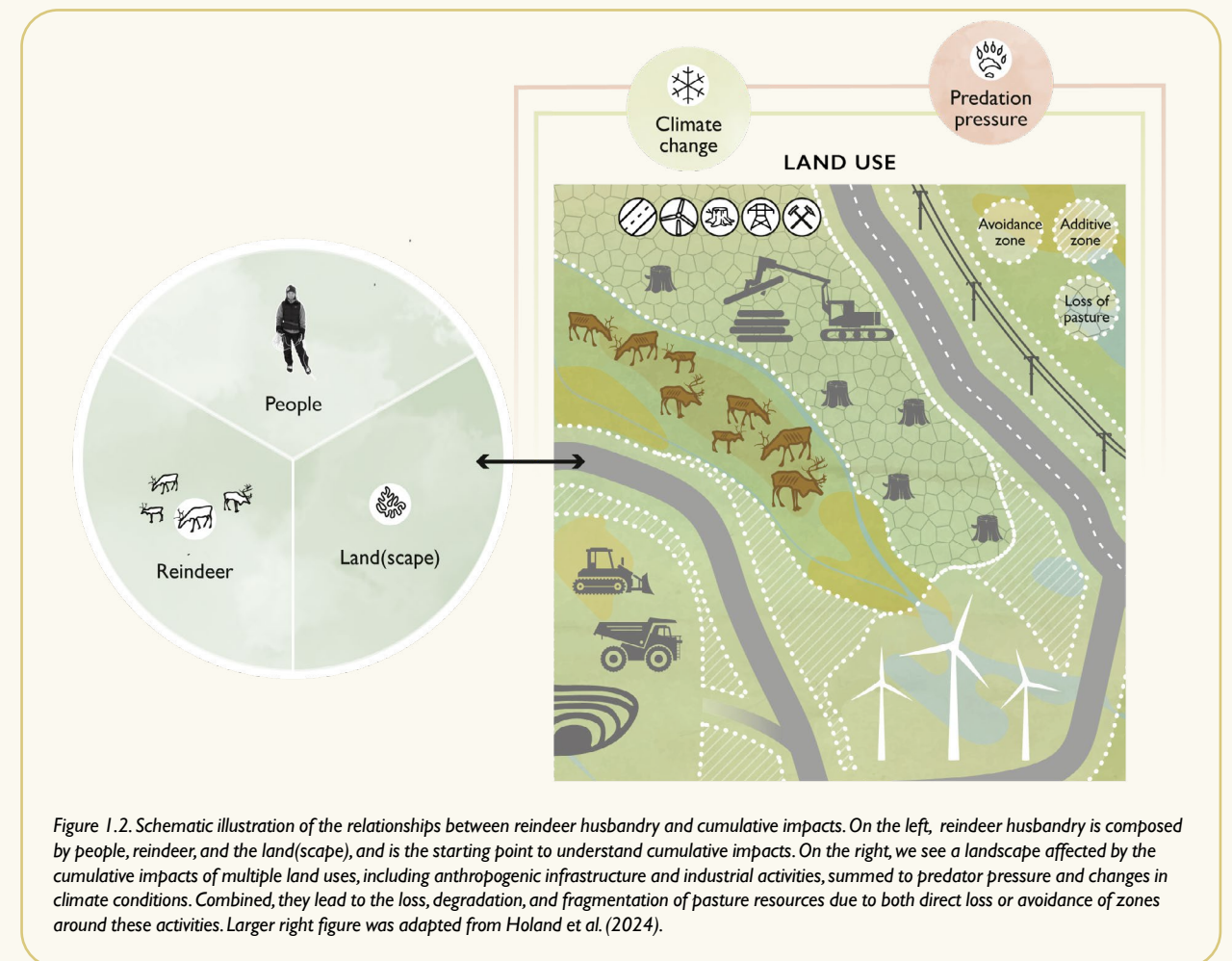


Figure 1.2. Schematic illustration of the relationships between reindeer husbandry and cumulative impacts. On the left, reindeer husbandry is composed by people, reindeer, and the land(scape), and is the starting point to understand cumulative impacts. On the right, we see a landscape affected by the cumulative impacts of multiple land uses, including anthropogenic infrastructure and industrial activities, summed to predator pressure and changes in climate conditions. Combined, they lead to the loss, degradation, and fragmentation of pasture resources due to both direct loss or avoidance of zones around these activities. Larger right figure was adapted from Holand et al. (2024).

present impacts of existing infrastructure and land use (Johnson et al., 2020; Österlin and Raitio, 2020). Many of the assessments and decisions in the three countries are made at the municipal level, which might not be meaningful considering the ecological requirements of reindeer, or practices and needs of reindeer husbandry. Cumulative impacts are rarely included in strategic environmental assessments or regional land-use planning, and impact assessment processes have often failed to include Sámi reindeer herding communities.

For example, assessments have been made within administrative borders, even though herding areas may span across them. The Sámi constitute one people residing across multiple states, therefore impacts on Sámi as Indigenous People should be assessed from a transboundary perspective. The challenges confronting Sámi communities throughout Sápmi are similar in nature and should be addressed through the same cumulative lens – an argument that Sámi representatives have made for decades (Larsen et al., 2017).

A key reason for the current situation is the lack of political priority given to a more coordinated land-use planning and impact assessment of industrial activities. Cumulative impact assessments (CIA) are rarely done, partly because cumulative impacts are difficult to conceptualize and turn into practical tools (Foley et al., 2017; Wärnäck and Hilding-Rydevik, 2009). CIAs are often area-based assessments, but CI are multidimensional and may extend over space, time, and different ecological and social levels.

Assessing cumulative impacts of multiple factors is a complex and challenging technical task, as many stressors correlate and influence each other. However, this does not mean that methods and data to assess CI do not exist. This report brings together main concepts, methods, and tools existing for CIA[‡].

[‡]Although crucial for CIA, legal frameworks are not within the scope of this report. For a comprehensive overview in Finland's context, see Hansen (2024).

We present examples of approaches that can identify, measure, and map different types of impacts within CIA. Our review is based on the experience of researchers and Sámi rightsholders across Norway, Sweden, and Finland, and on discussions from the workshop “Cumulative Impact Assessment in Sápmi”, held between researchers, reindeer herders and Sámi rightsholders, and governmental agency representatives in Oslo in August 2025. Even though CI affect all traditional Sámi livelihoods, this report focuses on reindeer and reindeer husbandry. Most of the existing research of CI of relevance to traditional Sámi livelihoods focuses on reindeer and reindeer husbandry, demonstrating a significant gap in comparison to other traditional livelihoods. Some examples and concepts are also drawn from other regions and contexts beyond Sápmi.

1.1. A brief introduction to cumulative impact assessment

To understand cumulative impacts, we start by defining “impacts” and “cumulative” based on the literature. To define impacts, we must start with identifying the causes of impacts (“impacts of what”), and what is being impacted (“impacts on what”). It is important to differentiate between the causes – factors, stressors, or disturbances – and the consequences or impacts themselves (Figure 1.3). This distinction helps to understand the focus of the different existing methods for CIA.

Factors, stressors or causes of disturbances are for instance, infrastructure (e.g. roads, railways, houses, industries, mining, wind and hydro power), land-use change (e.g. intensification of agriculture, forestry, or overall conversion of land cover), the intensity of human activity (e.g. intensity of mining activity, car traffic volume on roads), and the climate effects of human activity (e.g. higher global temperature)⁵. The direct changes made by human and industrial disturbances in the landscape or environment may be called *effects* (Johnson, 2016; Johnson and St-Laurent, 2011). *Effects* refer, for instance, to the removal of natural land cover where mines

or roads are installed, or to the area of old-growth forest that is converted into clear-cuts or planted forests through forestry practices. Therefore, *effects* are directly caused by (and focused on) the source of disturbance (Fig. 1.3).

In contrast, we define *impacts* as the consequences of these effects on the system we study. Impacts are therefore system-, process-, and context-specific. In other words, impacts depend on how the effects caused by factors, stressors, or disturbances might affect specific species, systems, or values of interest (Johnson, 2016). For instance, the disturbances from roads and mines (source, cause) may lead to removal of natural habitat and sometimes to addition of salt on roads (effects), and drive impacts such as loss of habitat, reduced access to grazing areas, and higher probability of traffic accidents. Similarly, other disturbances cause direct effect on landscapes and impacts on reindeer, reindeer herders, or other components of the socio-ecological system (Fig 1.3). While the terms *effect* and *impact* might create some confusion and are often used as synonyms, we find it important to distinguish between the stressors, the direct changes in the environment and how these changes are experienced as impacts by species or people in different contexts (Johnson, 2016).

We also need to define what we mean by *cumulative*. Many of the definitions and uses of the term support the understanding that *cumulative* means *additive*, i.e. that CI are a sum of the consequences of multiple stressors (Johnson, 2016). However, impacts from different stressors can interact in non-linear ways, for example strengthening or weakening each other, creating more complex consequences than only a sum (Crain et al., 2008; Johnson, 2016). Therefore, we follow here the definition from Johnson (2016, p. 25): “*Cumulative* refers to the synergistic, interactive, or unpredictable outcomes of multiple land-use practices or development projects that aggregate over time and space, and that result in significant consequences for people and the environment”.

⁵Here we refer mostly to human or industrial causes or disturbance, i.e. those caused by human activity and development or colonial pressures. However, for a general understanding of cumulative impacts we need also to understand the coverage and presence of natural factors that might be relevant to the processes or values under investigation.

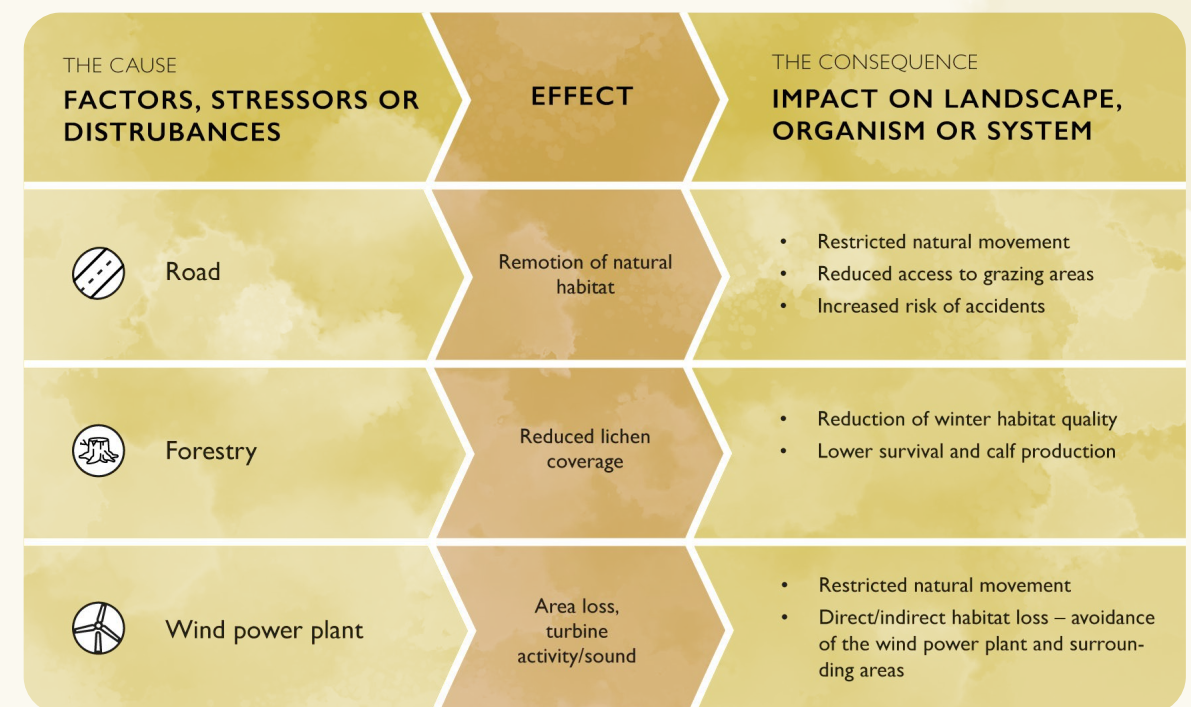


Figure 1.3. Illustration of the distinction between sources, effects, and impacts. The examples show the relationship between factors, stressors, and disturbances (left), the effects caused by them (middle), and some possible impacts on reindeer (right). The effects and impacts are only illustrative.

In this context, cumulative impact assessments (CIA) go beyond common environmental impact assessments (EIA), which are instruments typically applied to single projects, with limited budget, expertise, and time. CIA, by definition, needs to involve multiple existing and planned projects and disturbances, across sectors. As such, CIA needs to be applied within a regional context of land-use planning, evaluating multiple impacts through time and space.

When we evaluate cumulative impacts, we can refer to different definitions and components of impacts (Johnson and St-Laurent, 2011) (BOX 1). For instance, cumulative impacts can arise from the combined effects of disturbances beyond their immediate surroundings, that create a zone of influence (ZOI) in which species behaviour and ecosystem processes change. These impacts often include habitat loss, degradation, and fragmentation, both through direct land alteration and by creating barriers that restrict animal movement. Cumulative impacts can result from many similar disturbance features (e.g., several roads) or from interactions

between different factors and types of disturbance, such as infrastructure, human activities, and natural drivers. Importantly, cumulative impacts occur across space and time and they often interact with broader environmental drivers like climate change. Over time, these local effects can scale up, influencing landscape connectivity, population dynamics, and ecosystem functioning.

BOX 1 presents a short, non-exhaustive list of these components, mostly focusing on ecological impacts. These components are not mutually exclusive, and some impacts can be characterized by many of them. Understanding these definitions and how they can accumulate is an important step to understand the need for cumulative impact assessments, and be able to evaluate how past, present, and future development projects and interventions affect species and systems.

BOX 1

Box 1: Definitions and components of cumulative impacts

- 1. Zone of influence (ZOI).** Disturbances can often produce impacts beyond their spatial delimitation (Niebuhr et al., 2022; Polfus et al., 2011) (see section 2.1.2). The distance from an area around disturbance sources that is affected is often called the *zone of influence* (ZOI) of the impact, and can vary from a few meters to several kilometres, depending on the type of disturbance and the species, process, or context (Niebuhr et al., 2023; Skarin and Åhman, 2014). This can happen when an animal avoids grazing or moving through an area around the disturbance (Horstkotte et al., 2022b).
- 2. Habitat loss, degradation, and fragmentation.** Extractive activities may result in loss and degradation of habitats for species, either through the direct loss of resources or through animal avoidance of areas around disturbance (Horstkotte et al., 2022b; Panzacchi et al., 2015). Disturbances can also act as barriers, impeding or hindering animals from moving across certain areas and fragmenting the landscape for certain species or processes (Beyer et al., 2016; Paviolo et al., 2018).
- 3. Impacts of multiple features of the same type of disturbance.** Impacts of single types of disturbance are generally inferred based on distances to the nearest feature of that stressor, such as the nearest road, urban area, or tourist cabin (Torres et al., 2016). However, it is also possible to account for the cumulative impact of multiple features of the same type (e.g. multiple roads or houses), for instance by considering the spatial density of features within a certain radius. This approach might allow the detection of whether the impact of multiple features of the same type accumulate and affect species' habitat (Niebuhr et al., 2023).
- 4. Impact of different types of disturbance.** The impact of different types of infrastructure might interact with each other and with other environmental drivers such as predators, competitors, climate change, or natural disturbances (Stoessel et al., 2022; Valente et al., 2020). The result of such cumulative impacts might be synergistic and unpredictable and produce an overall combined impact, in some contexts denoted as human footprint (Lelotte, 2021; Venter et al., 2016). For example, difficult weather conditions can lead to partial inaccessibility of habitat areas by species, and with climate change advancing and environmental conditions becoming less predictable, this might lead to cumulative losses of areas (Rasmus et al., 2022).
- 5. Impacts across space and time.** Impacts can accumulate through space, as in the points 1–4 above, but they are also a result of processes that occur through time. This means that landscapes change through time, producing cumulative impacts over time (Johnson and St-Laurent, 2011; Saijets et al., 2024). That might be the case of an area used for forestry, which is cumulatively modified over time (Saijets et al., 2024; Sandström et al., 2016); the accumulation of multiple wind farms and associated infrastructure over time (Österlin and Raitio, 2020); or the consumption of heavy metals by animals or people on a contaminated river, which accumulates over time.
- 6. Upscaled impacts: from individuals to populations, landscapes, and ecosystems.** While local land-use alterations and behavioural responses from animals might lead to habitat loss and fragmentation, these impacts are mostly felt locally by separate individuals. However, impacts can also amount and spread throughout landscapes, affecting the whole spatial network of habitat areas (Van Moorter et al., 2023a). This might affect the amount of functional, connected habitat and the possibilities for animals to move across landscapes through corridors, affecting the connectivity between populations (Van Moorter et al., 2023a) and the connectivity of processes and services across landscapes and ecosystems (Beauchesne et al., 2025).

1.2 Cumulative impacts in a reindeer husbandry context

The components of CI presented in BOX 1 focus mostly on the environment and are general enough to be used in contexts other than reindeer husbandry. However, when it comes to the impacts of extractive industries and land-use change on Sámi culture and livelihoods, we need to acknowledge that we are addressing impacts not only on animals and ecosystems, but also on people within a social-ecological system. This requires bringing new components of impacts,

including, at least, (i) how ecological impacts on reindeer affect also the reindeer herding practices, and the workload and psychosocial wellbeing of reindeer herders (Uboni et al., 2020); (ii) how the impacts on pastures affect individual reindeer and upscale to whole reindeer herds and to the sustainability of reindeer husbandry as a livelihood (Pekkarinen et al., 2022); and (iii) how the participation in assessment and planning activities present an additional burden for reindeer herders (Österlin and Raitio, 2020). These components are better explained in BOX 2.

BOX 2

Box 2: Additional cumulative impacts on reindeer husbandry

- 1. Upscaled impacts on reindeer herding and Sámi livelihoods.** Industrial infrastructure and activities impact both reindeer and reindeer herding. Disturbances that affect reindeer lead to increased work for the reindeer herders, requiring reindeer herders to dedicate more time to herd the reindeer, for example finding alternative routes between seasonal pastures (sometimes not available) or pushing animals through or back to avoided areas (Eftestøl et al., 2023). Lack of access to good winter pastures, also caused by multiple pressures and barriers in the landscape and by climate change, might also lead to the need of supplementary feeding, causing significant increase in costs and workload for the herders.
- 2. Upscaled impacts to costs and economic viability of the livelihood.** The multiple impacts of natural and anthropogenic factors on the state, quality, condition, and accessibility of reindeer pastures can affect reindeer health and welfare and the overall viability of the reindeer herds (Kumpula et al., 2014). These mutual and non-linear relationships, combined with weather conditions and climatic events, influence whether reindeer herds can find enough resources (Simmonds et al., 2025), or if there is need for support to ensure the survival, such as subsidies for supplementary feeding. Overall, the effects of new infrastructure and human activity, summed with more unpredictability due to extreme weather events and climate change, require more active herding and increase the burden on reindeer herders, both physiologically and economically (Uboni et al., 2020). As a consequence, CI influence the viability and sustainability of reindeer husbandry (Pekkarinen et al., 2022, 2015).
- 3. Impacts of fragmented land-use planning.** Beyond the physical fragmentation of the landscapes, land-use planning is often fragmented into local, sectorial, and separated processes (Gillingham et al., 2016; Österlin and Raitio, 2020). This produces an additional burden for reindeer herders due to the increased time they need to dedicate to understand and assess the details in each planning process, through consultation meetings, hearings, court cases or in other types of arenas. This demands time and/or resources from the herding communities, or they risk being left out and being affected by every new project (Österlin and Raitio, 2020).

The Sámi traditional knowledge and experiences of reindeer herders form the basis to carry out CIA within a reindeer husbandry context. In the production of knowledge in relation to reindeer husbandry and how industrial impacts affect the life and livelihood in Sápmi, it is essential to acknowledge the central role and expertise of traditional knowledge of reindeer herders. Reindeer herders own the reindeer and the data produced about the animals. Thus, it is crucial that reindeer herders contribute to identifying research needs, raising hypotheses, and interpreting the data about the reindeer husbandry system.

Environmental Impact Assessments are often conducted by academically trained experts lacking expertise on reindeer and reindeer husbandry, without accounting for other land uses or including reindeer herders' knowledge and perspectives, or involving affected reindeer herders too late in the assessment process (Eilertsen et al., 2025b, 2025a). In both national governmental regulatory documents and at EU-level there are mentions of the need to account for CI. In Norway and Sweden, several court cases on industrial land use in the reindeer husbandry area have raised the need for more detailed content in the EIAs, highlighting CI and particularly emphasizing the role of Indigenous Peoples' rights. However, neither these guidelines nor the court decisions explain *how* CI should be assessed.

In this chapter, we provide key definitions and ideas for basic elements to be included in CIA in the context of reindeer husbandry as a social-ecological system. Tools and methods available are listed in Chapter 2 and more deeply presented in Chapter 4.



PHOTO: KNUIT LANGELAND

2

2. Methods and data in cumulative impact assessment: from infrastructure to social-ecological systems

In this chapter, we briefly describe some of the existing methods to understand and map CI and we point out data that are needed to perform CIA. Using the general concepts and context on CI and CIA presented in Chapter 1, we review frameworks and methods from scientific literature and from non-scientific reports when we consider the content valuable. We start by presenting methods focusing on infrastructure and land use and then switch to methods centered on the social-ecological system. The maps in Figure 2.1 illustrate a shift from gathering data and maps of sources of disturbance in Sápmi, such as infrastructure and density of predators, to approaches that emphasize their functional consequences for reindeer and the broader social-ecological system.

Our review looks at how cumulative impacts are understood using different approaches. We describe the main ideas behind these approaches, the tools and data they use, how the methods are similar or different, and whether they overlap or work well together. Finally, we discuss which factors are included and which ones are often left out.

2.1 Methods for cumulative impact assessment

2.1.1 Location of potential sources of disturbance and stressors

Typically, the first step to identify and quantify cumulative effects (as defined in section 1.1) is to map or gather geographical information on the stressors, pressures, or sources of disturbance. This is illustrated in figure 2.1A, which shows an overlay of public source data on infrastructure in Norway

and the reindeer herding area in Sweden. Such maps might include public and private roads, railways, hydropower reservoirs, wind farms, power lines, mines, and tourist resorts. Information about land use is usually managed by governmental agencies responsible for different activities. However, none of the three countries has a single map service that brings together all information about different land uses in one place. In Sweden, there are yearly efforts by the Sámi parliament to gather all available information within the reindeer husbandry area into one map system (see section 4.1). Similar efforts are also made in Finland and Norway.

Maps showing all land uses are useful to get an overview of the current land uses, but they represent a static “snapshot” of how much infrastructure there is in a region at a given point in time, and they do not show the development through time, nor their influence on the system. In contrast, it can be helpful

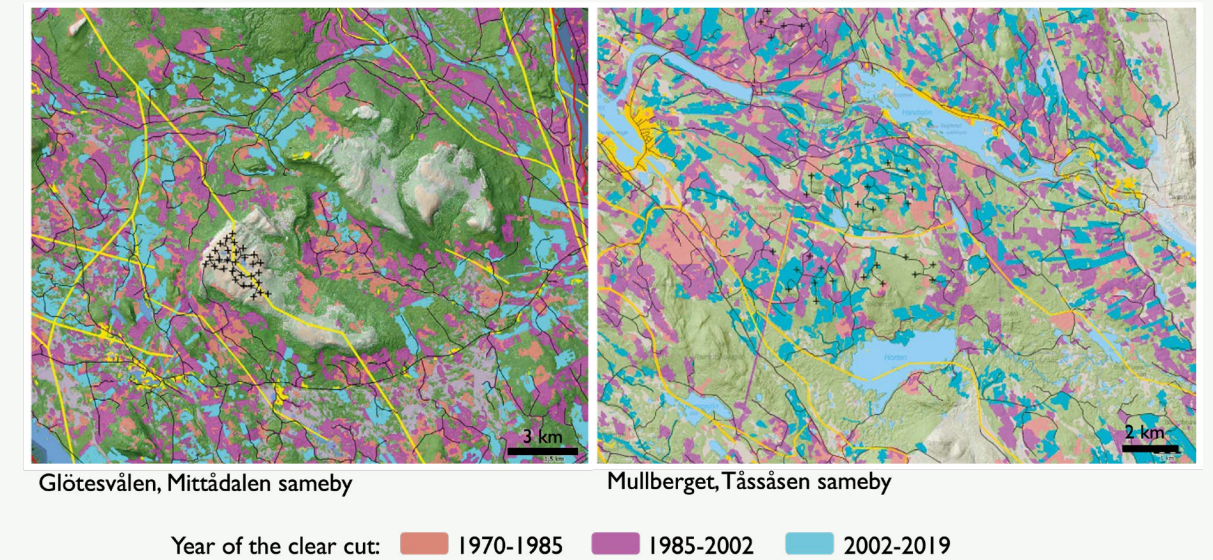
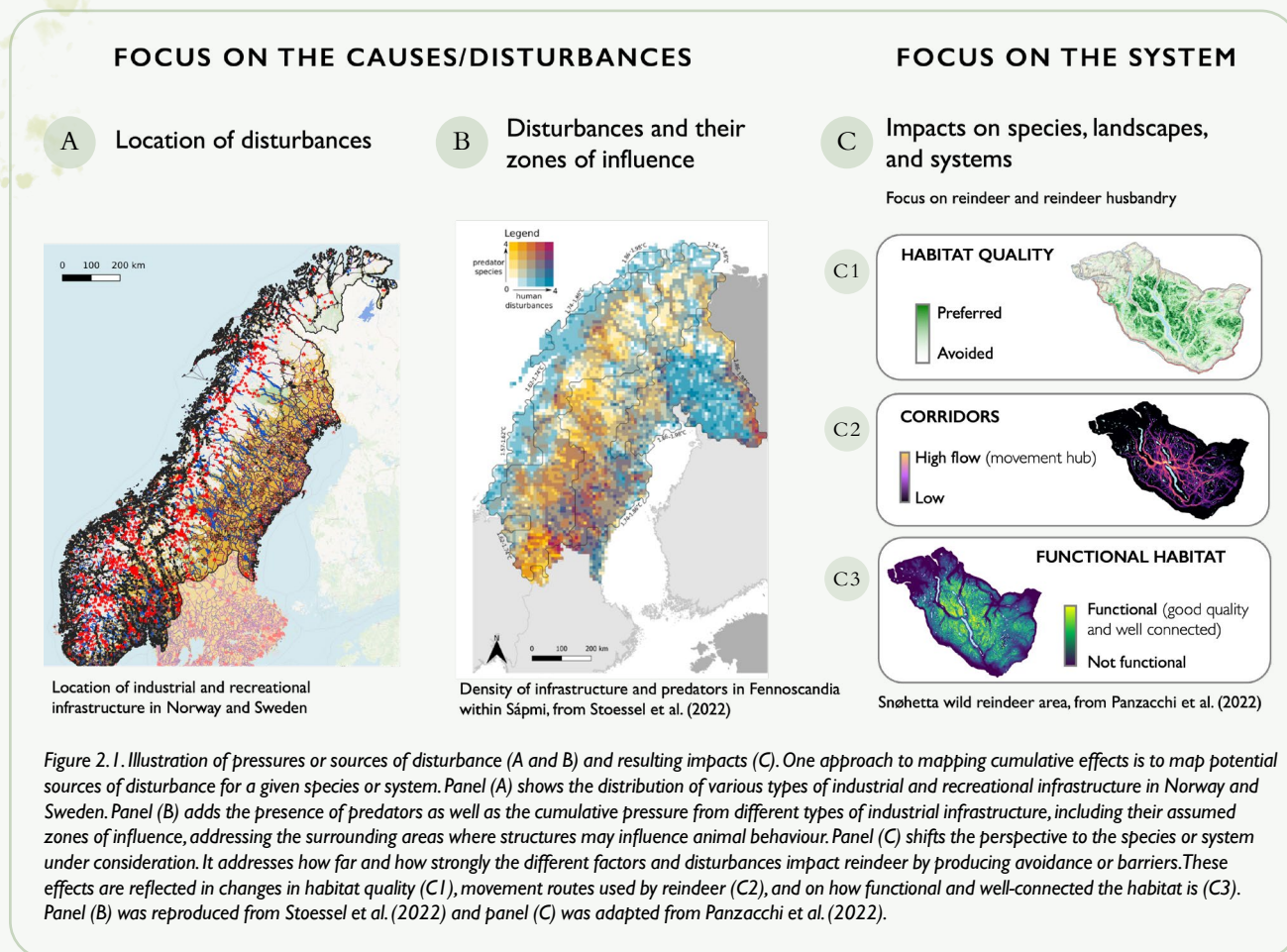


Figure 2.2. Illustration of the cumulative effects of forestry on two reindeer herding communities in Sweden, each surrounding a different built wind farm (crosses, +). The figure shows forestry clear-cuts from different periods, roads (in black), and traditional reindeer migration corridors (as mapped by the reindeer herders) in yellow. Figures adapted from Skarin et al. (2021).

to understand, for instance, the cumulative change in forestry through mapping the clear cuts through time, as in figure 2.2. The illustration shows how the impacts of clear-cuts from forestry extend through space and accumulate over time, and after some decades affect most of the area. Another similar case is presented in more detail in section 4.6.

2.1.2 Accounting for zones of influence on species, ecosystems and people

Impacts of human activity and infrastructure often go beyond the area they occupy. This can be assessed through the identification of zones of influence (ZOI). One way to account for the ZOI around infrastructure is to estimate how far the impacts of different stressors might reach in different processes or on the species under consideration and compute buffers around infrastructure types. The size of a ZOI can be calculated using the *distance* to, or the

density of, the disturbance sources (Figure 2.3). Knowledge of the magnitude of the impact may be estimated using experience-based knowledge or through analysis of data on the presence or movement of animals. The most common method today is based on data-driven approaches, usually derived from the use of data from GPS collars. This requires substantial data on reindeer positions and behaviour (Boulanger et al., 2021; Niebuhr et al., 2023; see sections 2.1.3 and 4.2).

There have been several studies, especially within the *Rangifer*-literature, to illustrate how the ZOI from different human activities and infrastructures may influence *Rangifer* populations (Environment and Climate Change Canada, 2024) and reindeer husbandry (Bäck et al., 1992; Fohringer et al., 2021; Larsen et al., 2016). For instance, some studies have estimated the area affected by infrastructure by creating a 500 meter zone around roads, buildings

and other development (Driedger (2014), Environment Canada (2011), Fohringer et al. (2021)) (Figure 2.3A). Other studies have defined different buffer sizes depending on the type of infrastructure, based on previous research, to better capture how multiple human activities together influence the landscape (Fjällberg, 2025; Larsen et al., 2016). Other studies have proposed the use of expert and traditional knowledge and experience to define the ZOI, which is possible in the case of reindeer husbandry, as reindeer herders closely observe and herd the animals throughout the year (Blom, 2023). The knowledge and experience of reindeer herders can therefore be combined with scientific data, or used as valuable sources on their own. This illustrates the importance of having reindeer herders included in impact assessment processes (Eilertsen et al., 2025b, 2025a).

These methods focus on how different disturbances overlap across the landscape, rather than looking at one impact at a time. They are relatively simple to use with standard GIS mapping tools. One challenge, however, is deciding how large the affected area around each disturbance should be, especially when local knowledge, research, or data are limited.

Many studies using these methods focus mainly on infrastructure and disturbances (what happens around infrastructure?), instead of focusing on what matters as requirements and resources for the affected animals and people. As a result, cumulative impacts are often assessed from the perspective of developers or land planners, rather than the perspective of animals or reindeer herders (Eilertsen et al., 2025b; Skarin and Åhman, 2014).

2.1.3 Estimating impacts on animal behaviour and populations

An important part of research on cumulative impacts focuses on understanding where animals live and how their habitats change when landscapes are affected by many different disturbances. One common method is to use statistical models to study animal movements and their relationships with environmental conditions across landscapes. These models can be called habitat models.

Habitat models have been widely used on caribou (Boulanger et al., 2021; Johnson et al., 2005; Plante et al., 2018), wild reindeer (Panzacchi et al., 2022, 2015), and semi-domesticated reindeer in reindeer husbandry systems (Anttonen et al., 2011; Horst-

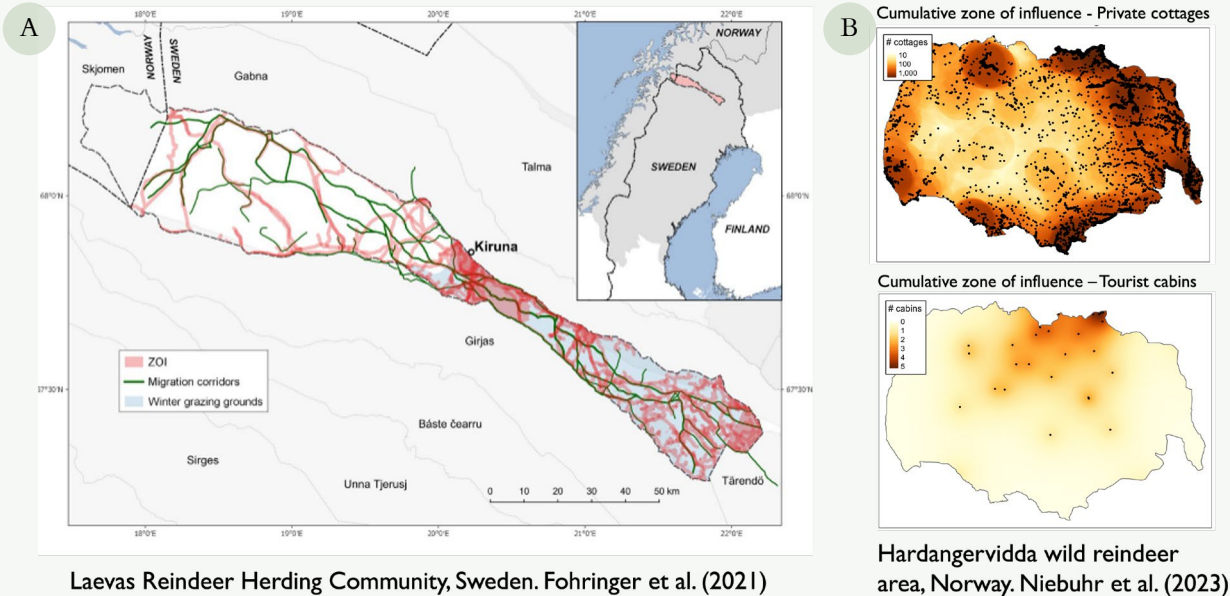


Figure 2.3. Different representations of impacts that go beyond the spatial boundaries of the infrastructure or development projects. Panel (A) shows a fixed-sized buffer of 500 m over multiple types of infrastructure, used as a proxy to represent areas under the influence of human infrastructure in the Laevas reindeer herding community in Sweden, reproduced from Fohringer et al. (2021). Panel (B) represents the density of private cottages and tourist cabins computed at different scales on the Hardangervidda wild reindeer area in Norway, which represent the ZOI of these infrastructures on reindeer, reproduced from Niebuhr et al. (2023).

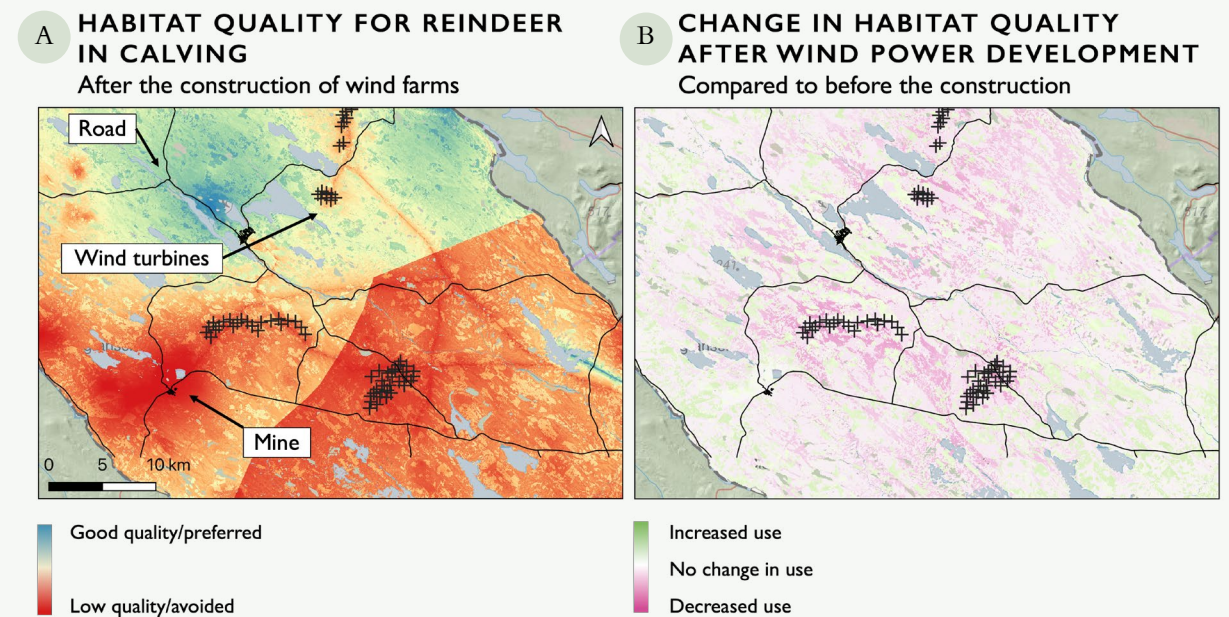


Figure 2.4. Spatial representation of (A) the habitat quality of reindeer during calving and (B) the changes in habitat quality after the construction of four wind farms in the Malå reindeer herding community in Sweden. The assessment is based on GPS and environmental data within a habitat modelling approach, considering the cumulative impact of wind farms, mining, roads, and other factors, and uses a before-after approach common to impact assessments. Figures adapted from Skarin et al. (2021).

kotte et al., 2023; Kumpula et al., 2014; Skarin et al., 2018, 2015). The models use information about where the animals move – often collected through GPS collars – together with environmental data to understand which areas animals prefer to use (Northrup et al., 2022). The use of GPS collars has become more common in recent decades and is also used by the reindeer herding communities for different purposes (Kuoljok, 2020).

Habitat models can help measure how animals use habitats and how much habitat may be lost due to different disturbances. One advantage of habitat models is that they can examine many different factors at the same time, including food resources, landscape features, climate, infrastructure, and different types of human activity or disturbance. This makes it possible to identify areas with high-quality habitat, where disturbances are limited or absent. The models also help distinguish between the effects of habitat quality and the effects of disturbances, making it easier to understand what influences animals and their use of the landscape.

Depending on how habitat models are computed, this approach might also account for the cumulative impacts of multiple features of the same type (Niebuhr et al., 2023; Panzacchi et al., 2022) and their zones of influence (Boulanger et al., 2021; Skarin et al., 2018), and assess changes when comparing animal behaviour before and after a certain land-use change or development project (Figure 2.4) (Eftestøl et al., 2021; Skarin et al., 2021). Examples of this approach are presented in sections 4.2 and 4.3.

In addition, habitat modelling can be used to measure cumulative impacts, habitat loss, and drivers of habitat loss (Lelotte, 2021; Van Moorter et al., 2023b). By using animal movement data (GPS data) it is also possible to identify barriers in the landscape (Beyer et al., 2016; Panzacchi et al., 2016), making it possible to study entire landscapes, looking both at where suitable habitats exist and how easily animals can reach them (Van Moorter et al., 2023a, 2021; see section 4.2 for more details). By assessing how habitats are connected, these methods can also help explain how individual animals are affected and how impacts may influence entire populations over time

(Van Moorter et al., 2023a), linking habitat loss and fragmentation to population dynamics (Lelotte et al., 2025).

Combining animal movement data with information such as population numbers or roadkill records can help reveal the wider effects of cumulative impacts. For example, the construction of a wind farm in a reindeer herding area in Sweden required roads to be opened and cleared during winter (Skarin et al., 2021). These roads made it easier for reindeer to move toward a major public road, leading to a sharp increase in traffic collisions and reindeer deaths after the construction of the wind farms (Figure 2.5). The roads also improved access for forestry companies, enabling further forest exploitation. This example shows how wind power development, roads, and forestry together can create cumulative spillover impacts that extend beyond habitat loss and affect reindeer survival.

Another way to study how reindeer populations are affected by multiple pressures is to monitor individual animals within herds. By combining this with environmental data such as snow conditions,

spring timing, plant growth, population density, and animal age, we can better understand how these factors influence body condition, survival, and reproduction (Henden et al., 2022; Lundqvist et al., 2009; Simmonds et al., 2025). These approaches require long-term monitoring of individual animals, but they make it possible to measure both direct and indirect impacts and understand how these effects build up over time across the population. This is explored in the example in section 4.4.

2.1.4 Knowledge co-production approaches to assess cumulative impacts

In reindeer husbandry, traditional knowledge (TK) is embedded in traditional practices and has been acquired and transmitted through generations of reindeer herders. TK includes the long-term observation of landscapes, reindeer migration patterns, grazing conditions, and descriptions and experiences of ecological change, to cite just some aspects (Riseth et al., 2011; Sandström, 2015). Approaches on multiple evidence-based knowledge and co-production of knowledge involve collaborative partnerships between scientists or consultants and

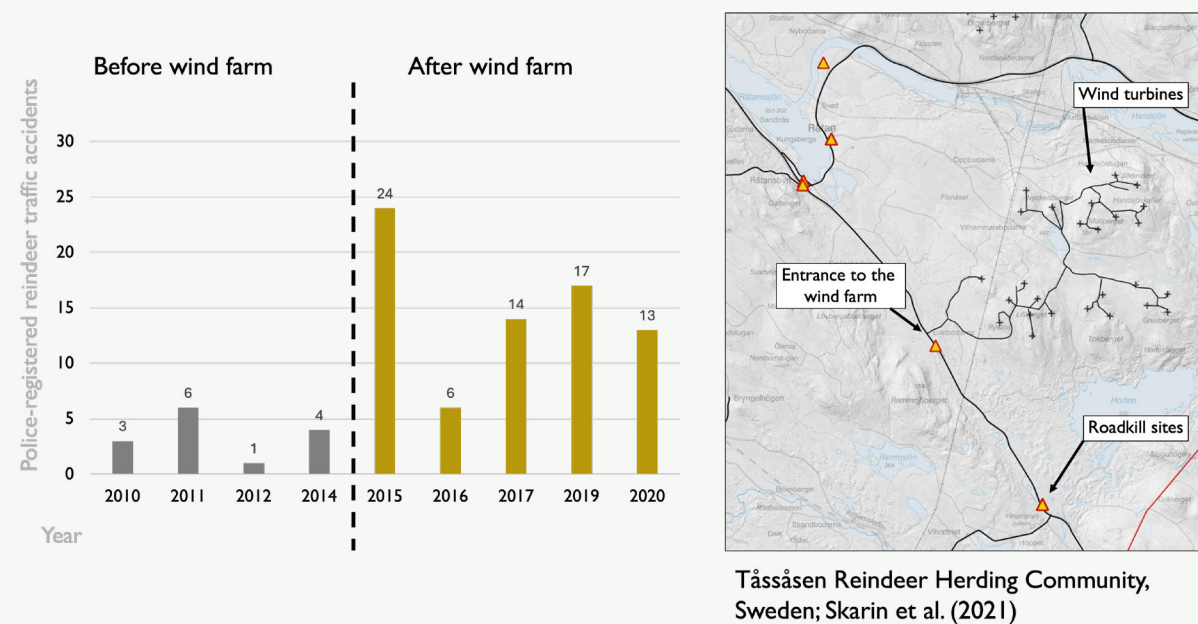


Figure 2.5. Number of police-registered reindeer traffic accident across time, before and after the construction of the Mullberg wind farm, located in Tåssåsen reindeer herding community, in Sweden. The map shows the wind farm together with associated local roads that link the wind farm to the main E45 road, and points in which reindeer were road killed in the main roads. The increased number of reindeer killed in traffic collisions illustrated the cumulative impact of the wind farm and associated infrastructure not only on the habitat and reindeer behaviour, but on reindeer mortality. Figure adapted from Skarin et al. (2021).

Indigenous Peoples and need to bridge “knowledge held by reindeer herders and knowledge created by the tools of academic science” (Heatta et al., 2025b, see also 2025a). In doing so, coproduced knowledge can allow for more just and inclusive evidence, respect and empowerment of Indigenous communities, and may produce assessments and solutions more grounded on specific contexts (Johnsen et al., 2024). Co-production requires the establishment of long-term, trust relationships, ensuring two-way communication and giving equal importance for different knowledge systems. However, implementing co-production of knowledge can be challenging because of historical legitimacy of science in detriment of TK, unequal power relations, geographical biases, and different motivations by the participants, and is often limited in the context of most current impact assessments.

In Sápmi, several projects have been documenting climate and environmental change using collaborative approaches, such as in the Climate Impacts on Terrestrial Environments (CITE) project led

by the Saami Council (Heatta et al., 2025b). This project documented and compared scientific predictions and maps related to climate change and observations and experiences from reindeer herders in different areas and contexts. In Sweden, co-production approaches were also applied in the construction of the Reindeer Husbandry Plans (*Renbruksplan*) and in environmental assessments carried out in research projects (Johnsen et al., 2024; Larsen et al., 2016; Skarin et al., 2021). These studies used both qualitative descriptions of the environmental change and quantitative assessments. See sections 4.1 and 4.3 for more in-depth examples of co-production approaches applied in reindeer husbandry. More broadly, co-production approaches were used in other regions, such as in Canada, to bridge Indigenous knowledge with scientific platforms such as ALCES (Carlson et al., 2014), that allow overlaying maps and simulating the spatial consequences of cumulative impacts on indigenous land uses (Carlson et al., 2025).

2.1.5 Counter-mapping, Indigenous mapping, and self-chartography

Reindeer herders’ knowledge and experience are unique and provide important ways to understand and map how landscapes are affected by different activities often referred to as self-assessment, self-chartography or Indigenous mapping. This includes approaches where reindeer herders themselves identify and describe important grazing areas, migration routes, and areas affected by disturbances.

One example is a study by Fjällberg (2025), which examined how key grazing areas identified by reindeer herders were affected by industrial activities and their surrounding zones of influence. Another example comes from the Protect Sápmi foundation, which developed a method where Sámi reindeer herders use their own knowledge and experience to define how different types of infrastructure affect surrounding areas (Blom, 2023). By combining these areas on maps, it becomes possible to visualize cumulative impacts across the landscape.

These approaches are part of a broader effort to include Indigenous knowledge and perspectives through counter-mapping and self-cartography of impacts (Kidd, 2019; Almeida, 2020). The aim is to create more inclusive and fair ways of understanding landscape change than approaches based only on information from companies, authorities, or researchers. Some studies have also adapted scientific tools, such as habitat models, to build maps based on traditional knowledge (Bridger et al., 2016; Gryba et al., 2025). Overall, these approaches highlight the importance of centering impact assessment not only on the animals, but on the relational practices of reindeer herders and Sámi livelihoods.

2.2 Data and knowledge for cumulative impact assessment

Cumulative impact assessment in reindeer husbandry relies on diverse forms of data and knowledge^{**}. Based on discussions from the workshop in Oslo in August 2025, we present principles for data use and collaboration, addressing some of the types of data needed for CIA, and potentials and limitations of existing data.

2.2.1 Principles for data use and collaboration

In reindeer husbandry areas, close collaboration and communication between reindeer herders and people conducting CIA is needed to conduct assessments that are ethically sound and contextually situated. A great part of the data related to reindeer husbandry is collected by or together with reindeer herders. The herders herd and observe the reindeer continuously. This means that reindeer herders should have an important role in impact assessments and land management – not only as providers of data, but also as active participants in shaping and interpreting analyses, maps, and other products. Lack of collaboration with reindeer herders poses a risk of misusing data, making assessments without considering the context, and, at worst, harming the communities in question.

Use of data and analyses for CIA in reindeer husbandry should follow standards such as the CARE principles for Indigenous data governance (Carroll et al., 2020). The CARE principles stand for Collective Benefit, Authority to Control, Responsibility, and Ethics, and should be guidelines for data and knowledge relations in all steps of CIA. Based on these, the Saami Council created the SODA (Sámi Ownership and Data Access) principles, which further includes the principle of ownership, making it a fundamental right of the Sámi people (Fjellheim, 2024). Further guidelines on how to use, or not to use, data and products of CIA must be developed to promote just assessments and protect the rights and interests of Sámi reindeer herders.

2.2.2 Types of data in cumulative impact assessment

Three main categories of data and knowledge are required in CIA in relation to reindeer husbandry: (i) environmental data; (ii) reindeer and biological data; and (iii) traditional knowledge (TK).

ENVIRONMENTAL DATA

Environmental data is referred here as data on reindeer resources, landscape variables, climate variables, infrastructure, and human activities. These variables are generally understood as drivers of

^{**}We do not intend on making a comprehensive list of existing, available, or desired data types and data sets for CIA on reindeer, reindeer husbandry, and Sámi livelihoods. Such a list would be valuable, but is beyond the scope of this report.

reindeer habitat selection and behaviour, which therefore affect reindeer herding. The data are often available as public geographical data, or it may be collected through remote sensing, such as satellite data, or through drone monitoring.

Activities relevant for providing environmental data for CIA include:

- **Mapping reindeer pastures** and how pastures are used during the reindeer annual cycle, how they are or can be impacted by weather conditions, and how they change through time. For example, lichens and grazing areas were mapped in parts of Norway (Erlandsson et al., 2024, 2022), Sweden (Adler et al., 2025, 2022), and Finland (Kumpula et al., 2014; Kumpula, 2006).
- **Harmonizing classifications across regions and countries.** Most data are produced at regional or national scales/ extents. This hinders the integration of approaches, analyses, and data across borders within Sápmi and makes it harder to compare the different contexts. For instance, synchronization between land cover classes across land cover maps would open for cross-border comparisons of CI on reindeer husbandry.
- **Increasing access to dynamic data rather than static ‘snapshots’.** CIA would benefit from better access to public data on dynamic maps that document landscape change. There is a need to go beyond static maps towards an understanding of spatiotemporal evolution of development on different sectors and how they affect reindeer and reindeer husbandry. Most of this dynamic, temporal data is not publicly available and accessible, sometimes not even under request. Consequently, governments, institutions and reindeer herding communities do not have an overview of how much development exists, to what extent, and how fast developments have been happening.
- **Climate data.** There is a need for better data on harmful weather events and on areas that are especially vulnerable to climate change, such as areas with sensitive vegetation or rapidly

shrinking snow and ice resources. It is also important to identify critical areas that help reindeer adapt to changing conditions, for example grazing areas used during icy winters or hot summer periods. Climate change can also affect herding conditions in other ways, such as thawing permafrost or changes in the tree line. Researchers and reindeer herders can work together to identify these areas and better understand the conditions that affect them.

REINDEER AND BIOLOGICAL DATA

Data on reindeer movement, behaviour, and population dynamics are central to CIA.

- **Reindeer location data.** In science and management, reindeer have been located using aerial counts, faecal pellet counts, or through indirect measures of lichen abundance. Over the past 20 years, GPS collars attached to reindeer have become an important tool for tracking reindeer movements across large areas and over long periods of time. Reindeer herders in Norway, Sweden, and Finland have collected large amounts of GPS data, which can provide valuable information for cumulative impact assessments when combined with other environmental and land-use data, and with contextual knowledge from the reindeer herders, as shown in the examples from section 4.2 and 4.3.
- **Drone data.** Drones have been used by reindeer herders over the past 10 years, allowing them to herd the animals and monitor them when they are close to infrastructure, such as roads and railways. Drones can record photos, videos, and locations of the animals. This information can be used to describe animal behaviour, disturbance, and barriers in the landscape. As a complement to GPS collars, drones can monitor many animals at the same time, making it possible to collect information about entire reindeer herds over shorter periods. Together, these data can provide new insights into how reindeer use habitats, interact with each other and with herders, and respond to disturbances from other land users.



Lichen inventory on reindeer winter pastures using a vegetation sampling frame.

- **Reindeer counts.** In Norway, Sweden, and Finland, reindeer herders report the size of their winter herds (after slaughter and before calving) each year to government authorities. In Sweden and Norway, authorities also carry out regular herd counts. However, these counts are uncertain because they do not account for animals that may be missed (due to problems during gatherings) during counting. Marking individual reindeer can provide additional information about herd condition and make it possible to study long-term effects of climate change and land use on reindeer populations (see section 4.4).
- **Data infrastructure.** Standardizing and centralizing datasets can be an important tool for collaboration, as in the case of Movebank (<http://movebank.org/>) or Euromammals (<https://euromammals.org/>) databases, aggregating data from multiple projects and species. Most of the reindeer position data is private but may be archived in databases managed by research institutions, such as WRAM (Wireless Remote Animal Monitoring <https://wram.slu.se/>) hosted in Sweden and Dyreposisjon (Animal Positions <https://www.dyreposisjon.no/>) hosted in Norway. These databases store

and display positions of animals equipped with GPS transmitters and access to the data from different projects is subject to authorization from the data owners. The databases make it easier for data to be stored, standardized, and shared. Other datasets are kept within private/personal repositories. Putting data into shared infrastructures and making them findable might be a good solution for future Nordic collaboration and open possibilities for CIA beyond the borders of specific regions, reindeer herding districts, or nations. Yet such initiatives need to be followed by ethical guidelines on how to (not) use the data and need to account for the responsibilities and costs of storing the data.

TRADITIONAL KNOWLEDGE

Traditional knowledge (TK)^{††} is built on long experience and embedded in daily practices in reindeer husbandry. The knowledge and observations shared by reindeer herders are essential for understanding long-term environmental change, including changes that are difficult to capture through technical monitoring. This is especially important in a time of rapid climate change and more frequent extreme weather events. As holders of TK, reindeer herders can provide important context about landscapes and environmental conditions that cannot be understood through technical data alone. Their knowledge includes seasonal grazing patterns, migration routes, herding practices, and how reindeer and pastures respond to changing environmental conditions. It also includes relationships within and between herding groups, the close connection between herders and reindeer, and the ability of future generations to continue reindeer husbandry. Traditional Knowledge can be shared through participatory methods such as interviews, participatory mapping, and community-based monitoring. Accounting for TK is essential for meaningful CIA, but is rarely integrated into such assessments, even though in some cases the herding communities spend considerable time supporting consultants and contributing with knowledge to assessments on reindeer husbandry.

^{††} The traditional knowledge of Sámi reindeer herders is also sometimes referred to as Indigenous knowledge, practitioner knowledge, local knowledge, inherited knowledge, or experiential knowledge.

Consideration of TK on CIA should rely on:

- Free, prior, and informed consent;
- Respect for ownership and governance by Sámi knowledge holders;
- Careful contextual interpretation, avoiding misuse of the data.

Developing data infrastructure and ways of storing data based on TK could allow sharing data already collected in different contexts useful for CIA and would be useful for avoiding research fatigue by Sámi knowledge holders. However, any data initiative in this context should be fully governed, owned and controlled by knowledge holders themselves, and not replace direct interaction with and participation of reindeer herders for new specific projects and contexts.



PHOTO: KNUIT LÅNGELAND

3. Advancing cumulative impact assessment in Sápmi: recommendations and considerations

In this chapter, we outline key recommendations and knowledge gaps identified during the work leading to this report. We first present recommendations for strengthening future collaboration. We then discuss how climate change can be better integrated into CIA, and highlight the importance of understanding how maps and models are created and interpreted in the context of Sápmi and Sámi traditional livelihoods.

3.1 Recommendations for further collaboration

1.

Recommendation 1: Transition from project-based to cumulative impact assessment and land-use planning

- Comprehensive land-use planning and CIA in relation to reindeer husbandry is urgently needed, addressing past, present and planned land-uses regionally and across government and development sectors (see, for instance, Horstkotte et al., 2022a; Johnson et al., 2020; Larsdotter and Olsson, 2026; Panzacchi et al., 2022).
- CIA should extend beyond reactive impact assessment and inspire long-term planning processes, tools, and regulatory development^{##} to guide land-use decisions. They should aim to bridge knowledge systems and enable predictive and participatory assessments of cumulative impacts.
- CIA requires institutional and governance infrastructure capable of taking into account the spatial and temporal scale that CIA methods and extensive socio-ecological systems like reindeer husbandry require. Methods on CIA centred on reindeer husbandry can only gain relevance in decision-making if the current fragmented design of institutions is also modified and reworked to address socio-ecological concerns that span across seasons, regions and externally established political boundaries.

^{##} Legal frameworks are outside the expertise of the authors of this report, but are mentioned here given its importance to formalize and create minimal standards for CIA in Sápmi.

2. Recommendation 2: Upscaling Nordic collaboration

Advancing the inclusion of CI in impact assessment and land-use planning in the context of Sápmi depends on a strong and continued collaboration between Sámi rightsolders, researchers, authorities and industry, with an interdisciplinary composition of participants from Norway, Sweden and Finland. Some examples of this include:

- Increased sharing of information within and across countries. This requires shared platforms to increase the availability and awareness of existing methods and data. Both digital platforms, such as websites, and physical platforms, such as meetings, are needed.
- Reinforcing collaboration settings that build trust across partners. Open science and open practices of knowledge production should go beyond sharing data and resources, but “primarily fostering meaningful communication between the humans involved”, allowing long-term trust relationships to be built and a diversity of ways of knowing and understanding impacts and systems to be considered.
- Capacity building in the form of training and guides to implement CIA in practice.
- As current datasets are fragmented and inconsistent across borders, harmonization of spatial and climate data classifications, indicators, and data standards between Norway, Sweden, Finland is needed to implement transboundary CIA.

3. Recommendation 3: Respecting and supporting Sámi authority

- Cumulative Impact Assessment in the context of Sápmi and Sámi traditional livelihoods needs to build on the expertise of the Sámi rightsolders and support their right to self-determination as Indigenous People.
- Co-designing of meaningful participation models for Sámi communities and rightsolders in CIA is needed, while avoiding unnecessary burden and considering fair compensation of time and expertise shared.
- Sámi traditional knowledge is key in understanding reindeer herding systems and how they are affected by cumulative impacts. Any decision on sharing traditional knowledge should be handled by Sámi organizations and individuals. If shared, all knowledge should be managed confidentially, following the terms determined by the Sámi communities, and only for the purpose for which the knowledge was shared. Knowledge and spatial information are not static and always needs to be interpreted with the Sámi communities in question.
- Data governance should follow ethical guidelines, such as the CARE (Collective Benefit, Authority to Control, Responsibility, and Ethics) and SODA (Sámi Ownership and Data Access) principles (Axelsson and Mienna, 2020; Carroll et al., 2020; Fjellheim, 2024).

4. Recommendation 4: Filling research and data gaps

- One large gap is the lack of studies developing and applying CIA in Sámi livelihoods other than reindeer husbandry. Therefore, one pressing need for broader consideration of CI and CIA in Sápmi is the extension and development of CIA to all traditional Sámi livelihoods.
- To mitigate and compensate for the negative impacts, solutions to restore and enhance the pastures and landscapes need to be further studied on a Nordic scale.

3.2 Consideration of climate change as a cumulative driver

Reindeer husbandry traditionally involves rotation of areas used as pastures in different years, seasons, and *siida* or *tokkakunta*. Understanding how climate and variability on weather affect landscapes and grazing conditions for reindeer is part of the traditional knowledge built through observation and herding practices, and allows a sustainable management of the herds under different conditions (Heatta et al., 2025b). In this context, climate change is a risk multiplier, acting on top of other cumulative land-use pressures (Rasmus et al., 2022, 2020). Future research on CIA should explicitly account for the cumulative impacts of land use and climate change. Approaches in this direction could include:

- Mapping critical seasonal pastures needed as buffers during extreme weather events (heat waves, rain-on-snow, difficult snow conditions). Adaptation to climate change links directly to conditions and land use on pastures. Some pasture areas are more vulnerable to climate change than others (sensitive vegetation, summer-time snow and ice resources) and some habitats are more crucial than others during harmful conditions (icy snow, heat), which will likely become more common with climate change. The diversity of pastures is part of the adaptive capacity of herding communities. Understanding and identifying these critical and diverse areas will be important when developing CIA, to allow prioritization within land-use planning.
- Monitoring shifts or relocations of migration routes and pasture use by reindeer due to climate change. Climate change leads to changes in vegetation and snow and ice conditions, for example, on seasonal pastures, migration routes, and calving grounds. This means changes in conditions for reindeer gathering, slaughter and calf marking, not even mentioning the costly needs for supplementary feeding during difficult winter conditions.
- Incorporating local observations and traditional knowledge into studies related to climate

change, as meteorological observations are sparse and climate modelling data still too coarse to capture the fine-scale events. Several weather-related conditions critical in reindeer herding are also not currently monitored or properly simulated (Menard et al., 2024).

- Acknowledging and collaborating with locally-led initiatives like the CITE project (<https://www.saamicouncil.net/en/cite>), led by the Saami Council. In this project, the aim was to create a digital tool for herding communities for systematic documentation of herders' observations and experiences related to observed changes on their land.
- Aligning land-use planning with climate adaptation strategies. As land-use planning directly impacts the possibilities for adaptation in reindeer husbandry, policymaking related to land use and climate adaptation should not be isolated from each other. According to the European Union Climate-ADAPT documents, for instance, “land-use planning is identified as one of the most effective processes to facilitate local adaptation to climate change.” (Richardson and Otero, 2012; Wilson and Piper, 2010)

3.3 Considerations about maps, models, and interpretation in cumulative impact assessment

Maps play an important role in CIA, as they can help communicate needs, impacts, and changes. They should be understood as tools for dialogue and interpretation, not as standalone decision-making instruments. Here we list some considerations related to the use and interpretation of maps and models in CIA.

- Most maps are static, i.e., they represent a “snapshot in time”. Static *maps* have inherent limitations. They capture a moment in time, whereas landscapes and herding practices are dynamic. Future developments in CI and CIA should include dynamic maps that represent how human pressures and reindeer conditions change both in space and time.
- To address this, CI and CIA should focus on producing *models* (not only maps) that capture

complex relationships and mutual effects of components of the system, such as the ones presented further down in Chapter 4. Models can then be used to create maps, summaries, and other products that might be useful to understand, illustrate, and predict CI. Also, models should be informed not only by environmental and reindeer data but also by Sámi traditional knowledge. Importantly, maps, models, and other spatial tools require institutional support, so they can be iteratively developed and maintained and be allowed to be tested and used for management, as well as updated according to new data and feedback from reindeer herders.

- Both maps and models require context to be meaningful (Heatta et al., 2025b). Decision-makers often lack the baseline knowledge needed to interpret maps and models, making it essential to provide instructions on how maps should be used and what they do not show. Here both scientific knowledge and Sámi traditional knowledge are essential. Equally important is the need to respect Sámi perspectives on landscapes. Maps should not impose prevailing cartographic concepts; they should also reflect what constitutes a meaningful landscape from the viewpoint of reindeer herders. This includes recognizing functional relationships between areas and valuing herders' knowledge on equal terms with technical, established academic representations. They should articulate ways of knowing that help maintain Sámi traditions and livelihoods.

- Tools like the Reindeer Husbandry Plans developed in Sweden (see section 4.1) can be useful for reducing conflicts and bringing in reindeer herders' perspectives into land-use planning, but their application requires caution, to avoid misinterpretation of data. For example, if a map shows an area as "not much used", developers should not assume it is available for development, overlooking that such areas may be critical under specific conditions, such as under certain snow or climate conditions. Maps and CIA results need to be understood in context and as part of a functional whole, in which every area matters in different situations. In most cases, the information and knowledge on reindeer and Sámi reindeer herding is to be understood as the intellectual property of the Sámi rightsholders. All use of such resources therefore needs to be consensual and follow the principle of Free, Prior, and Informed Consent.



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4. Cumulative impact assessment in practice: examples on reindeer and reindeer husbandry

In this chapter, we provide examples of cumulative impact approaches that have been applied in Sápmi, or in other reindeer herding or wild reindeer areas of Fennoscandia. The approaches touch on different components of CI, as presented in Chapter 1. The aim of the chapter is to provide tools and examples of applications of CIA and point to existing resources, which may also be useful to assess CI in other contexts.

Despite the differences in context and content, we systematically address the same key aspects in each example:

1. What is the overall vision and aim of the approach, and how can it contribute to understanding, quantifying, and mapping cumulative impacts?
2. What are the steps and how does the approach work?
3. What is the output of the analysis or assessment?
4. Has this framework been used in practice in environmental impact assessment or land-use planning?
5. What are the strengths and limitations of the different methods?

The examples are summarized in Table 4.1. Besides a systematic explanation, the examples offer references to applications, publications, and tools as resources for readers that are interested in searching for further information.

4.1 Reindeer Husbandry Plans: co-producing maps describing reindeer resources, reindeer husbandry, and cumulative impacts

What is the approach?

The Renbruksplan programme (RBP, Reindeer Husbandry Plan) in Sweden has been ongoing for more than 25 years. The programme emerged from needs expressed by Sámi reindeer herders for tools that could support operational reindeer husbandry and improve consultations with other land users. Initially, the programme specifically aimed to strengthen dialogue between reindeer husbandry and forestry by providing a planning tool comparable to the forestry sector’s tools, *skogsbruksplan*. As the programme evolved, the need to also address interactions with all other land uses became increasingly clear. The RBP programme therefore became a tool for supporting dialogue, planning, and negotiations related to multiple land uses across landscapes.

Today, the RBP programme functions both as a planning tool and as a platform for cumulative impact assessment. It helps visualize the needs of reindeer husbandry and understand landscape changes and cumulative impacts of forestry, energy develop-

Table 4.1. Summary of the examples of CIA frameworks presented in this chapter.

Section	Country	CI dimension / overall view	Applied context
4.1 Reindeer Husbandry Plans	Sweden	Co-production of maps and spatial data on reindeer resources, land use, landscape change, and cumulative impacts; dialogue and planning tool for CIA.	Applied in reindeer herding communities in Sweden through the Renbruksplan programme and RenGIS, especially in dialogue, planning, negotiations, and assessments related to forestry, mining, wind power, infrastructure, and other land uses.
4.2 The Connected Habitat Approach	Norway and Sweden	Functional habitat and connectivity; cumulative impacts of multiple infrastructure types, barriers, zones of influence, and landscape-level habitat loss and fragmentation.	Developed for wild reindeer in Southern Norway and later applied in reindeer husbandry contexts to assess how infrastructure, tourism, hydro-power, forestry, mining, wind power, climate, and other factors affect habitat quality, connectivity, and corridors.
4.3 Collaboration between reindeer herders and researchers	Sweden	Collaborative assessment combining traditional knowledge, GPS data, and habitat-selection models to understand cumulative impacts on reindeer behaviour and habitat use.	Applied in reindeer herding communities in Sweden in research on wind power development, including before-after analyses of wind farms together with other infrastructure, weather conditions, predators, and herding practices.
4.4 The cumulative influence of climatic and population dynamic factors in animal populations	Norway	Population-level and demographic cumulative impacts; direct and indirect effects of climate, reindeer density, management, and environmental variation on reindeer body mass and reproduction.	Applied in different reindeer herding communities in Norway, using long-term monitoring of individually marked females together with snow, plant productivity, spring onset, and herd-density data.
4.5 From pasture inventories to economics in reindeer husbandry	Finland	Economic-ecological or bio-economic systems view of cumulative impacts, integrating pastures, reindeer ecology, herd productivity, management, and profitability.	Developed and applied in reindeer herding cooperatives in Finland to evaluate how multiple ecological, economic, social, and land-use pressures affect pasture condition, herd productivity, herd structure, feeding, slaughtering, and profitability.
4.6 Cumulative impacts in time: impacts of forestry in Finnish Sápmi	Finland	Temporal cumulative impacts; accumulation of forestry impacts through space and time on winter grazing productivity, lichen biomass, and need for supplementary feeding.	Applied in Finnish Sápmi to reconstruct logging history and assess how forestry has cumulatively affected winter pastures and reindeer husbandry over decades.

ment, tourism, infrastructure and other land uses on reindeer husbandry.

The programme expanded from a pilot project in two reindeer herding communities to cover the grazing lands of 50 reindeer herding communities.

More than 400 Sámi reindeer herders have participated, contributed, and been involved in trainings in satellite image interpretation, field inventory techniques, forestry, drone use and GPS technologies. They also received training in *RenGIS*, a

custom-made Geographic Information System (GIS) designed specifically to contain datasets and serve the needs of reindeer husbandry.

The work is carried out through a close collaboration between reindeer herders, researchers, and authorities as part of a mutual learning process.

How does it work?

The RBP programme developed iteratively together with participating reindeer herding communities. Over time, four main components emerged.

- 1. Mapping important grazing lands.** The first and most central component is the delineation and description of important seasonal grazing lands into grazing types: key, core and general grazing area. The Sámi reindeer herder with most knowledge of each specific, local area carries out the mapping through on-screen digitizing in *RenGIS*, using the most up-to-date satellite images. Delineations are discussed and adjusted in consultations with other local experts from each *siida* (winter group). Through this process, grazing lands for all eight reindeer grazing seasons have been mapped across entire reindeer herding communities. Maps for each local area were subsequently merged to cover the entire grazing lands for each season. Today, nearly 10,000 key areas have been delineated and described, with the large majority situated in the boreal forest.
- 2. Field inventories of vegetation conditions and grazing resources.** As mapping of seasonal grazing lands progressed, the need to support these mappings with field inventories became clear. Building partly on protocols from the Swedish National Forest Inventory, a vegetation classification system for reindeer grazing types was developed and further adjusted based on recommendations from reindeer herders. Field inventories were conducted by local reindeer herders using inventory protocols for forest lands, wetlands, mountain areas and ground lichens. Information collected during field visits was added directly into *RenGIS* through a mobile application. These inventories improve satellite-image interpretation, support adjustments of mapped grazing areas, and strengthen dialogue and land-use negotiations with forestry and other land users.
- 3. GPS monitoring of reindeer movements and habitat use over time.** The use of real-time GPS collars on reindeer has become commonplace in most reindeer herding communities, since it was first introduced in 2006. The introduction of real-time GPS into reindeer husbandry became the first example of a fully participating data user – the reindeer herder – taking full operational advantage of real-time GPS data. In addition to their practical use in herding, GPS data provide important long-term information on reindeer movements and habitat use. These data have created an extensive database used in research projects, impact assessments and court cases. GPS data are also used to refine grazing-land maps and verify lichen maps by comparing present and historical reindeer use. As of 2022, about 35 reindeer herding communities use and manage their real-time GPS-collar systems, and several thousand reindeer have been equipped with GPS collars over time.
- 4. Compilation of spatial information on other land uses.** The RBP programme also compiles spatial information on other land uses and land cover from multiple authorities into *RenGIS*. Compiled data originates from different state agencies for their respective geographic areas and responsibilities, including the Swedish Forest Agency, the Swedish Mining Inspectorate, the Swedish Energy Agency, the Swedish Meteorological and Hydrological Institute, the

Swedish Board of Agriculture, the County administrative boards, the Swedish Land Survey, the Swedish National Heritage Board and the Sámi Parliament.

Most of the data are publicly available but are otherwise not compiled into one single database. Having all this data compiled in RenGIS provide a basis for analyses of land use changes and cumulative impacts over time. The resulting database provides a basis for dialogue, planning, negotiations and cumulative impact assessments.

What does it produce?

The main outputs of the RBP process include:

- local reindeer herders' maps of seasonal grazing lands and key and core grazing areas;
- field inventories of vegetation and grazing resources;
- GPS-based locational data on reindeer movements and habitat use;
- a compiled spatial database of other land uses.

The RBP programme contributes to understanding cumulative impacts by compiling information on reindeer grazing areas, habitat conditions, reindeer movements and other land uses, including forestry, energy infrastructure development, tourism, and urban growth. These datasets allow analyses of landscape change, shifts in reindeer habitat use and reindeer herding needs over time, and interactions with other land uses.

For Sámi reindeer husbandry, the RBP programme plays an important role in explaining, maintaining and incorporating the complex and geographically extensive reindeer husbandry system into the context of other land use systems. In this way, the RBP programme can be seen as a challenging real life test case for advanced, sustainable landscape management seeking to address cumulative impacts.

An important outcome of the programme is also the collaborative process itself. It allows long-term cooperation, communication of needs, and trust-building between reindeer herders, acade-

mics, and authorities. In this way, the RBP programme functions not only as a database, but also as a platform for cumulative impact assessment from a reindeer husbandry perspective.

Data and methods from the RBP programme have been used in studies and assessments related to wind power, forestry, mining, infrastructure development, climate impacts, cumulative impacts and environmental court cases. Furthermore, data from RBP have been directly part of several research projects, including the application of the approaches described below in sections 4.2 and 4.3.

Learn more

OVERVIEW

- **Official RBP programme website:** <https://sametinget.se/renbruksplan>

DEVELOPMENT AND IMPLEMENTATION OF THE PROGRAMME

- **Sandström, P., Pahlén, T. G., Edenius, L., Tømmervik, H., Hagner, O., Hemberg, L., Olsson, H., Baer, K., Stenlund, T., Brandt, L. G., & Egberth, M.** (2003). Conflict Resolution by Participatory Management: Remote Sensing and GIS as Tools for Communicating Land-use Needs for Reindeer Herding in Northern Sweden. *Ambio*, 32(8), 557–567. <https://doi.org/10.1579/0044-7447-32.8.557>
- **Sandström, P.** (2015). *A toolbox for Co-production of Knowledge and Improved Land Use Dialogues* [Doctoral thesis]. Swedish University of Agricultural Sciences.
- **Sandström, P., Sandström, S., Roos, U., & Cronvall, E.** (2023). Case study: Reindeer husbandry plans – “Is this even monitoring?” In *Monitoring Biodiversity*. Routledge.

INVENTORY METHODS, MOBILE APPLICATIONS AND RENGIS TOOLS (IN SWEDISH)

- **Sametinget** (2017). Manual för fältinventering. <https://sametinget.se/6528>

- **Sametinget** (2021). Instruktionsfilmer. <https://sametinget.se/utbildningsfilmerRBP>
- **Sametinget** (2021). Manual för beteslandsindelning <https://sametinget.se/6525>
- **Sametinget** (2022). RenGIS 2.0. <https://www.sametinget.se/renGIS>

SELECTED APPLICATIONS WITHIN CUMULATIVE IMPACT ASSESSMENTS

- **AMAP.** (2017). Adaptation Actions for a Changing Arctic: Perspectives from the Barents Area. Arctic Monitoring and Assessment Programme (AMAP).
- **Larsen, R. K., Skarin, A., Stinnerbom, M., Vannar, J., Alam, M., Kuhumunen, M., Lawrence, R., Nygård, J., Raitio, K., Sandström, P., Sandström, S., Stinnerbom, J., Wikkarlsson, J., & Österlin, C.** (2020). *Omtvistade landskap: Navigering mellan konkurrerande markanvändning och kumulativa effekter* (No. 6908). Naturvårdsverket. (in Swedish)
- **Skarin, A., Sandström, P., Niebuhr, B. B., Alam, M., & Adler, S.** (2021). *Renar, rensköt-sel och vindkraft: Vinter- och barmarksbete*. Naturvårdsverket.

4.2 The Connected Habitat Approach: cumulative impacts of anthropogenic infrastructure and activity on reindeer habitat and connectivity

What is the approach?

We can track where reindeer move using GPS, but understanding why they move is more complicated. Roads, for example, may be avoided by reindeer, but they often occur together with other features such as buildings, power lines, or valleys. In addition, reindeer movements also depend on factors such as snow conditions or predators. These factors co-occur and are correlated in space and time, making it difficult to isolate their individual effects.

The Connected Habitat approach was developed to address this challenge. It aims to identify and quantify how multiple factors together affect reindeer habitat and movement.

A central concept in this approach is *functional habitat*, which represents areas that are both suitable (i.e. provide good grazing conditions) and well connected (i.e. can be reached by reindeer). In this sense, the approach focuses on the conditions that matter for reindeer, rather than only on the location of infrastructure.

The approach was originally developed at the Norwegian Institute for Nature Research (NINA) for wild reindeer in southern Norway and has more recently been applied in reindeer husbandry contexts in Norway and Sweden, where similar pressures from infrastructure, tourism, energy development, forestry, and climate change affect reindeer and their habitats.

How does it work?

The Connected Habitat approach is carried out in a preparation step related to data collection and compilation, and three main analysis steps (Fig. 4.1):

- Before the analysis: data collection, compilation, and collaboration

The Connected Habitat approach is based on combining different types of data to understand reindeer space use and movement (Fig. 4.1A). This includes biological data on reindeer locations (e.g. GPS tracking) together with spatial data describing landscape, land cover, human activities, climate and weather, and other relevant factors. The approach relies on having spatial data that represent key resources, barriers, and environmental conditions across the study area. These may include landscape characteristics, climate and weather variables, infrastructure and human activity, and the presence of other species. High-quality and harmonized data are needed across all areas where analyses and predictions are carried out.

Collecting and combining these data requires long-term efforts and collaboration, especially regarding GPS or other biological data. In practice, large-scale analyses have only

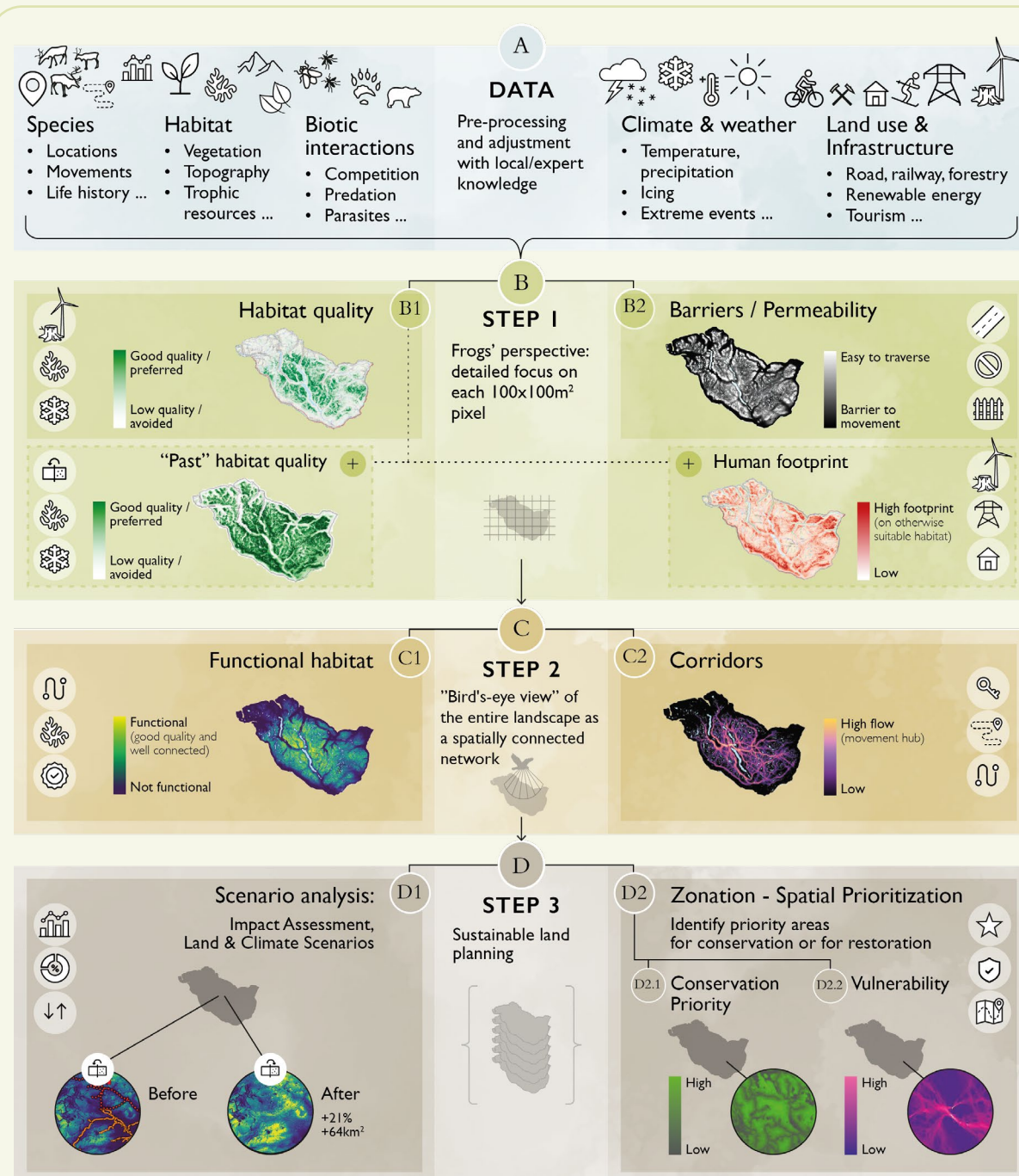


Figure 4.1. Workflow showing the main elements of the Connected Habitat approach to quantify and map cumulative impacts. The approach uses species location and environmental data (and possibly also traditional knowledge; Panel A) and, through statistical models, aims to identify the conditions that correspond to good habitat and to barriers to animal movement (Panel B, STEP 1). These models can be used to produce maps in which areas with good quality (B1) and easy to traverse (B2) can be identified at fine scale (for each 100 m x 100 m pixel). Results from STEP 1 are fed into spatial network models that upscale the reindeer habitat and behaviour into entire landscapes, considering how areas are connected to each other (Panel C). STEP 2 comprises a "bird's-eye view" and allows the identification of functional habitat (areas with good quality and well-connected habitat, C1) and corridors connecting them (C2). Finally, Panel D shows how these models can be used as tools for sustainable land-use planning, in scenario analyses to evaluate the landscape-level impacts of landscape or climate change (D1), or within zonation approaches, to prioritize areas for conservation or restoration (D2). Figure adapted from Panzacchi et al. (2022).

been possible through cooperation between researchers, institutions, and reindeer herding communities, who often collect and manage reindeer tracking data. This collaboration is essential to ensure both data availability and correct interpretation of the results. While GPS data provide the most detailed information on reindeer movement, other types of data (e.g. occurrence or abundance data) can also be used, although with more limited applicability.

B. STEP 1: Habitat quality and barriers

The first step is to analyse how reindeer use the landscape at a local scale (e.g. at the level of pixels or small areas). The aim is to understand what makes an area suitable for reindeer, and what makes it difficult for them to move through.

Statistical models are used to estimate:

- habitat quality**, based on the reindeer's requirements for resources (e.g. lichen or other forage, terrain, snow conditions) and preferred environmental conditions, and impacts of disturbance (how much they avoid being close to infrastructure or other stressors);
- barriers to movement**, based on how easy it is for reindeer to move throughout the landscape, in terms of how different landscape features (e.g. land cover types, valleys, fjords) and anthropogenic features (roads, railways, urban areas) are either selected or avoided along the movements, and how they act as barriers.

A key aspect of this step is that it considers multiple factors at the same time, including different types of infrastructure, environmental conditions, and climate variables. It also accounts for the zone of influence of disturbances, meaning that impacts are not limited to the exact location of infrastructure but can extend into surrounding areas. The result of this step is a set of models that describe how different factors affect reindeer space use and movement, and that can be used to map habitat quality and barriers across the landscape (Fig. 4.1B).

These habitat quality and habitat permeability models can also be used to map the extent and intensity of each factor on habitat loss and as barriers, to quantify and map the (cumulative) human footprint of all human infrastructure on habitat loss (Fig. 4.1B, Human Footprint), and to predict areas that would be good grazing grounds in the absence of human infrastructure and activity (Fig. 4.1B, "Past" Habitat Quality).

C. STEP 2: Functional habitat and connectivity

The second step scales up the results from STEP 1 to the landscape level. While STEP 1 focuses on local conditions, this step looks at how different areas are connected to each other (Fig. 4.1C). Using spatial network models, the approach identifies:

- functional habitat**, meaning areas that are both of good quality and accessible to reindeer;
- corridors**, i.e. the most likely routes that reindeer use to move between these areas.

This step is important because even high-quality grazing areas may become less useful if they are isolated or difficult to reach due to barriers such as roads, infrastructure, or other disturbances. By combining habitat quality and movement constraints, the approach provides a "bird's-eye view" of how the landscape functions for reindeer, highlighting key areas and connections that support their seasonal movements and use of resources.

D. STEP 3: Scenario analyses and spatial prioritization

In STEP 3, the models developed in steps 1 and 2 are used as tools to explore how changes in the landscape may affect reindeer habitat and movement (Fig. 4.1D). This includes:

- scenario analyses**, where the potential impacts of new infrastructure, land-use changes, or mitigation measures are evaluated by predicting how habitat quality, barriers, and connectivity would change;

2. **spatial prioritization**, where the analysis identifies areas that are particularly important for maintaining functional habitat and connectivity, and that may therefore be priorities for conservation, restoration, or careful planning.

These applications make the approach especially useful for decision-making. They allow Sámi rightsholders, planners, and stakeholders to compare different development options, anticipate cumulative impacts, and identify measures that can reduce negative effects on reindeer husbandry.

What does it produce?

The approach produces a set of models and maps that describe how reindeer interact with the landscape under the influence of multiple factors. These include:

- maps of habitat quality;
- maps of barriers and cumulative human impact;
- maps of functional habitat and connectivity;
- identification of key corridors and priority areas.

Importantly, the statistical models represent relationships between reindeer and the environment and, beyond maps, can be used in different contexts. These outputs can be used to assess cumulative impacts of multiple land uses, support land-use planning and decision-making, compare alternative development, restoration, and mitigation scenarios, and identify areas for conservation or restoration.

Because the approach combines multiple factors and operates across scales, it provides a more integrative understanding of cumulative impacts than assessments based on single projects or types of disturbance.

Strengths and limitations

STRENGTHS

- Focuses on reindeer habitat and movement, rather than only on infrastructure
- Accounts for multiple types of disturbances, their interaction, and their spatial extent

- Allows upscaling from local behaviour to landscape-level impacts
- Can be used for scenario analyses and planning
- Can be combined with traditional knowledge and expert input

LIMITATIONS

- Requires substantial data, especially reindeer location data and environmental variables
- Requires technical expertise in statistical modelling and GIS
- Results depend on data availability and quality
- Cross-border applications are challenging due to differences in data between countries

Learn more

OVERVIEW

- **Panzacchi, M., Van Moorter, B., & Niebuhr, B. B.** (2022). Wild reindeer Maps. View Norwegian landscapes as reindeer do. Reindeer WebApp: <https://reindeermaps.nina.no/>. (summary of the approach, tools, examples of applications, and links to the resulting maps for wild reindeer)

METHODS

- **Panzacchi, M., Van Moorter, B., Tveraa, T., Rolandsen, C. M., Gundersen, V., Lelotte, L., dos Santos, B. B. N., Bøthun, S. W., Stien, A., Andersen, R., & Strand, O.** (2022). *Statistisk modellering av samlet belastning av menneskelig aktivitet på villreinområder: Identifisering av viktige leveområder og scenarioanalyser for konsekvensutredning og arealplanlegging* (NINA Rapport 2189). Norsk institutt for naturforskning. <https://hdl.handle.net/11250/3031987> (presentation of the approach for wild reindeer, in Norwegian)
- **Van Moorter, B., Kivimäki, I., Panzacchi, M., Saura, S., Niebuhr, B. B., Strand, O., & Saerens, M.** (2023). Habitat functionality:

Integrating environmental and geographic space in niche modelling for conservation planning. *Ecology*, 104(7), e4105. <https://doi.org/10.1002/ecy.4105> (presentation of the approach in English)

- **Niebuhr, B. B., Van Moorter, B., Stien, A., Tveraa, T., Strand, O., Langeland, K., Sandström, P., Alam, M., Skarin, A., & Panzacchi, M.** (2023). Estimating the cumulative impact and zone of influence of anthropogenic features on biodiversity. *Methods in Ecology and Evolution*, 14, 2362–2375. <https://doi.org/10.1111/2041-210X.14133> (how the approach accounts for zones of influence and cumulative impacts)

APPLICATIONS

- **Dorber, M., Panzacchi, M., Strand, O., & van Moorter, B.** (2023). New indicator of habitat functionality reveals high risk of underestimating trade-offs among sustainable development goals: The case of wild reindeer and hydropower. *Ambio*, 52(4), 757–768. <https://doi.org/10.1007/s13280-022-01824-x> (example of scenario application)
- **Van Moorter, B., Panzacchi, M., Niebuhr, B. B., Lelotte, L., Rolandsen, C. M., & Tveraa, T.** (2023). *Menneskelig påvirkning på alle villreinområder i Norge. Et nytt Dashboard leverer kart og statistiske estimater til støtte for forvaltningsprosesser*. (NINA Rapport 2342). Norsk institutt for naturforskning. <https://hdl.handle.net/11250/3107550> (application for wild reindeer management, in Norwegian)
- **Larsdotter, E., & Olsson, E.** (2026). *Ramverk för nationell planering: Förutsättningar och verktyg att analysera kumulativa effekter med fokus på renskötsel och samisk kultur*. Sametinget, Länsstyrelsen Västerbotten (framework on how to use it for land planning, from a Sámi reindeer husbandry perspective, in Swedish)

4.3 Cumulative impacts assessments through collaboration between reindeer herders and researchers

What is the approach?

In a series of collaborative research projects with reindeer herding communities in Sweden, researchers examined how wind farms and related infrastructure affect reindeer and reindeer husbandry. The studies also explored how these impacts combine with other pressures, such as existing infrastructure, predators, weather conditions, and other land uses (Skarin et al., 2021).

The approach combines TK from reindeer herders with GPS data and environmental information to assess how reindeer behaviour and habitat use are affected by wind power development and other environmental pressures (Figure 4.2). A key part of the approach is the close collaboration between researchers and reindeer herders throughout the analyses and interpretation of results.

How does it work?

The approach includes both qualitative (experience-based) and quantitative (data-based) assessments. The experience-based assessment consists of documenting traditional knowledge from reindeer herders about how reindeer herding has been practiced in each area (Fig. 4.3). This was done through focus group meetings, project meetings, and repeated knowledge-sharing sessions with reindeer herders actively using the study area. The data collection was iterative, revisiting questions across several full-day and multi-day meetings. The work also builds on experience from developing the Sámi Reindeer Husbandry plans with the reindeer herding communities (section 4.1).

The data-based assessment is based on GPS data collected from reindeer monitored before, during, and after the construction of the wind power plants, allowing before–after analyses of change in reindeer movement behaviour (see also section 2.1.3 and 4.2). GPS data collected by reindeer herders during several years were analysed together with spatial data on landscape, anthropogenic disturbance, predators, and winter grazing conditions (Fig. 4.3).

HOW IS REINDEER AFFECTED?

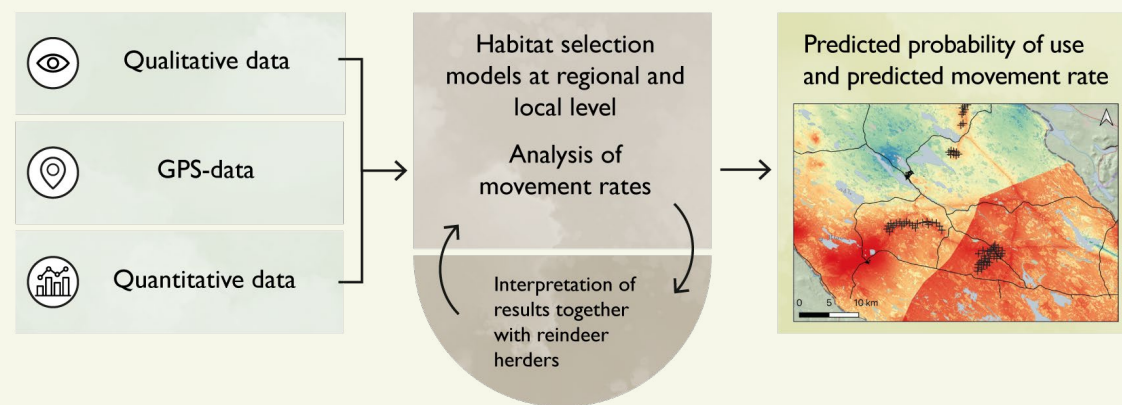


Figure 4.2. Workflow showing the data, statistical models, and output of the collaborative cumulative impact approach. The approach combines qualitative data, including reindeer herders' knowledge and notes, with GPS data from tracked female reindeer and environmental data, such as landscape, infrastructure, climate, and predator data. Habitat models and movement analyses, interpreted together with reindeer herders, are used to produce maps and estimates of cumulative impacts related to wind power development and other factors. Adapted from Skarin et al. (2021).

Researchers and herders worked together in a two-step, iterative process. First, focus-group meetings were used to document herders' knowledge on reindeer herding practices, range use before and after development, and the role of weather, predators, and other land uses. Second, GPS data were jointly reviewed in *RenGIS* to map seasonal movements, identify herding activities, and distinguish between natural reindeer movements and movements influenced by active herding.

Snow conditions in each winter are particularly important for winter grazing. To account for this, the snow conditions in each winter were classified on a scale from good to difficult using: 1) herders' descriptions based on diaries and memories, 2) interpretation of Swedish Meteorological and Hydrological Institute weather-station data, and 3) interpretation of reindeer movement patterns, by reviewing ("playing back") GPS tracks together with herders. This classification occurred before the statistical analyses were performed.

Using this information, habitat and movement models were fitted to GPS and environmental data. The analyses included distance to different types of infrastructure, topography, vegetation type, snow conditions (in winter grazing areas), and predator presence – factors known to influence reindeer

habitat selection and movement.

Several alternative models representing different hypotheses were tested for each area and season. The best-fitting models were then used to assess how wind power development and other land uses influenced reindeer habitat selection and movement patterns. Results were discussed together with reindeer herders to refine the analyses and interpret the findings in the practical context of reindeer husbandry (Fig. 4.2).

What does it produce?

The approach produces both experience-based and data-based assessments of cumulative impacts. The experience-based assessments produced maps showing reindeer movements and herding events, together with descriptions of grazing conditions and herding practices in different years (Fig. 4.3). The data-based analyses estimate the strength of reindeer avoidance or selection in relation to different types of infrastructure and land use. The results are presented as statistical estimates, plots, and maps showing changes in habitat use and movement patterns in relation to wind power development and other environmental factors. Together, these analyses provide a broader understanding of how multiple pressures interact and affect reindeer husbandry over time.

QUALITATIVE ASSESSMENT

QUANTITATIVE ASSESSMENT

INPUT DATA	QUALITATIVE ASSESSMENT	QUANTITATIVE ASSESSMENT
	• Herding and reindeer management events • Yearly events (e.g. predation, road kill, reindeer avoidance or attraction) • Winter grazing conditions • Location of important grazing areas	• Reindeer GPS-data • Landscape maps (e.g. land cover) • Anthropogenic disturbance (e.g. roads, forestry activities, mines, wind turbines, sound and view-scape of the wind turbines) • Predator abundance maps • Winter grazing conditions (e.g. reindeer herders classification, snow depth)
RESULTS	• Maps showing reindeer movement and reindeer herding events • Tables synthesizing dates, events, and conditions in each year and area	• Strength of selection or avoidance of the different factors • Plots of predicted probability of use of the different factors • Number of crossings of important roads • Movement parameters in different conditions

Figure 4.3. Input data and results of the co-production cumulative impact approach.

Strengths and limitations

STRENGTHS

- Combines experience- and data-based knowledge in the same assessment.
- Integrates TK, GPS data, and environmental analyses.
- Allows interpretation of statistical results together with reindeer herders in the practical context of herding.
- Supports understanding of cumulative impacts from multiple pressures acting simultaneously.

LIMITATIONS

- Requires extensive collaboration and repeated meetings between herders and researchers.
- Data collection and interpretation are time-consuming.
- Results may depend on long-term access to GPS data and traditional knowledge.

Learn more

Skarin, A., Sandström, P., Niebuhr, B. B., Alam, M., & Adler, S. (2021). *Renar, renskötsel och vindkraft: Vinter- och barmarksbete*. Naturvårdsverket.

4.4 The cumulative influence of climatic and population dynamic factors in animal populations

What is the approach?

Climate is changing especially rapidly in Arctic and alpine regions. It is therefore urgent to understand how changing snow conditions, rain-on-snow events, and shifts in plant phenology influence forage availability and quality. For instance, deep or compact snow and ice layers during winter severely restrict access to forage, depleting females' body reserves and reducing calf survival. Conversely, early spring onset and high summer plant productivity enhance body condition and reproductive success through improved forage quality and quantity. These environmental factors increasingly interact with population densities and expanding land-use pressures, including wind farms, infrastructure, mining, aquaculture, military activity, and recreative use related to cabins and outdoor activities.

While climate change has been accelerating, animal population responses to changes in climate, population density, land use, and food availability are slow processes. Long-term data are therefore needed to reveal the underlying ecological relationships, which add to the cumulative impact of other stressors on animal populations. As reindeer are relatively long-lived species, it is necessary to monitor individually marked animals over many years to

be able to disentangle the effects of environmental conditions and population density on the performance of individual animals.

One way to analyze these long-term relationships is through structural causal modelling, also known as path analysis or structural equation modelling. This approach provides a framework to map cause-and-effect relationships of factors affecting reindeer populations and estimates both the direct effects and the indirect effects operating through intermediate steps. Thereby, it becomes possible to identify how factors such as snow depth, timing of the greening in the spring, plant productivity, and population density jointly affect reindeer body mass and reproduction.

In that sense, structural equation models are a powerful tool for evaluating cumulative impacts on populations. By linking environmental conditions, population density, and individual performance, they make it possible to explain how multiple pressures accumulate and affect reindeer populations over time.

The system

The case study used to illustrate this approach is the pastoral system with semi-domestic reindeer in Finnmark, northern Norway, a high-latitude environment characterised by strong seasonality. Reindeer depend on a short plant-growing season to restore body reserves and support lactation before the long, resource-limited winter. These pronounced seasonal differences in forage availability drive density-dependent processes, with competition for food typically being strongest outside the growing season.

In this case study, we linked long-term individual data on female body mass in spring and autumn, and reproductive status in autumn from a herd in Finnmark with snow depth, timing of spring onset and plant productivity. During winter, the herd grazes on continental pastures on Finnmarksvidda, and during summer on coastal summer ranges. This herd is representative of the pastoral system in Fennoscandia, where animals roam freely for most of the year but are handled during calf marking, autumn slaughter, and migrations between pastures.

How does it work?

In Simmonds et al. (2025), a structural causal model was used to evaluate how environmental conditions and population density together influenced female reindeer body mass and reproductive success. For example, high population density in winter and deep snow reduce females' body mass in spring, which in turn lowers their likelihood of producing a calf. Spring body mass therefore acts as a key linking variable, connecting conditions and forage availability in winter to reproductive outcomes later in the year.

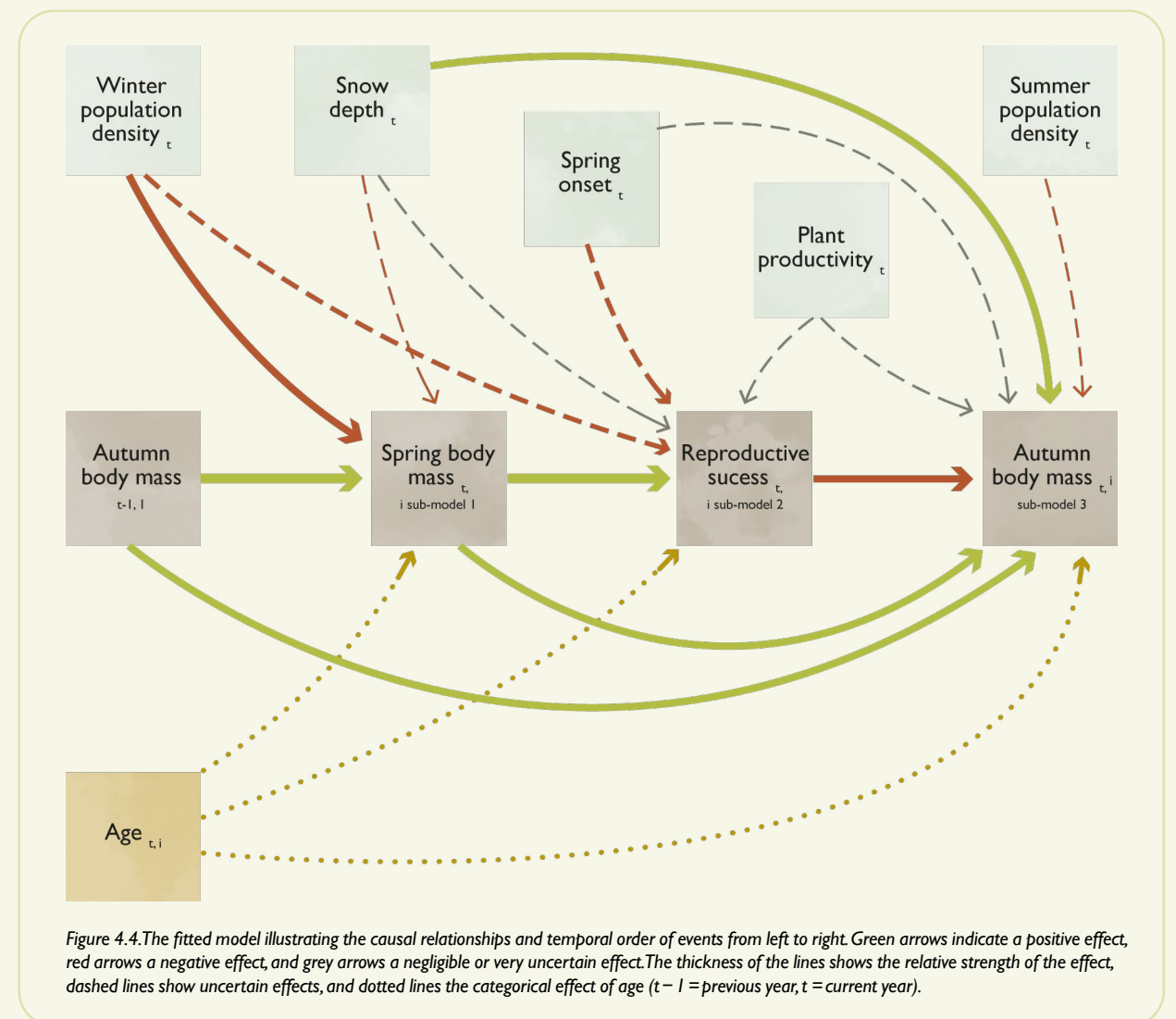
This approach relies on detailed monitoring of marked individuals and enables quantification of the influence of both environmental factors and herders' management decisions on reindeer vital rates. The Monitoring Program for Semi-domestic Reindeer at NINA (see www.reinbase.no) has collected individual-based data of marked females since 2000. These records were combined with reindeer management statistics, satellite-derived vegetation indices, and meteorological data on snow depth and rain-on-snow events and analyzed through structural causal models.

Key findings

The approach produces estimates of how strongly each factor affects female body mass and reproductive success, both directly and through intermediate pathways (Fig. 4.4).

Key findings for this case include:

- **Population density matters most in winter.** High population density in winter had strong negative effects on both spring body mass and reproductive success (Fig. 4.4). Its total effect on reproduction was twice as large as either pathway (direct or via body mass) considered alone. The estimated impact of winter population density on female body mass in spring was 25% stronger than the effect of summer population density on female body mass in autumn. This pattern highlights that relying on harvest records of body mass in autumn can mask strong density dependence operating during winter.
- **Costs of reproduction and individual heterogeneity.** Females that successfully raised a calf



were, on average, 5 kg lighter in autumn than non-reproductive females. However, some individuals consistently maintained higher body reserves than others across seasons.

- **Role of body mass as a key state variable.** Female body mass in spring serves as a central state variable through which both density dependence and environmental variability influence reproductive success. Body mass in autumn integrates resource availability and reproductive costs during summer, but on its own it may not reflect strong density dependence in winter and compensatory adjustments in reproductive effort. Measuring body mass before and after the lactation period,

alongside individual reproductive status, is essential to capture the effects of both reproductive costs and individual quality.

Strengths and limitations

STRENGTHS

- Reveals the mechanisms by which environmental variability and population density affect reproductive success through both direct and indirect pathways
- Captures seasonal dynamics and individual variation
- Enables forecasting under alternative environmental or management scenarios

LIMITATIONS

- Snow depth data are interpolated at 1 km² resolution and may miss fine-scale conditions relevant to grazing reindeer
- Meteorological stations in Finnmark are sparse and located in valleys rather than on the plateaus where reindeer actually graze
- Integrating this approach with spatial land-use data remains a methodological challenge.
- Reindeer herders' knowledge is not yet integrated; this could rely e.g. on structured interviews or participatory mapping

Use in cumulative impact assessment

The structural causal model framework for semi-domestic reindeer in Norway has not yet been formally integrated into CIA. However, it provides a mechanistic basis for understanding how multiple drivers affect response variables of interest both directly and indirectly. For instance, GPS data for individually marked reindeer, with recorded seasonal body mass and reproductive history, are available through the Monitoring Program for Semi-domestic Reindeer. Combining this individual performance data with spatial tracking and land-use mapping might directly link demographic responses to habitat selection, avoidance patterns, and disturbances from land use, providing a more comprehensive understanding of the relationships between anthropogenic pressures and reindeer behavioural and population responses.

Individual-based analyses offer seasonal or annual temporal resolution at the district level, while spatial CIA tools provide fine-scale mapping of land-use pressures, but they are typically averaged across years. These two approaches can be connected through shared environmental covariates, yet integrating pixel-level spatial data with time-series at herd scales presents a key methodological challenge. The combination of CIA with data from individually marked reindeer would enable assessments that simultaneously capture the spatial distribution of pressures from land-use and the temporal dynamics of population responses.

Learn more

Tveraa, T., Stien, A., Langeland, K., & Stokmo, J. A. (2020). *Reinbase: The monitoring programme for semi-domestic reindeer in Norway.*

<https://www.reinbase.no/en-us/>. (description of the data and animal monitoring)

Simmonds, M., Hamel, S., Henden, J., Langeland, K., Stien, A., Tveraa, T., & Yoccoz, N. G. (2025). Disentangling seasonal effects of environmental variability and population density on life-history traits in a capital breeder. *Journal of Animal Ecology*, 94(6), 1259–1271.

<https://doi.org/10.1111/1365-2656.70048> (modelling framework, application, and results)

4.5 From pasture inventories to economics in reindeer husbandry

What is the approach?

Reindeer husbandry systems are constituted by interconnected ecological, social, cultural, and economic components. The relationship between reindeer and their pastures depends on several ecological interactions and the decisions of the herders. In turn, the herders' income depends on the body condition, survival and productivity of reindeer, as well as the quantity and quality of the pastures. Nevertheless, research often focuses on a single dimension, typically ecology or biology. Viewing reindeer husbandry from a too narrow perspective can lead to EIA and land-use planning that lack a more comprehensive research base.

Reindeer husbandry relies on the availability of natural pastures, and therefore expanding land use within reindeer management areas is one of the main threats to its profitability and productivity. When combined with predation and accelerating climate change, cumulative pressures from other land use may threaten the livelihood of reindeer husbandry. Reindeer husbandry systems can be conceptualized through interacting internal elements – the herders, the reindeer and the pastures – and external elements affecting the system (Fig. 1.1, Fig. 4.5), which need to be addressed together.

To address these challenges, researchers from the

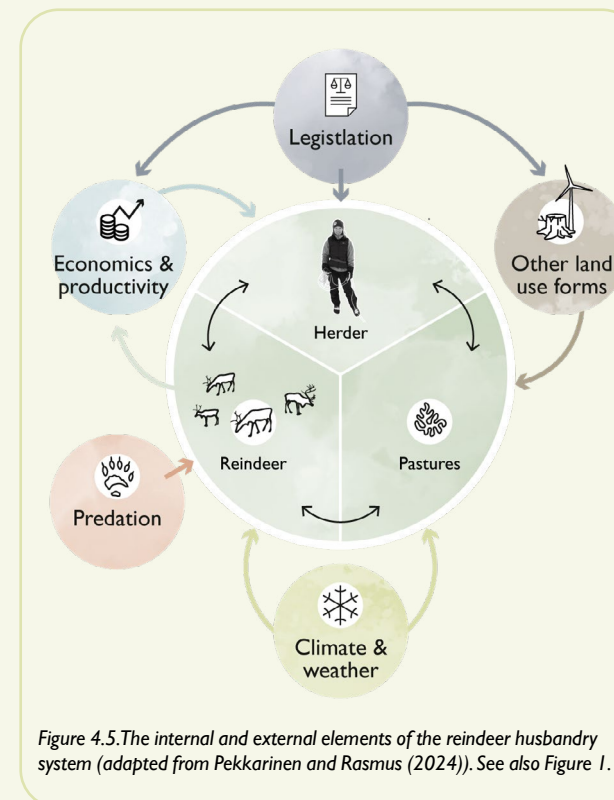


Figure 4.5. The internal and external elements of the reindeer husbandry system (adapted from Pekkarinen and Rasmus (2024)). See also Figure 1.1.

Natural Resources Institute Finland (Luke) and the University of Helsinki proposed the use of economic–ecological system models grounded in empirical data on pasture resources and reindeer ecology. Combined with statistical analyses and practitioners' knowledge, these models can provide a multidimensional understanding of the interacting factors influencing reindeer husbandry. This approach uses economic–ecological system models (bioeconomic models) to evaluate how internal and external factors influence the productivity and profitability of reindeer husbandry.

The strength of bioeconomic models lies in their ability to represent multiple interacting factors within a system framework and to evaluate their cumulative effects on reindeer husbandry. For example, these models allow the estimation of how different land-use projects may affect pasture quantity and quality, herd productivity, and reindeer husbandry income under varying conditions.

How does it work?

A bioeconomic model of reindeer husbandry has been developed jointly by Luke and the University

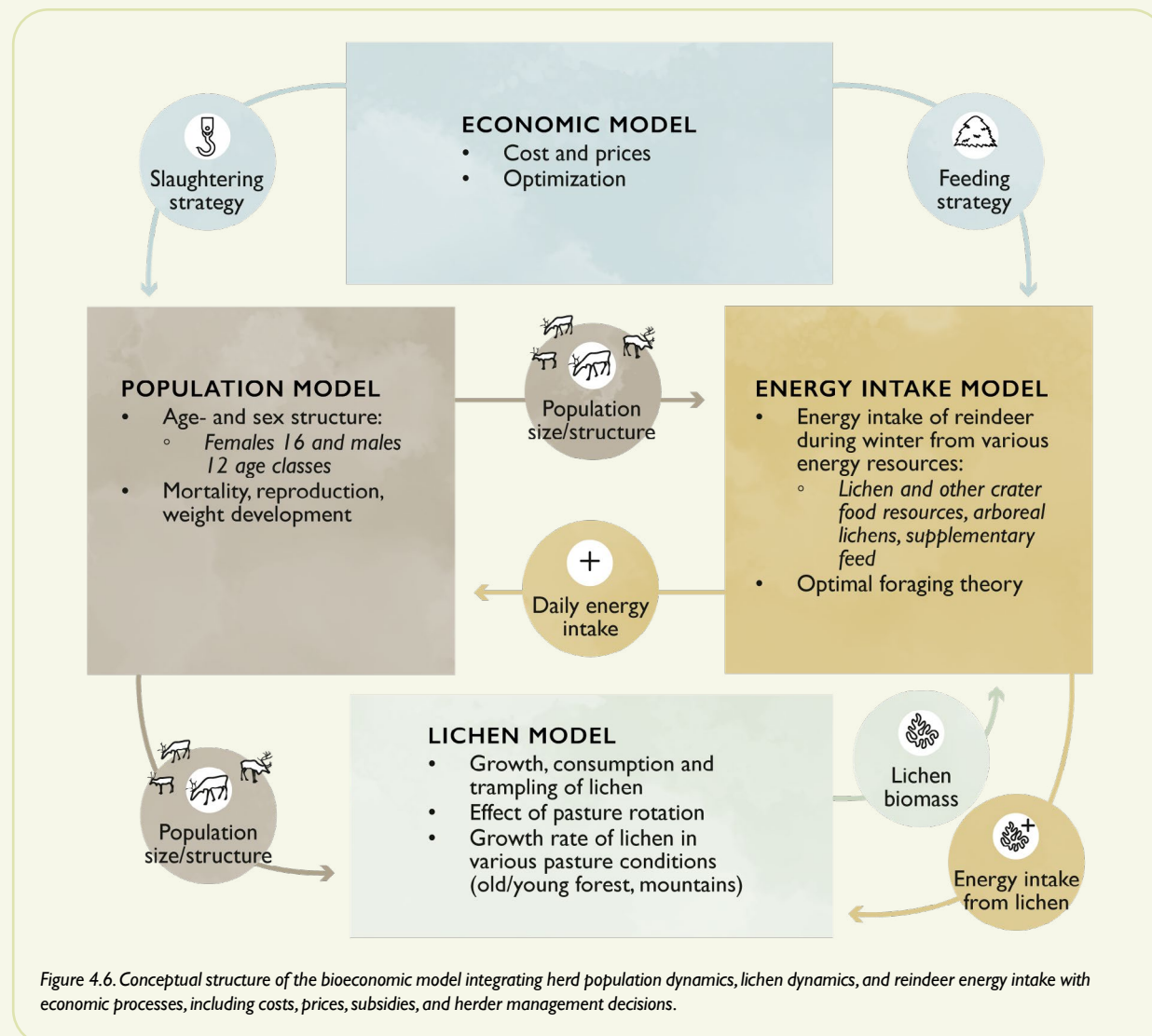
of Helsinki. Its structure is shown in Figure 4.6, and it aligns with the conceptual system presented in Figures 1.1 and 4.5. At the core of the model is the interaction between the reindeer population and winter pastures. The Population Model describes the age- and sex-structured herd, including mortality, reproduction and weight development. The Lichen Model represents lichen growth, grazing consumption, and trampling under different pasture conditions. The Energy Intake Model describes how reindeer utilize different energy sources, including ground lichens, arboreal lichens, other forage resources and supplementary feed. These ecological components are integrated with an Economic Model that includes costs, prices, subsidies and herder decisions regarding slaughtering and feeding. Using optimization algorithms, the model identifies strategies that maximize long-term net income and assesses pasture and herd values.

The usability and practical relevance of the models depend strongly on the quality of the empirical data and information used in the analyses. One of the main datasets used in the development of the model has been data collected through Finnish pasture inventories conducted at ten-year intervals since the late 1990s. Additional data were gathered from several sources, including the Kutuharju Experimental Reindeer Research Station and statistics from the Finnish Reindeer Herders' Association.

These data include:

- reindeer energy requirements, weights, mortality and reproduction under varying conditions;
- economic data such as prices, costs and subsidies; and
- data on lichen growth, grazing, trampling and recovery.

Empirical datasets alone are insufficient. A deep understanding of the interactions within reindeer husbandry systems is required to construct biologically and economically realistic model structures. Results from statistical analyses, together with practitioner and expert knowledge, play a key role in developing this understanding.



Successful application of the approach requires interdisciplinary collaboration, including expertise in pasture inventories, quantitative analyses, bioeconomic modelling, reindeer ecology, husbandry practices, economics, and land-use dynamics.

What does it produce?

The main outputs of bioeconomic analyses include estimates of how various pressures affect pasture quantity and quality, herd productivity, and the economics of reindeer husbandry, and how herders might adapt under different conditions.

The models can provide information on:

- changes in pasture condition, herd productivity

and profitability under different ecological and economic conditions;

- optimal herd sizes and herd structures in different situations and scenarios;
- optimal slaughtering and feeding strategies;
- long-term values of reindeer and pasture resources.

Statistical analyses on pasture inventories and other datasets can complement these outputs by estimating how ecological and external factors affect pasture productivity and condition.

One practical application is evaluating the value of a hectare of pasture under different ecological and economic settings. Model results indicate high variation in the value of lichen pastures. For instance, in high-growth lichen pastures located in old pine forests, annual production value exceeded €30 per hectare (prices from 2010–2011). In contrast, all-year pastures with low lichen growth, such as young forests, had values below €10 per hectare. This demonstrates how cumulative impacts from forestry, by reducing lichen growth, and from other land uses, by preventing efficient pasture use and rotation, can reduce pasture value dramatically, even when reindeer and herders continue to use these pastures.

Strengths and limitations

STRENGTHS

- Integrates ecological and economic processes into a single analytical framework.
- Allows evaluation of cumulative impacts from multiple external pressures simultaneously. These impacts can include, for example, reductions in pasture quality, herd productivity and incomes of reindeer herding.
- Provides decision-relevant information on herd size, pasture condition, as well as estimates of income and outcome in reindeer herding.
- Supports long-term planning by modelling interactions across decades.

LIMITATIONS

- Model validity depends heavily on the quality and completeness of empirical data and model structure.
- The analyses require substantial expertise, computational resources, and interdisciplinary collaboration.
- Underlying assumptions must be grounded in ecological and socioeconomic understanding; poor assumptions can lead to misleading results.
- Applying the model to other regions and contexts requires re-evaluation of key interactions and parameters.

Learn more

OVERVIEW AND METHODS

- **Pekkarinen, A.-J., Kumpula, J., & Tahvonen, O. (2015).** Reindeer management and winter pastures in the presence of supplementary feeding and government subsidies. *Ecological Modelling*, 312, 256–271. <https://doi.org/10.1016/j.ecolmodel.2015.05.030> (development and application of the bioeconomic model)
- **Tahvonen, O., Kumpula, J., & Pekkarinen, A.-J. (2014).** Optimal harvesting of an age-structured, two-sex herbivore–plant system. *Ecological Modelling*, 272, 348–361. <https://doi.org/10.1016/j.ecolmodel.2013.09.029>
- **Pekkarinen, A. J., Kumpula, J., & Tahvonen, O. (2020).** What drives the number of semi-domesticated Reindeer? Pasture dynamics and economic incentives in Fennoscandian reindeer husbandry. In “*Nordic perspectives on the responsible development of the Arctic: Pathways to action*” (pp. 249–270). Cham: Springer International Publishing. (Application of the bioeconomic model to study the effects of various economic and ecological factors)
- **Pekkarinen, A. J., Kumpula, J., Holand, Ø., Åhman, B., & Tahvonen, O. (2022).** Bioeconomics of reindeer husbandry in Fennoscandia. In *Reindeer Husbandry and Global Environmental Change* (pp. 211–231). Routledge. (Application of the Bioeconomic Model to Study Variation in the Bioeconomics of Reindeer Husbandry in Fennoscandia)

APPLICATIONS

- **Pekkarinen, A.-J., & Rasmus, S. (2024).** Poronhoidon varautuminen ja selviytymiskeinot uusiin, äkillisiin ja poikkeuksellisiin olosuhteisiin: POVAUS-hankkeen loppuraportti. Luonnonvarakeskus. <https://jukuri.luke.fi/handle/11111/13664> (application of the bioeconomic model, in Finnish)

- **Pekkarinen, A. J., Kumpula, J., & Tahvonen, O. (2020).** Predation costs and compensations in reindeer husbandry. *Wildlife Biology*, 2020(3), 1–14. (Development and application of the bioeconomic model to study the effects of predation)
- **Pekkarinen, A. J., Rasmus, S., Kumpula, J., & Tahvonen, O. (2023).** Winter condition variability decreases the economic sustainability of reindeer husbandry. *Ecological Applications*, 33(1), e2719. (Development and application of the bioeconomic model to study the effects of harsh winters)
- **Pekkarinen, A. J., Kumpula, J., & Tahvonen, O. (2020).** Bioekonominen analyysi poronhoidon ja talvilaidunten tilan taloudellisesta kestävydestä Suomessa. In *"Kestävä biotalous porolaitumilla-hankkeen osaraportit, johtopäätökset ja toimenpide-ehdotukset"* (pp. 6–27). – Luonnonvara- ja biotalouden tutkimus, 29(2020) (Application of the bioeconomic model to study the effects of pasture rotation, forestry, and reindeer grazing on pastures, in Finnish)

4.6 Cumulative impacts in time: impacts of forestry in Finnish Sápmi

What is the approach?

Forestry is one of the industries with the longest and most extensive activity in Sweden and Finland. In Finland, the impact of forestry on reindeer grazing grounds increased dramatically after World War II. How did the impacts of forestry accumulate on reindeer husbandry through space and time? That was the central question of a GIS-based method developed to estimate the loss of lichen productivity and the economic impacts on reindeer husbandry in reindeer herding cooperatives on the Finnish side of Sápmi. The example presented here estimated forestry impacts on the pastures and reindeer husbandry of Hammastunturi cooperative (Fig. 4.7A), but the method has also been applied in other Finnish reindeer herding cooperatives.

Reindeer husbandry relies on the availability of

natural pastures, and lichen pastures are an essential and limiting food resource for reindeer during winter. Before intensive logging started in the 1960s, there were approximately 70,000–90,000 ha of old forests suited for logging in the cooperative area. Intensive forestry has since been practiced on 40,000 ha, corresponding to 45–60% of the original amount of old forests. Between 1960 and 1985, logging intensity was approximately 1,000 ha/year, after which yearly logged areas gradually decreased.

The approach produced a cumulative impact assessment of forestry on winter grazing productivity as a function of time, producing yearly estimates of logged areas, lichen biomass available for reindeer, and the amount of supplementary feeding needed during winter (Fig. 4.7). The approach is based on lichen growth equations such as those used in the economic–ecological system approach presented in section 4.5, combined with yearly mapping of forestry activities from different data sources.

How does it work?

The approach combines GIS mapping of forestry activities over time with models of lichen biomass, lichen growth, reindeer population dynamics, energy intake, and reindeer husbandry economics.

The analyses rely on:

- maps of logged areas over time representing the history of forestry and land use;
- a static lichen biomass model and maps of lichen pastures;
- a lichen growth model;
- an economic–ecological system model coupling changes in pastures due to forestry, reindeer population dynamics, lichen growth, and the economics of the reindeer herding cooperative.

Logging areas and historical land use were mapped using change-detection algorithms based on Landsat and Sentinel satellite images (Fig. 4.7A). Accurate delineations of logged areas were produced from lidar canopy models provided by Metsäkeskus and the National Land Survey of Finland. Mapping forests through time made it possible to estimate the cumulative logged area over time (Fig. 4.7B), which was used as input for pasture productivity simulations.

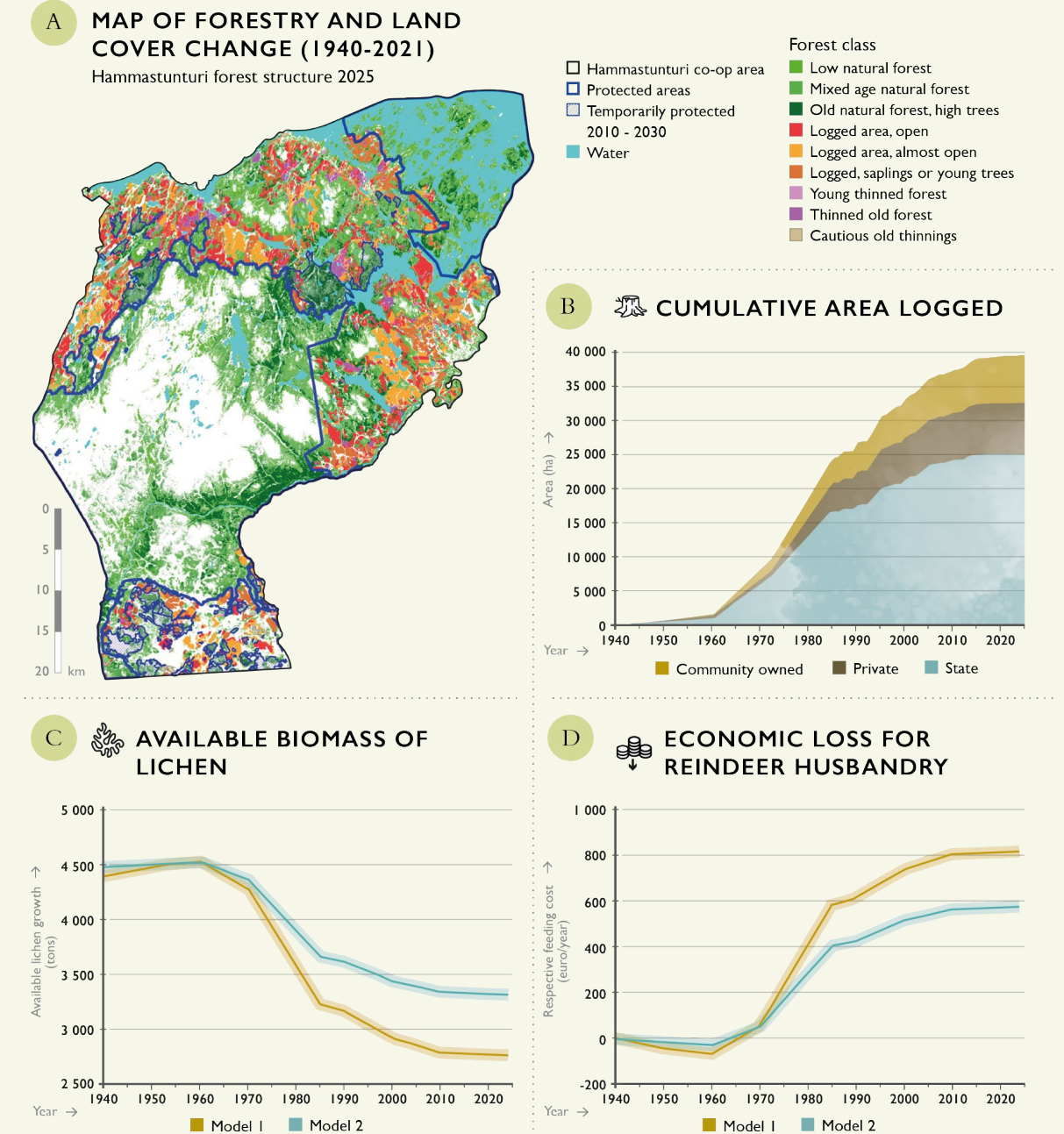


Figure 4.7. Overview of the elements involved in the temporal cumulative impact assessment. (A) Map of forested areas in Hammastunturi reindeer herding co-operative area, Finland, illustrating forest structure and logged areas between 1940 and 2021. The remaining natural or seminatural forests (green colors) are located in protected or temporarily protected areas, whereas the economy forests have mainly been logged after 1960. (B) Cumulative logged area over time, showing logging in state-owned, private-owned, and community-owned areas. (C) Annual lichen biomass available. (D) Annual feeding cost, based on the GIS-data and the lichen model-based simulation.

This study relied on a pasture model developed to capture the combination of factors affecting ground lichen biomass and a series of pasture

inventories that show that lichen biomass depends strongly on forest stand development class. Young or recently logged forests have approximately half

of the ground lichen biomass found in old forests. Because reindeer mainly graze on lichen pastures during winter, forestry directly decreases winter pasture productivity. The analyses therefore require not only current pasture conditions, but also a history of logging activities to quantify the cumulative impacts of forestry through time. This includes estimating the costs of supplementary feeding needed for reindeer.

As lichen biomass depends strongly on forest age, forest aging also had to be included in the simulations. Logged forests and sapling stands were defined as 0–30 years old, young forests as 30–80 years, mature forests as 80–140 years, and old forests as older than 140 years. Lichen inventories show that the largest lichen amounts are found in forests older than 140 years, whereas lichen amounts are drastically smaller in forests younger than 80 years. This long recovery time results in long-lasting cumulative impacts from logging.

In the Hammastunturi cooperative, the central protected areas are mainly used as summer grazing areas, whereas lower-altitude forests are used as winter and year-round grazing areas (Fig. 4.7A). In addition to productive forests, there are also extensive low-productivity forests with sparse tree cover that are less suitable both for forestry and winter grazing.

What does it produce?

The simulations produce estimates of lichen pasture productivity and the costs of feeding reindeer through time. Two alternative assumptions were used for lichen growth available to reindeer. In model 1, reindeer could graze the yearly lichen growth estimated from previous studies, whereas in model 2 reindeer could use 50% of yearly lichen growth.

In model 1, lichen biomass available for reindeer decreased from approximately 4,400 tons in 1940 to 2,700 tons in 2025, corresponding to a 40% reduction in lichen pasture availability. In model 2, the reduction was approximately 27% (Fig. 4.7C).

The simulations also produce a cumulative economic loss curve, which puts into monetary values how much it would be necessary to supplementary feed reindeer and compensate for these producti-

vity losses (Fig. 4.7D). The analyses suggest annual additional feeding costs of approximately 300,000–400,000 euros for reindeer herders. Compared to a meat production turnover of 500,000–700,000 euros in the cooperative, these costs are substantial.

The analyses also indicate that with the forest structure of 1940, lichen growth could have been 40–60% higher than today. Consequently, meat production turnover could also have been substantially higher under historical forest conditions.

The simulations also show that, although logging activities decreased strongly after 2000, lichen productivity did not recover immediately because of the long-lasting cumulative impacts of historical logging. If additional forestry activities and other disturbances are avoided, significant improvement in lichen productivity is expected only after 2040, as forests mature.

Strengths and limitations

STRENGTHS

- Combines GIS mapping and ecological–economic modelling to assess cumulative impacts through time.
- Links forestry history directly to changes in lichen productivity and reindeer husbandry economics.
- Produces spatially explicit and long-term estimates of pasture productivity and feeding costs.
- Can be expanded to include other land-use pressures if they are mapped through time.

LIMITATIONS

- Results depend strongly on the quality and availability of historical land-use and pasture data.
- Long recovery times and complex ecological interactions introduce uncertainty into long-term projections.
- Applying the approach to other regions requires local adjustments to pasture conditions and reindeer husbandry systems.

Learn more

- Saijets, J., Raitio, K., Pyykkö, J., Hansen, L., Aikio, E., Feodoroff, P., & Seurujärvi, O. (2024). Impact assessment and indigenous rights: Cumulative impact assessment of forestry on winter pastures in Mudusjärvi reindeer herding co-operative in Finland. <https://doi.org/10.1101/2024.10.01.616203> (description of the approach and application to estimate cumulative impacts of forestry on reindeer husbandry in Finnish Sápmi)
- Kumpula, J., Kurkilahti, M., Helle, T., & Colpaert, A. (2014). Both reindeer management and several other land use factors explain the reduction in ground lichens (*Cladonia* spp.) in pastures grazed by semi-domesticated reindeer in Finland. *Regional Environmental Change*, 14(2), 541–559. <https://doi.org/10.1007/s10113-013-0508-5> (static lichen biomass model for northern Finnish reindeer herding cooperatives)
- Kumpula, J., Siitari, J., Siitari, S., Kurkilahti, M., Heikkinen, J., & Oinonen, K. (2019). *Poronhoitoalueen talvilaitumet vuosien 2016–2018 laiduninventoinnissa: Talvilaidunten tilan muutokset ja muutosten syyt* (No. 33/2019; Luonnonvara- ja biotalouden tutkimus). Luonnonvarakeskus. (pasture inventories and lichen biomass, in Finnish)

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Sápmi is changing. Forestry, mining, energy production, tourism, roads and climate change are adding pressure and reshaping landscapes that reindeer, reindeer herders and Sámi communities depend on. While the impacts of each development project may seem limited on its own, together they can reduce access to pastures, fragment migration routes, increase workload for herders and affect the long-term viability of reindeer husbandry. To understand these changes, we need to look beyond single projects and consider how impacts accumulate across space, time, sectors and borders.

Drawing on an academic literature review, on practical examples and on a Nordic workshop with experts, authorities and reindeer herders, this report brings together concepts, tools and collaborative approaches for including cumulative impacts within impact assessments and land planning in Sápmi. The report focuses mostly on spatial data and methods and how they can be used for assessing cumulative impacts on reindeer and reindeer husbandry, but also offers resources for bringing this discussion to other contexts.

The report calls for stronger cross-border cooperation, better integration of data, meaningful participation of Sámi rightsholders and reindeer herding communities, and land-use planning that is regional and integrated across sectors, respecting Sámi rights and livelihoods. We hope to give means to take a step towards shared knowledge, improved methods and more just decision-making for the future of reindeer husbandry and landscapes in Sápmi.

