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Research Article

How dis-services illuminate divergence between "nature's contribution to people" and "ecosystem services" – an assessment of *Empetrum nigrum*

Pham Minh Nhat‡, Claire W Armstrong‡, Maria W Tuomi‡, Kari Anne Bråthen‡

‡ UiT The Arctic University of Norway, Tromso, Norway

Corresponding author: Pham Minh Nhat (phamminhnhat0512@gmail.com)

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Abstract

Encroachment of a native invasive species – *Empetrum nigrum* (crowberry) – has impacted Arctic ecosystems and the indigenous Sámi people. To understand comprehensively the impacts of this native invader, we adopted three concepts, ecosystem services (ES), ecosystem disservices (EDS) and nature's contributions to people (NCP), to identify and classify systematically crowberry's beneficial and detrimental impacts on the Arctic ecosystem. Through a systematic literature review of 116 articles, we show that, amongst 12 positive and negative impacts of *E. nigrum*, the species only provide detriments to humans *indirectly*. Specifically, the detriments are the negative impacts on the local ecosystems and biodiversity, which indirectly affect locals' way of life. We identify one additional beneficial impact of crowberry – carbon fixation – which was not included in previous review studies. The analysis reveals that the CICES framework, despite its detailed categorisation capabilities, lacks specific differentiation for certain services (e.g. food vs. medicinal) and neglects ecosystem disservices. We propose integrating EDS into the MAES/CICES and IPBES frameworks, classified in a manner parallel to its existing ES categories, for a more holistic assessment.

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Furthermore, we demonstrate that the NCP concept, contrary to IPBES claims, does not consistently offer a more inclusive lens for assessing multifaceted impacts, due to the lack of elements equivalent to disservices. Consequently, we suggest improving the neutrality of NCP subcategories and adopting an endogenous perspective in assessing nature's contributions. Ultimately, the choice of concept may depend on specific research objectives.

Keywords

millennium ecosystem assessment, IPBES, CICES, systematic literature review, Norway, reindeer husbandry, crowberry

Introduction

The Arctic is being impacted significantly by climate change and many ecosystems in this part of the planet are being destabilised (Olofsson et al. 2011, Bokhorst et al. 2018, Warwick 2019). Arctic terrestrial ecosystems, particularly the tundra and the boreal landscapes, are experiencing several abrupt changes in species distribution, leading to shifts in flora and fauna communities (Wardle et al. 2012, Ylanne et al. 2015, Svensson et al. 2018). Since the European terrestrial ecosystems provide social, cultural and economic benefits to many northern European countries, including Norway, Sweden, Finland and the north-western part of Russia (this area is often called Fennoscandia), several aspects of Arctic people's lifestyles are directly and indirectly affected (Weladji and Holand 2003, Malinauskaite et al. 2019). In particular, tundra and boreal landscapes act as common grazing pasture for the iconic reindeer husbandry of the indigenous Sámi people in Fennoscandia (Riseth 2007). Due to extreme weather volatility, unfavourable conditions for the husbandry are happening more frequently, such as rain-on-snow events, expansion of the birch treelines (arctic greening), moth outbreaks (arctic browning), shrubification of Salix spp. (willow) and invasive species introduction (Mainka and Howard 2010, Jepsen et al. 2013, Karlsen et al. 2013, Jones et al. 2015, Fauchald et al. 2017, Maliniemi et al. 2018, Myers-Smith et al. 2020). These events decrease the quantity and quality of reindeer grazing pastures, causing disruption in reindeer natural habits and habitats (Bråthen et al. 2007, Risvoll and Hovelsrud 2016, Turunen et al. 2016 Tuomi et al. 2024). The Sámi reindeer herders, hence, are facing great difficulties in maintaining their traditional way of life.

Amongst the above-mentioned climate change consequences in the Arctic, invasive species have been destabilising native ecosystems and causing severe damage to local people (Mooney and Cleland 2001, Mainka and Howard 2010, Ziska et al. 2011, Milanović et al. 2020). Invasive species in northern Europe, for example, the Japanese knotweed (*Reynoutria japonica*) and the giant hogweed (*Heracleum mantegazzianum*), have caused serious socio-economic impacts on local residents, including the loss of harvest and production of key natural resources, the health cost caused by invasion of these alien species and the removal/control costs to return the ecosystems to their

previous states (Keller et al. 2011, Milanović et al. 2020). Furthermore, alterations of ecosystem functions and processes, caused by climate change, can turn a native species into a native invader (Hellmann et al. 2008, Valéry et al. 2009, Carey et al. 2012). Research about identification, classification and dynamic valuation of native invasive species are nevertheless few and the term is not even mentioned in recent global climate and environmental reports (Invasive Species Centre 2021, IPCC 2022, Convention on Biological Diversity 2023). In these reports, invasive species are still considered only as non-native, or alien, invasive species; yet a native species can also become invasive due to habitat condition alterations (Carey et al. 2012). To contribute more to the study of non-alien invasive species, we focus our study on an encroaching native plant invader in the Arctic terrestrial ecosystem. An aim of this work is to understand comprehensively and systematically the impacts of a native invader, crowberry, on Fennoscandian nature and people.

Empetrum nigrum (crowberry), the evergreen dwarf shrub, has, due to climate and environmental changes in recent decades, abundantly encroached tundra ecosystems in Fennoscandia (Bråthen et al. 2007, Wilson and Nilsson 2009). *E. nigrum* is an allelopathic species, producing leaf chemicals harmful to other organisms (Nilsson et al. 1993). In addition to allelopathy, *E. nigrum*’s three distinctive characteristics can explain its competitive success: (1) its horizontal creeping growth form which impedes access to light and hence growth of other subordinate species; (2) its phenolic-rich litter which causes lowered nitrogen-availability in soil and (3) its low nitrogen content in leaves inducing low palatability (Tybirk et al. 2000). Via these characteristics, *E. nigrum* can impact and shift the vegetation communities (Bråthen et al. 2018), which may cause indirect effects on the reindeer husbandry of the indigenous Sámi people, as crowberry can deteriorate the quality and quantity of the grazing pasture. Therefore, from an ecological perspective, this species is a profound example of how nature and human-well-being are affected by climate change consequences. On the other hand, *E. nigrum* berry, which is rich in anti-oxidant substances (Hyun et al. 2016), is an important food source not only for indigenous people, but also for many wader birds and herbivores (Lorion and Small 2021). Furthermore, *E. nigrum* endophytes have been tested for their anti-inflammatory substances in the treatment of urinary catheter-associated infections (Monteiro et al. 2019). Besides, polyphenolic compounds from the leaves contain orosensory properties, potentially making the species fit for industrial food production (Laaksonen et al. 2011). Conclusively, *E. nigrum* causes both beneficial and detrimental impacts on the ecosystem outputs, depending on which perspective we employ to evaluate this species. It is therefore of interest to have a comprehensive study of *E. nigrum* beneficial and detrimental impacts on the native ecosystems and the local people.

Nature’s and species’ benefits to human well-being can be identified and classified by the ecosystem services (ES) framework, extensively presented in the Millennium Ecosystem Assessment (MA) (Millennium Ecosystem Assessment 2004, Millennium Ecosystem Assessment 2005). Application of ES for assessment of species impacts has proven fruitful both academically and practically (Fisher et al. 2008, Tallis et al. 2008,

Braat and de Groot 2012, Costanza et al. 2017). There have been several major initiatives building on the MA's ES concept – for instance, The Economics of Ecosystems and Biodiversity (TEEB) (TEEB 2010), the System of Environmental-Economic Accounting (SEEA) (King et al. 2024), the Mapping and Assessment of Ecosystem Services (MAES) (Vári et al. 2024) and the Common International Classification of Ecosystem Services (CICES) (Haines-Young and Potschin 2018). In these frameworks, ecosystems are considered to be the main service providers.

As the most long-standing framework in ecosystem services research, MA defined and categorised ES in 2005 into four groups – provisioning, regulating, cultural and supporting. Due to the ambiguity between supporting and regulating ES and issues of double counting in valuation of these services, the MAES framework later clarified this structure by shifting supporting services into ecosystem condition, thereby separating ecological functions from final service flows (Vári et al. 2024). Following this restructuring, CICES was originally developed within the MAES initiative as a standardised, operational classification system for final ecosystem services (Haines-Young and Potschin 2018). CICES was launched in 2009 by the European Environment Agency's Task Force (led by Haines-Young & Potschin) to convert the MA typology into a practical, hierarchical "Section–Division–Group–Class" system. By providing clear definitions and nested categories, CICES enables researchers to classify nature's benefits more easily and supports consistent ES accounting and reporting across scales and sectors. Other major initiatives, such as SEEA EA (King et al. 2024), were also built on MAES/CICES and are international statistical standards designed for ecosystem accounting and integration with national economic accounts. The framework also explicitly frames invasive species as pressures on ecosystem condition that alter flows of services. This perspective aligns with our perspective about the impacts of *E. nigrum* on the local ecosystem.

Nevertheless, the ES concept only covers the benefits humans receive from nature, leaving out the detriments that nature causes. This led to the creation of an adverse concept – ecosystem disservices (EDS). The concept was defined by Lyytimäki et al. (2008) to address species' detriments, either real or perceived, that affect human well-being (Lyytimäki et al. 2008). Literature on EDS is more scarce than for ES, not only because the concept was developed later (Power 2010, Lyytimäki 2015, Shackleton et al. 2016, Schaubroeck 2017), but also because species' detriments have presumably always tacitly been acknowledged and accounted for (Shapiro and Báldi 2014). A systematic literature review showed that EDS articles stand for 0.4% of the total ES literature, with 87% of EDS studies being published after 2012 (Kadykalo et al. 2019).

Although there exist challenges in relation to EDS definition and categorisation (Guo et al. 2022), acknowledgement of EDS can increase the comprehensiveness of species assessments, potentially resulting in better decisions (Vaz et al. 2017, Campagne et al. 2018, Wu et al. 2021). Here, the phrase "beneficial and detrimental impacts" is used as a neutral descriptor of the positive and negative impacts of ecosystem processes and functions on human well-being; they do not yet imply assignment to any particular classification (e.g. ES/EDS or NCP). In practice, decision-makers tend to act faster when

both species’ detrimental and beneficial impacts are known rather than when only the positive impacts are recognised (Schaubroeck 2017, Blanco et al. 2019, Herd-Hoare and Shackleton 2020). Many have used ES-EDS integration for comprehensive assessments of various ecosystem types, such as trees in urban areas (Lyytimäki et al. 2008, Lyytimäki 2014, Lyytimäki 2017, Escobedo et al. 2018, Teixeira et al. 2019, Davoren and Shackleton 2021), agricultural ecosystems (Zhang et al. 2007, Mouchet et al. 2017, Herd-Hoare and Shackleton 2020) or rangeland ecosystems (Swain et al. 2013). Both ES and EDS are also included to identify beneficial and detrimental impacts of many invasive species, such as mussels and weeds in freshwater ecosystems (Limburg et al. 2010, Sheergojri et al. 2022), different types of trees and plants in rangeland ecosystems (Shackleton and Shackleton 2018, Milanović et al. 2020) and ants in agroecosystems (Wielgoss et al. 2013). However, ES-EDS of Arctic invasive species, either alien or native, have so far not been addressed or assessed.

The ES concept in itself has been criticised due to multifaceted values of nature not being reflected comprehensively (Díaz et al. 2018), suggesting that the MA framework has solely an anthropocentric perspective excluding ecocentric aspects (Wallace 2007). Hence, the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) constructed the more recent concept of nature’s contributions to people (NCP) that intended to provide a more pluralistic philosophy within nature-human relationships (IPBES 2016). One attempt of IPBES to promote the NCP concept as an alternative to the ES concept is to acknowledge that NCP consists of both species’ positive and negative impacts towards human well-being. IPBES combined supporting and regulating ES-EDS to form a new group of regulating NCP, in addition to the so-called material and non-material NCP (IPBES 2019)*[1]. The latest version of CICES also does not take into account the EDS concept.

Comparisons of ES and NCP regarding how these concepts identify and classify species’ beneficial and detrimental impacts have been conducted, with some concluding that NCP might be better and more inclusive as it addresses diversity of values under multiple perspectives (Kadykalo et al. 2019), while others refute the novel contributions of NCP suggesting it is merely another name for ES (Muradian and Gómez-Baggethun 2021). Moreover, while comparisons of both concepts’ definitions and classifications were investigated, case studies to compare the two concepts’ applicability are largely lacking. Additionally, comparisons in categorisations between CICES and IPBES frameworks have not yet been conducted although there exists one study adopting the NCP concept as a baseline approach with CICES as the complementing classification system (Moreira et al. 2024). Here we contribute to the literature of ES, EDS and NCP and of native invaders, particularly in the Arctic, by adopting these three concepts in the case study of an Arctic native invader – *Empetrum nigrum* (crowberry). We hence apply the classification of the MA, MAES/CICES and IPBES frameworks to assess *E. nigrum*’s beneficial and detrimental impacts. From our assessment, we first systematically determine crowberry’s direct and indirect impacts and, second, compare the applicability of ES-EDS and NCP, based on three frameworks in identifying and classifying these impacts. Our study, therefore, contributes to expand upon assessments of climate change

impacts on the Arctic nature and people by studying the impacts of *E. nigrum* in the Fennoscandian socio-ecological systems.

We assess *E. nigrum*'s beneficial and detrimental impacts by applying a systematic literature review (SLR) and identify its impacts on human well-being following both ES-EDS and NCP concepts. The main research questions are:

1. What are the beneficial and detrimental impacts of *E. nigrum* towards the native ecosystem and the local people?
2. Which concept, ES-EDS or NCP, is more suited for analysing the impacts of the native invader, in particular and of a species, in general?
3. Which framework is best suited for classifying nature's impacts?

We give an overview of EDS and NCP concepts in the second section, while the methodological approach is detailed in the third section. This is followed by the results from the systematic literature review, with the final part discussing the findings and comparing the applicability of the two frameworks.

[1] Regarding the topic of invasive species, IPBES addresses invasive species as a significant topic for assessment, but the comprehensive thematic report on the topic is yet to be finalised.

Introductions to EDS and NCP concepts

EDS concept

One great challenge of the EDS concept is its definition (Guo et al. 2022). EDS was first defined as ecosystem functions with negative impacts on human well-being (Lyytimäki et al. 2008), which then is dependent on personal perceptions. For instance, urban forests provide EDS to some, but not to others (Lyytimäki 2015, Conway and Yip 2016, Lyytimäki 2017). Others view EDS as biodiversity loss (Chapin et al. 2000) or decrease in ES caused by some ecosystem functions and processes (Shapiro and Báldi 2014). Specifically, one study also defined the negative externalities of human actions on ES generation as EDS (Balmford and Bond 2005), while other studies have not followed this approach, but only focus on the detriments of nature on humans. The EDS definition of Lyytimäki et al. (2008) has received support in several studies (Escobedo et al. 2011, Von Döhren and Haase 2015, Vaz et al. 2017), although the wording used in these studies might vary (Guo et al. 2022). Overall, integration of ES-EDS in nature and species assessment has been encouraged (Swain et al. 2013, Mouchet et al. 2017, Schaubroeck 2017, Vaz et al. 2017, Escobedo et al. 2018, Blanco et al. 2019, Davoren and Shackleton 2021, Guo et al. 2022).

There are two ways to categorise EDS within literature, dependent on whether one focuses on the impacts of disservices on human well-being or the disservices themselves. Regarding the first classification, different studies apply a variety of impact formulations (Table 1). EDS can be divided into three impact groups by Shackleton et al.

(2016), three other groups by Escobedo et al. (2011), six groups by Lyytimäki et al. (2008) , five groups by Von Döhren and Haase (2015) and five other groups by Vaz et al. (2017). Amongst these classifications, several impact groups are mentioned repeatedly, such as health, security, economy and leisure, while others give different names, but can be understood to be largely the same EDS (such as economic and financial cost or health and psychological impacts). Indirect EDS , which may be defined as the indirect negative impacts of nature on human well-being, (which was categorised as ecological impact (Von Döhren and Haase 2015)) are not usually the focus of this approach (as only one paper identifies ecological EDS (Table 1)). The reason might be that, as EDS are categorised by their impacts on human-well-being, direct impacts can be easily thought of and, thus, receive much more focus than indirect ones. Overlap of EDS categories challenges not only the integration of EDS into the ES concept, but also the validation of the concept itself.

Table 1.

Differences of EDS categorisations.

Paper		Shackleton et al. (2016)	Lyytimäki (2008)	Escobedo et al. (2011)	Von Döhren & Haase (2015)	Vaz et al. (2017)
Categorisations	Economic	X	X		X	
	Financial cost			X		
	Health	X	X		X	X
	Psychological				X	
	Safety	X	X			X
	Security		X			X
	Aesthetics		X			X
	Cultural	X				X
	Social nuisances			X		
	Environmental pollution			X		
	Ecological				X	
	Material					X
	Leisure and creation					X
	Mobility		X			
	General impacts on human well-being				X	

The second categorisation is to classify EDS according to their disservices: provisioning, regulating, cultural and supporting (Friess 2016, Mouchet et al. 2017, Springer et al. 2018 Wu et al. 2021) (Fig. 1). Differing from the first classification mentioned above, here indirect EDS (supporting disservices under the MA framework or negative changes in ecosystem conditions according to MAES framework) are usually emphasised to an equal degree compared to other EDS groups. With the importance of identifying and

classifying indirect species' detriments, this type of classification was used in many assessments of invasive species where the mention of both direct and indirect EDS in the ES-EDS assessment of these species are indispensable (Wielgoss et al. 2013, Vaz et al. 2017, Shackleton and Shackleton 2018, Milanović et al. 2020). Various ES-EDS assessments show that invasive species, both native and non-native (or alien), can harm neighbouring species, either by competing with the natives, reducing natural habitats (Springer et al. 2018, Shackleton et al. 2019, Tebboth et al. 2020, Sheergojri et al. 2022), disturbing stability of native ecosystems (Limburg et al. 2010, Tebboth et al. 2020) or by decreasing biodiversity (Wielgoss et al. 2013, Milanović et al. 2020). This classification approach, hence, allows easier integration of EDS into many frameworks, such as the MA, MAES/CICES frameworks, creating a better foundation for adoption of both ES and EDS. Moreover, it emphasises the importance of species' indirect detriments for clearer and more comprehensive decision-making processes.

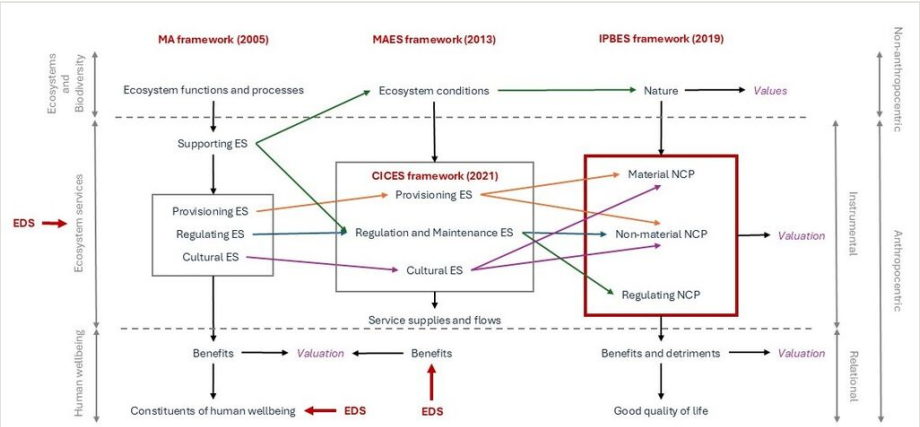


Figure 1.

Differences in MA (2005), MAES/CICES (2013,2021) and IPBES (2019) frameworks. Schematic illustration of the relationship between ES and NCP, the various ways economic valuation enters and the different entrance points of EDS into the frameworks. Fig. 1 compares how the MA (2005), MAES/CICES (2013,2021) and IPBES (2019) frameworks classify and link nature's benefits and detriments. Supporting ES, explicitly addressed in MA, were reframed as "Ecosystem conditions" in MAES, while, to a small degree, still merged into Regulation & Maintenance ES in CICES, yet feeds both into Non-material and Regulating NCPs in IPBES.

NCP concept

Critique of the ES concept spans from anthropocentrism (Wallace 2007) and over-optimism (Lyytimäki et al. 2008) to insufficient recognitions of biodiversity (Faith 2018), intrinsic values of nature (IPBES 2016), Indigenous and Local Knowledge and the relational value of nature (Díaz et al. 2018). Based on these suggested limitations, the IPBES framework with the NCP concept was formed. IPBES reframes "services" as "contributions", since "services" were seen as an anthropocentric concept where humans

are above nature, while “contribution” is supposed to underline the nature-human gifting relationship with a lesser lord-and-servant impression (Díaz et al. 2018). Moreover, nature’s or species’ contributions are recognised as potentially being both beneficial and detrimental depending on different contexts and perspectives. To emphasise not only anthropocentrism, but also ecocentrism, the IPBES framework surrounds the NCP concept with two other entities: (1) nature – which includes the impact of the natural entity in question on other organisms, biodiversity, biophysical assemblages and biophysical processes; and (2) good quality of life – which indicates how human well-being is impacted by nature (Fig. 1). Including NCP, these three “foci of values” constitute the IPBES framework. The MA also mentioned ecosystem conditions and human well-being, which can be corresponding elements for two above-mentioned entities in IPBES.

Significantly, the three different types of ES defined by the MAES framework – provisioning, regulating and cultural – were re-defined in IPBES as regulating, material and non-material NCP*[2] (Díaz et al. 2018) (Fig. 1). Provisioning ES became material NCP, consisting of materials, physical objects and substances that humans extract from nature. Second, non-material NCP emanates from both cultural and regulating ES, including human intellectual experiences with nature, such as in religion, education, recreation etc. The reason non-material NCP covers both cultural and regulating ES is because, to obtain experiences and inspiration, both tangible and intangible contributions are necessary. Third, the framework, in its 2019 version, combines regulating and supporting ES (from MA framework) into regulating NCP, including ecosystem functions and processes, which can provide both direct and indirect contributions to humans IPBES (2019). Regulating NCP sustain natural environments and are the foundation for material and non-material NCP (IPBES 2017). Furthermore, all three types of NCP include both nature’s benefits and detriments.

Values are assessed differently under the IPBES and MAES/CICES frameworks. Supporting ES were disregarded in the valuation phase in CICES and IPBES to avoid double counting, since supporting ES influence indirectly human well-being via the direct services (Fig. 1). IPBES adopted another perspective regarding valuation where all three compartments of the framework – nature, NCP and good quality of life – are valued concurrently (Fig. 1), using different methodologies. Furthermore, IPBES acknowledged that valuation of these three compartments can overlap, thus the mode of valuation should be based on the purpose of the assessment (IPBES 2016). Several ES studies also follow the same approach (Schröter et al. 2016). Thus, we distinctly separate “valuation” from NCP and Good quality of life with “values” from nature (Fig. 1) since the latter compartment can provide pluralistic types of values in which some cannot be estimated economically.

Critiques of IPBES’ works quickly emerged, especially with Kenter (2018) discussing challenges within the NCP terminology in relation to the viewpoints of Díaz et al. (2018) regarding the ES concept. Both ES and NCP are shown to have their own semantic problems, suggesting that NCP is only a rephrasing of ES, though the latter concentrates mostly on a unidimensional flow of values from nature to people, disregarding the anthropogenic impact on nature. However, this seems to be incorrect as the ES cascade

model incorporates anthropogenic responses back to ecosystem conditions (Potschin-Young et al. 2018, Rugani et al. 2019). Kenter (op cit) stated that the term NCP puts much focus on the instrumental value of nature, which does not sufficiently encapsulate the pluralist philosophy of the overall framework. Thus, the author suggested keeping the ES concept within a pluralistic setting, including NCP. The NCP concept was further criticised (Braat 2018, Maes et al. 2018), especially in response to the claim of Díaz et al. (2018) that the MA framework lacks the weight of social science participation, especially anthropology. Maes et al. (2018) have pointed out that, over the evolution of the ES concept, more recent studies included the participation of social scientists in policy-making, even with the involvement of local and ethnic practitioners. Therefore, they called for an integration of ES within the IPBES framework to compliment and revise it for improved environmental assessment. Additionally, Braat (2018) claimed that the article "Assessing nature's contribution to people" by Díaz et al. (2018) was narrow-sighted and contained false claims about the evolution and knowledge accumulation in relation to the ES concept, alerting readers to the problems of embracing the NCP concept too soon with insufficient time for practical application and peer-review. It seems fair to claim that the debate whether to adopt NCP or ES has not yet reached its conclusion.

Methodology

As discussed earlier, ES-EDS and NCP concepts possess their own advantages and disadvantages. While ES-EDS are more widely accepted and applied, NCP helps to clarify nature's positive and negative impacts on human well-being, especially with explicit classifications and explanations regarding the indirect impacts. To compare their differences in detail, we applied the case of the allelopathic species *E. nigrum* in the context of the Fennoscandian tundra and boreal ecosystems as a case study. From a systematic literature review, we identified, classified and analysed the direct and indirect impacts of *E. nigrum* on ecosystems, which, in turn, alter the supply of ES-EDS and NCP.

While the more recent MAES/CICES framework is adopted as our primary classification system for ES in this paper, we retain the original MA framework, because it remains influential and continues to appear in recent literature, particularly in studies that still classify Supporting Ecosystem Services (Maund et al. 2020, Paudel et al. 2021, Wang et al. 2021, Whiteis et al. 2025). While Supporting ES are not included in the MAES/CICES to avoid double-counting, this concept is nonetheless still analytically important for understanding how *E. nigrum* affects ecological processes that underpin final services.

As our scope is a conceptual and qualitative assessment of a single native invader, we focus on MAES/CICES as the operational framework, while including MA for historical continuity and to capture Supporting ES and include the IPBES framework for comparison with more recent pluralistic framing. This overview allows us to demonstrate how different frameworks classify the same set of positive and negative impacts while keeping the analysis within a manageable scope.

Systematic literature review

The Systematic Literature Review (SLR) method not only captures the big picture of research achievements and limitations in specific fields, but also reduces the risks of bias within individual and selected studies, or across filtered studies, also providing reliable reference sources (Liberati et al. 2009). So far, three review studies of *E. nigrum* have been published (Tybirk et al. 2000, Nilsson and Wardle 2005, Lorion and Small 2021). While Tybirk et al. (2000) and Nilsson and Wardle (2005) concentrated in the allelopathic impact of *E. nigrum* on ecosystems, Lorion and Small (2021) stress its role in relation to birds, mammals and humans. None of the reviews was conducted systematically or assessed broadly positive and negative contributions of *E. nigrum*.

Data collection

This SLR was conducted following the criteria of the AMSTAR framework (Welsh et al. 2015). The AMSTAR guideline was created to evaluate the quality of systematic literature reviews, thus enhancing validity of the SLR (Shea et al. 2017). The AMSTAR guideline requires the SLR research to be specific and transparent by meeting several conditions, ranging from the requirement of multiple databases to data inclusion, duplication and exclusion control, statistical method in meta-analysis and details with respect to chosen studies.

Amongst scientific databases, ScienceDirect, Jstor and Web of Science (WoS) were chosen since they are central databases for peer- and non-peer-reviewed publications. *Empetrum* includes several species, but we concentrated on *E. nigrum* and its common English name – crowberry. Two main keywords were chosen under a connected boolean: “*Empetrum nigrum*” OR “crowberry”. From each database, only those mentioning the search query in titles, abstracts or specified keywords were selected (Fig. 2). Duplication amongst and between databases was eliminated first by the built-in checking tool in Mendeley, followed by a re-examination of title, abstract and list of authors. Amongst the remaining 275 papers, 16 were eliminated due to either *E. nigrum* being mentioned only one time or that it was not a central subject or object of the research or the paper was about another type of crowberry – white crowberry (*Corema album*) – which falls outside the scope of this study. Amongst the remaining pool, eight publications were so old that their sources could not be found, leading to the final total number of chosen publications for inspection of 251 (Fig. 2).

Following the AMSTAR guideline, the chosen publications were double-checked, first by conducting another procedure to create the data pool and then by inspection of two co-reviewers. The second procedure was operated by not merging three datasets into a pool within Mendeley as before, but choosing the one with the most publications as a base source – in this case the WoS. Then comparison between ScienceDirect and Jstor datasets in relation to the WoS pool was handled manually to include those publications that were not listed in WoS. This second pool, then, was compared with the first to see whether any publication was excluded between pools. Following this, two co-authors were asked to go through the eliminated publications for re-confirmation. Duplicated

papers which were not detected by Mendeley were handled within this double check procedure. This procedure fulfils the AMSTAR requirement for study selection and data inclusion, exclusion and duplication management.

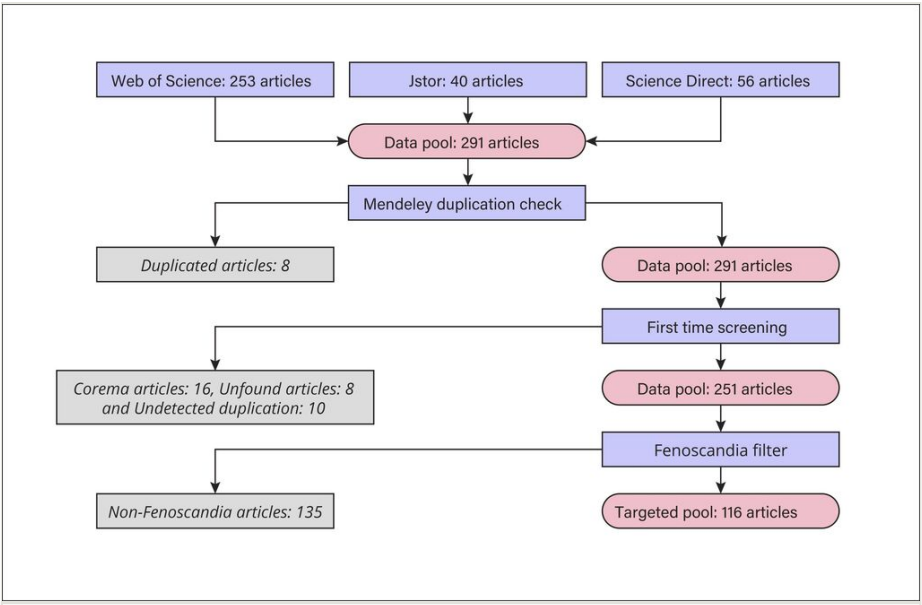


Figure 2.

Data filtration and selection.

With the pool of 251 chosen publications, preliminary analysis was implemented. Different context variables were extracted, including geographic location – where the study was conducted, timeline – when the experiment took place, field of science – whether the study belongs to natural science or social science and research areas – fields and sub-fields of the publications. Since Fennoscandia possesses the earliest and largest part of the publications and also since *E. nigrum* is considered a key species within this region (Tybirk et al. 2000), papers which are geographically relevant to the Fennoscandia region were filtered as a subset for quantitative analysis. This led to 116 publications being chosen for the final pool.

Data coding

Regarding ecological aspects, *E. nigrum* impacts on four different categories – on other organisms and species, on biodiversity, on biological assemblages and structure and biophysical processes and functions. Organismal impact covers the responses of other species to *E. nigrum*'s pressure, while impacts on biological assemblages and structure indicate changes of ecological communities and habitats. Biodiversity impact involves alteration of taxonomic, functional or genetic diversity of the community, while impact on biophysical functions and processes is concerned with changes in element dynamics through changed biotic and abiotic interactions, for example, food web dynamics and

nutrient cycling. These ecological effects were then interpreted as changes in ecosystem outputs relevant to ES/EDS or NCP. Information related to anthropogenic aspects was extracted, based on the researched and referenced beneficial and detrimental impacts of *E. nigrum*.

Direct beneficial and detrimental impacts were recognised and recorded through the title, abstract, discussion and conclusion of each publication. Indirect impacts may often be unaccounted for, since they are regularly embedded within ecological publications and refer to supporting services, disservices or the subcategories in the regulating NCP groups. Therefore, to include these aspects, *E. nigrum*’s impacts on other species, towards whole communities or the dynamic of local ecosystems, are also accounted for. A piece of information within a study is grouped as explicit when that study explicitly researched *E. nigrum*’s impacts and as implicit when these impacts were only mentioned via reference to other studies. These impacts of *E. nigrum* were then mapped to ES/EDS and NCP categories, with negative impacts interpreted as ecosystem disservices. Regarding negative impacts, we grouped the detriments following the functions of the disservices (provisioning, regulating, cultural and supporting (according to MA) or negative impacts of ecosystem conditions (as defined in MAES)) or negative contributions (all 18 NCP sub-categories). Data variables and their categories are summarised in Table 2.

After sorting out the impacts of crowberry, we define as direct the impacts that feed directly from dis-/services or contributions into well-being, not having come via ecosystem functions and processes or supporting dis-/services. We use 18 sub-categories of IPBES (IPBES 2019) and CICES classes (CICES 2021) to categorise crowberry’s benefits and detriments.

Table 2.
List of data variables and categories for paper analysis.

Data variables	**Categories**
Geographic location	Finland; Norway; Sweden; Russia; Fennoscandia
Timeline	1971; 1972; …; 2019
Field of science	Natural science; Social science; Both
E. nigrum impact on organisms	Negative or Positive; Implicit or Explicit,
E. nigrum impact on biodiversity	Negative or Positive; Implicit or Explicit
E. nigrum impact on biological assemblages and structure	Negative or Positive; Implicit or Explicit
E. nigrum impact on biophysical functions and processes	Negative or Positive; Implicit or Explicit

Ecological role	Inhibit growth of *Pinus sylvestris*; Diet for *Entephria polata*; Lower species richness and abundance of herbaceous vascular plants; …
MA Categorisation	Provisioning ES; Regulating ES; Cultural ES; Supporting ES; Provisioning EDS; Regulating EDS; Cultural EDS; Supporting EDS
CICES Class Categorisation	Wild plants used for nutrition; Bioremediation by micro-organisms, algae, plants and animals; Elements of living systems used for entertainment or representation outside the setting concerned; Filtration/sequestration/storage/accumulation by micro-organisms, algae, plants and animals; …
IPBES Sub-categories	Food and feed, Materials and assistance, Learning and inspiration; Physical and psychological experiences; Regulation of climate; …

Cross-check reading was conducted by three co-reviewers to assess the reliability and validity of the analysis. Each co-author randomly chose 15% of the articles in the pool for re-assessment.

Results

E. nigrum has, on average, been included in one publication per year before 1995 and 4-6 publications from 1997 to 2021 (Fig. 3). Amongst the 116 publications of the targeted pool, 69 publications belong to the field of ecology, involving eight publications within zoology, 52 publications in plant phenology and physiology and nine publications related to other sub-fields of ecology. Besides ecology, 25 publications involve phytochemistry, 17 publications belong to biogeochemistry and one publication is in the field of biogeography. Strikingly, none of the targeted publications belongs to the field of social science though one study utilised the social phenomena of hiking and berry picking as ecological disturbance factors (Manninen and Peltola 2013).

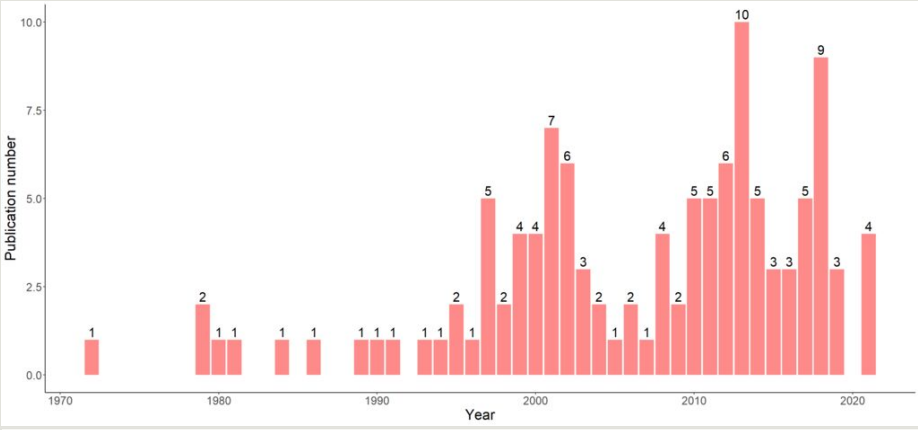


Figure 3.

Temporal span of total 116 publications on *E. nigrum* (1972 – 2021).

Geographically, nearly half of the publications investigated *E. nigrum* in Finland. The country is also the pioneer in this niche of *E. nigrum* research with the first publication in

the 1970s. Research in Sweden, Norway and Russia started later in the 1990s, but the number of publications has increased substantially, especially in Norway and Sweden (Fig. 4). The geographic term Fennoscandia represents the publications whose research area cover more than one country and these publication numbers seem largely constant since the late 1990s.

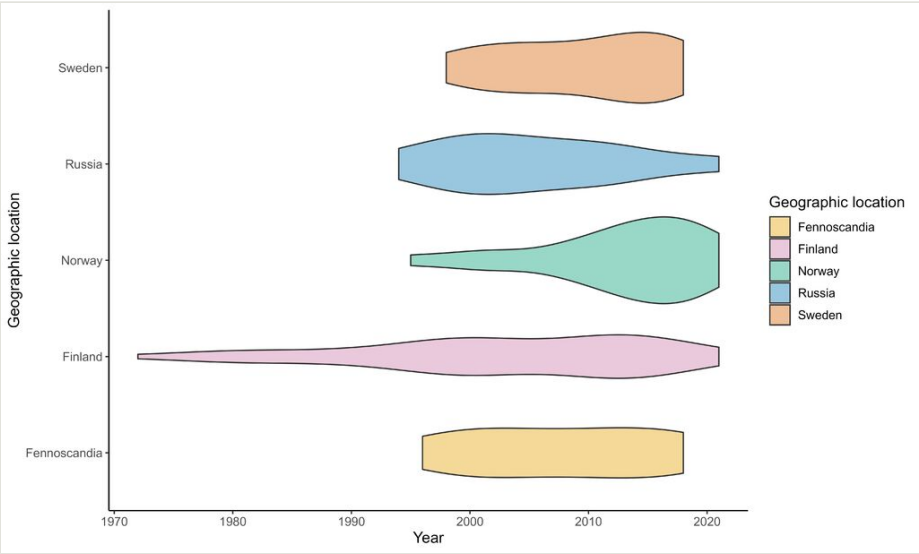


Figure 4.

Temporal span of *E. nigrum* articles within Fennoscandia region. The violin plots show the differences in number of articles from corresponding regions throughout the publication years.

Based on the analysis, we categorised a total of 12 impacts of *E. nigrum*. We grouped them by the mechanism through which the plant affects humans or ecosystems, then noted whether each impact is direct (a tangible good or experience delivered straight to humans) or indirect (an ecological relationship within the local ecosystems). Benefits like “Food”, “Medicinal Benefits” and “Resources for Production” are all direct impacts as the berries and extracts are harvested to be consumed or used as input to other production processes. Recreational benefits, such as “Berry Picking”, likewise yields a direct cultural experience to humans. “Bioindicators” is defined as when crowberry density is used as a variable in research for humans to understand the states of the local ecosystems. “Phytoremediation” is crowberry’s ability to take up or break down soil pollutants. This impact benefits humans by decreasing pollution in soil, while it also assists the local ecosystems by supporting microbial and plant life. “Carbon Sequestration” is crowberry’s capture and storage of CO_2 in its stems, roots and surrounding soil. This contribution assists humans in the fight against climate change. “Plant Growth Facilitation” and “Animal Food” are indirect benefits to humans by supporting ecosystem health and regulating climate and habitat. Finally, the three detriments, “Plant Growth Inhibition”, “Biodiversity Depression” and “Habitat Deterioration”, are all indirect negativities as

crowberry's allelopathic encroachment suppresses neighbouring plants' regeneration, reduces species richness and, hence, degrades wildlife habitat.

Differences in categorisation emerge when we group *E. nigrum*'s beneficial and detrimental impacts following the MA, MAES/CICES and IPBES frameworks. Following the MA framework, 12 benefits and detriments were divided into five groups, including provisioning ES (71 articles), regulating ES (9 articles), cultural ES (11 articles), supporting ES (17 articles) and supporting EDS (13 articles). Additionally, we found no direct EDS of *E. nigrum* in literature, emphasising that crowberry only impacts negatively on the ecosystem conditions. Regarding the CICES framework, *E. nigrum*'s impacts were categorised into seven classes (Fig. 3). As the MAES/CICES framework does not address nor categorise disservices, three indirect detriments of crowberry were considered as "Not Categorised" as they are not disservices, but only negative impacts on ecosystem conditions. Within the IPBES framework, eight sub-categories were categorised (Fig. 3). Though the NCP concept was claimed to be inclusive of both positive and negative nature's contributions (IPBES 2019), the name of the sub-categories only reflect positive impacts of nature on humans. Hence, three indirect negative impacts of crowberry were also considered as "Not Categorised" in IPBES (see Tables 3, 4).

Table 3.

Publication number regarding beneficial and detrimental impacts of *E. nigrum* following MA, CICES and IPBES frameworks.

*PES: Provisioning Ecosystem Services, CES: Cultural Ecosystem Services, RES: Regulating Ecosystem Services, SES: Supporting Ecosystem Services, R&M: Regulation and Maintenance.

** The square brackets show the beneficial and detrimental impacts categorised by the MAES.

Crowberry Category	MA	MAES/CICES Class	IPBES Sub-category	Number of Articles
Food	PES*	Wild plants used for nutrition [PES]**	Food and feed	23
Medicinal Benefits	PES	Wild plants used for nutrition [PES]	Medicinal, biochemical and genetic resources	43
Resources for Production	PES	Fibres and other materials from wild plants for direct use or processing [PES]	Materials and assistance	5
Bioindicators	CES*	Elements of living systems used for entertainment or representation outside the setting concerned [CES]	Learning and inspiration	8
Berry Picking	CES	Elements of living systems that enable activities promoting health, recuperation or enjoyment through active or immersive interactions [CES]	Physical and psychological experiences	3
Phytoremediation	RES*/SES*	Bioremediation [R&M*]	Formation, protection and decontamination of soils and sediments	6

Crowberry Category	MA	MAES/CICES Class	IPBES Sub-category	Number of Articles
Carbon Sequestration	RES/SES	Filtration/ sequestration/ storage/ accumulation by micro-organisms, algae, plants and animals [R&M]	Regulation of climate	3
Plant Growth Facilitation	SES	Maintaining or regulating nursery populations and habitats or breeding grounds [R&M]	Habitat creation and maintenance	7
Animal Food	SES	Maintaining or regulating nursery populations and habitats or breeding grounds [R&M]	Habitat creation and maintenance	10
Plant Growth Inhibition	Supporting EDS	Not Categorised [Negative impacts on ecosystem conditions]	Not Categorised	9
Biodiversity Depression	Supporting EDS	Not Categorised [Negative impacts on ecosystem conditions]	Not Categorised	1
Habitat Deterioration	Supporting EDS	Not Categorised [Negative impacts on ecosystem conditions]	Not Categorised	3

Table 4.

List of articles identifying beneficial and detrimental impacts of *E. nigrum* and our corresponding categorisation, based on CICES and IPBES frameworks.

***E. nigrum* beneficial and detrimental impacts**	**MAES/CICES framework (Section)**	**IPBES framework**	**Articles**
Food (berries)	Provisioning ES	Material NCP	Hakkinen et al. (1999); Hellström et al. (2013); Järvinen et al. (2010); Kallio & Yang (2014); Koskela et al. (2010); Laaksonen et al. (2011, 2013, 2014); Manninen & Peltola (2013); Ollanketo & Riekkola (2000); Sjögren & Arntzen (2013); Viljakainen et al. (2002); Wallenius (1999);…
Medicinal benefits	Provisioning ES	Material NCP	Järvinen et al. (2010); Hellström et al. (2013); Ho et al. (2017); Huttunen et al. (2011); Kallio & Yang (2014); Koskela et al. (2010); Moskaug et al. (2008); Toivanen et al. (2011); Törrönen et al. (2012);…
Phytoremediation	Regulation and Maintenance ES	Regulating NCP	Helmisaari et al. (2007); Lyanguzova (2021); Monni et al. (2000);…
CO_2 fixation	Regulation and Maintenance ES	Regulating NCP	Silvola & Hanski (1979); Silvola & Heikkinen (1979); Ylanne et al. (2015);…
Species growth facilitation	Regulation and Maintenance ES	Regulating NCP	Grau et al. (2010); Lindholm & Vasander (1981); Mod et al. (2014); Pellissier et al. (2010); Svensson et al. (2018);…
Animal feed	Regulation and Maintenance ES	Regulating NCP	Bokhorst et al. (2018); Dahle et al. (1998); Hertel et al. (2016); Itamies & Varkonyi (1997); Pulliainen & Tunkkari (1991); Stenset et al. (2016); Tabell et al. (2019);…
Biodiversity depression	Not categorised	Regulating NCP	Bråthen & Ravolainen (2015);…
Habitat deterioration	Not categorised	Regulating NCP	Gallet et al. (1999);…

E. nigrum beneficial and detrimental impacts	MAES/CICES framework (Section)	IPBES framework	Articles
Species growth inhibition	Not categorised	Regulating NCP	González et al. (2015); Grau et al. (2010); Hypponen et al. (2013); Mod et al. (2014); Monni et al. (2000); M.-C. Nilsson et al. (2000); Pellissier et al. (2010); Pilsbacher et al. (2021); Vistnes & Nellemann (2008);…
Bioindicators	Cultural ES	Non-material NCP	Bråthen & Ravolainen (2015); Lyanguzova (2021); Middleton et al. (2018); Pulkkinen et al. (1989); Reimann et al. (2001); Steyaert et al. (2018);…
Berry picking	Cultural ES	Non-material NCP	Manninen & Peltola (2013);…

Under the MA framework, two beneficial impacts of *E. nigrum*, carbon fixation and phytoremediation- were categorised as both regulating and supporting ecosystem services. Regarding carbon fixation, *E. nigrum* expansion increases carbon stocks in aboveground biomass (Silvola and Hanski 1979, Ylanne et al. 2015). While increased primary production can also translate to increased food for wildlife herbivores, a supporting ES, such bottom-up effects are strongly modulated by, for example, palatability, a functional trait which *E. nigrum* does not possess (Tybirk et al. 2000). Regarding phytoremediation, *E. nigrum* can tolerate and accumulate heavy metals at contaminated sites (Monni et al. 2000, Middleton et al. 2018). Since both humans and nature gain benefits from carbon fixation and phytoremediation, these impacts were categorised as both supporting and regulating ES.

Under the MAES framework, though the direct beneficial impacts of crowberry are grouped similarly to the MA, the indirect benefits are considered slightly differently. As MAES and CICES re-categorised the Regulating ES and some of the elements in the Supporting ES from MA to a new group called Regulation and Maintenance (Fig. 1), the four benefits of crowberry – phytoremediation, carbon sequestration, plant growth facilitation and animal food – belong to this group.

Discussion

Our systematic literature review of *E. nigrum*'s beneficial and detrimental impacts provides results which are in line with other reviews of this species. Ecological impacts of *E. nigrum*, such as its ability to degrade local habitats, outcompete neighbouring species and depress biodiversity, were the main focus of Tybirk et al. (2000) and Nilsson and Wardle (2005). However, since both reviews concentrated on the field of ecology, anthropocentric impacts of *E. nigrum*, such as medicinal benefit or educational value, were ignored. Lorion and Small (2021), in contrast, focused more on the overall benefits of this species towards nature and humans, yet with only brief mention of the negative impacts of *E. nigrum*. In our study, we recognise that, under different contexts and perspectives, crowberry can have either beneficial or detrimental impacts or even both. For instance, from a social medical or health perspective, crowberry is a rich source of vitamins and nutrients for human well-being, while, within an ecological perspective, *E.*

nigrum supports growth of some plants at particular stages, yet still induces shifts in vegetation communities. Ours is the first systematic literature review, contributing to a broader impact analysis of *E. nigrum* under different contexts and perspectives.

Amongst our 12 impacts, 11 were identified when combining the three other reviews (Tybirk et al. 2000, Nilsson and Wardle 2005, Lorion and Small 2021), but none considered carbon fixation as a positive impact of *E. nigrum*. In light of *E. nigrum*’s detrimental effects and the increase of these given climate change (Buizer et al. 2012, Svensson et al. 2018), carbon fixation can be seen as a positive trade-off in relation to the other negative impacts. Recent modelling work (Nhat et al. 2025a) explicitly accounts for ecosystem-level carbon sequestration from both palatable vegetation and crowberry. This study shows that, since *E. nigrum* stores a higher proportion of carbon per unit biomass than other vegetation, together with its allelopathic encroachment, more carbon volume is sequestered in total in the ecosystems.

In the provisioning section, CICES categorises all wild-harvested plant products into a single class, “Wild Plants for Nutrition, Materials or Energy”. This means the same label covers both the use of crowberries as a food source and their processing into pharmaceutical products for their anti-inflammatory compounds. By treating edible and medicinal uses as indistinguishable, CICES obscures crucial differences in how people value and manage the resource. Furthermore, MAES/CICES’s framework was designed exclusively to categorise the direct ES groups without taking on board either supporting ES or direct and indirect EDS. Due to this, the three crowberry detriments can only be categorised as negative impacts on ecosystem conditions using MAES/CICES. Additionally, though there exists one CICES group, “Pest and Disease Control”, which could be relevant to our case because *E. nigrum* are considered as a pest species under the perspective of the reindeer herder (Nhat et al. 2025), yet those three mentioned detriments obviously do not belong to this CICES group. This is because crowberry does not control other pests or diseases, but is itself a pest.

While the CICES framework offers a structured and hierarchical approach to classifying crowberry’s ES, its exclusion of ecosystem disservices represents a limitation. This omission hinders the ability to conduct a holistic assessment of a species' net impact on human well-being. By focusing solely on the positive contributions, CICES, in its current form, provides an incomplete picture, potentially leading to skewed perceptions and suboptimal management decisions. A more comprehensive framework could have room for both the benefits and the detriments that humans experience from nature to support balanced and informed policy-making. To address this gap, we propose the integration of ecosystem disservices into the CICES framework. This could be achieved by introducing a new, parallel "Disservices" section with a hierarchical structure mirroring the existing "Services" section. This new section would have its own Divisions, Groups and Classes, allowing for a systematic and standardised classification of negative impacts. Such a layered approach would not only maintain the clarity and consistency that are the hallmarks of CICES, but also transform it into a truly comprehensive framework for assessing the full spectrum of nature's contributions to people, both positive and negative.

The IPBES framework explicitly aims to capture both positive and negative roles of nature, yet the titles of its eighteen subcategories are framed almost entirely in terms of benefits or, at best, neutral NCP. The framework's subcategories, framed in positive or neutral terms, struggle to accommodate the negative indirect contributions of crowberry to humans. Subcategories like “Habitat creation and maintenance” or “Regulation of climate” still describe nature acting for our good, rather than acknowledging harm such as allelopathic encroachment. Specifically, in the IPBES report on invasive alien species assessment (Bacher et al. 2024), both positive and negative impacts of many invasive species were summarised systemmatically. The report, by analysing the impacts of invasive species on NCPs (e.g. how they degrade ecosystems that provide clean water or food) (Bacher et al. 2024), introduces positive and negative effects of invasive species. Crowberry was not included in that assessment, but its detrimental impacts can similarly be interpreted as changes in ecosystem condition that reduce existing NCPs. Nevertheless, there exists many other negative direct impacts of nature to human, especially natural disasters, which was not covered much either in this IPBES report. This understanding makes clear that new “negative NCP” categories are actually required.

Although incorporating EDS into the MAES or CICES framework can improve the comprehensiveness of nature assessment, a semantic problem exists in the valuation phase. The semantic problem lies in the assumption underlying the terminology “services”. The purpose of the MA framework was to emphasise the indispensable relationship between nature and humans, so that nature would be accorded a conservation priority in policy development and decision-making. Thus, positivity was embedded within the ES concept. However, more recent works aimed to value nature’s benefits, especially represented by the TEEB initiative, which separated the “services” and “benefits” that ecosystems provide (TEEB 2010). Following TEEB’s categorisation (with which studies of ES valuation have been following) (DeGroot et al. 2010, TEEB 2010, Braat and de Groot 2012, TEEB 2013), if the concept of “services” – what nature provides – should be understood separately from the concept of “benefits” – what humans receive – then the “service” itself can have different directions of influence on human beings under different contexts. Thus, the terminology “ecosystem services” can be seen as a neutral noun. Yet the term “ecosystem disservices” was coined with the purpose of finding a complementary concept for ES. Even though it was agreed that EDS would also be analysed differently under specific contexts (Shackleton et al. 2016, Vaz et al. 2017), the term “ecosystem disservices” was still charged with negativity. If the term ES had been considered a neutral noun (DeGroot et al. 2010, Haines-Young and Potschin 2010, TEEB 2010) without positive meaning embedded, then the term EDS would not have been necessary. This philosophical and semantic conflict in relation to services will remain unless the importance of both the benefits and detriments that humans receive from nature is recognised.

For a comparative perspective, the MA is now dated, but the framework can explicitly allow space for Supporting EDS, making indirect negative impacts conceptually visible. More recent frameworks, such as MAES and CICES, are more widely adopted and provide a clearer and more operational categorisation of ecosystem services; however,

they do not include direct ecosystem disservices, while indirect disservices are reframed as negative impacts on ecosystem condition. The IPBES framework claims conceptual neutrality by recognising both positive and negative contributions of nature, yet in practice, its sub-categorisation does not explicitly accommodate either direct or indirect negative contributions. By explicitly identifying the indirect detriments of crowberry, this study reveals a shared gap across these frameworks, where negative indirect impacts have historically not been a primary focus and, thus, remain weakly categorised despite their growing relevance.

To further emphasise the indirect EDS of *E. nigrum*, we illustrated particularly one of its detriments – species growth inhibition – using a bioeconomic perspective*[3] (Clark 2010) in Fig. 5. The x-axis represents the Vegetation Stand (which contributes indirect ES to humans), while the y-axis stands for the Harvest of Reindeer Meat (i.e. provisioning ES to humans). The bell-shaped curve describes a logistic growth for a plant community where the end of the curve is the maximum carrying capacity and the highest point is equivalent to the maximum sustainable yield (msy) of the vegetation stand (unit can be, for example, tonne biomass). As *E. nigrum* inhibits the growth of neighbouring vegetation, i.e. a reduction in their intrinsic growth rate (González et al. 2015), this is shown by the downward shift of the curve. Furthermore, crowberry encroachment impacts the potential spread of the vegetation and biodiversity, shown by the decrease in maximum carrying capacity and inward shift of the curve. In total, this shrinks the maximum sustainable growth, leading to a decline in other direct services of the pasture.

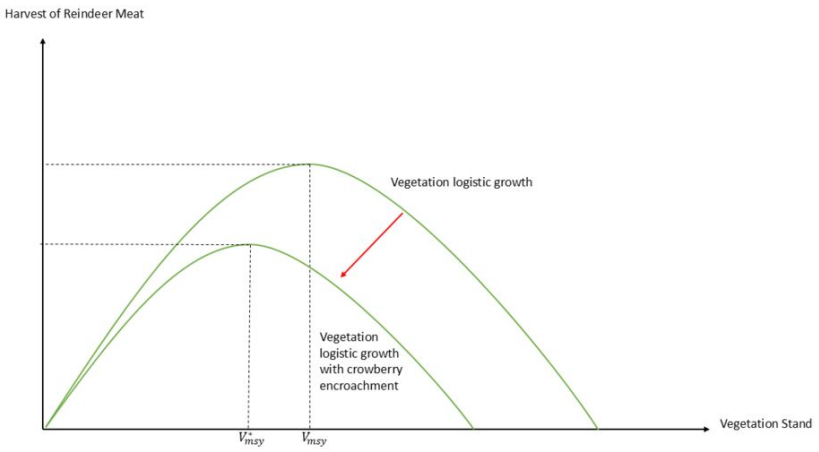


Figure 5.

Illustration of negative impact of *E. nigrum* on a plant community’s ES-EDS/ NCP. V_{MSY} describes the stock of plants that provides the maximum provision of services or contributions, while V^*_{MSY} is the stock that yields maximum services or contributions when impacted by crowberry (adapted from Armstrong et al. (2014)).

Fig. 5 emphasises the importance of species impacts in relation to both indirect and direct ES-EDS/ NCP of the native ecosystems. By allelopathic impact of crowberry and its faster growth rate induced by climate and environmental changes, the biodiverse understorey landscape is homogenised by *E. nigrum*. Thus, not only can the impacts' magnitude, here the abundance of crowberry, amplify its detriments, but it also affects other ES-EDS/NCP of the ecosystems, which then potentially lead to new impacts or elimination of existing ones. For example, direct ES/NCP provided by the local ecosystem (i.e. harvest of reindeer meat, beautiful and biodiverse landscape, hiking and picking other berries etc.) will decrease. Crowberry encroachment also inhibits growth of many palatable plants and decreases plant biodiversity of the local ecosystem, which will have further negative consequences on many herbivores whose diets are not based on crowberry's fruit. In Fennoscandia, reindeer – an iconic ungulate of Sámi culture – can be affected by this shift of vegetation communities, which then consolidate the indirect impacts of *E. nigrum* to the reindeer husbandry of the Sámi people. Thus, indirect detriments of a species may not only decrease other indirect benefits, but also direct benefits provided by other ecosystem functions and processes. On the contrary, high abundance of crowberry might, for instance, increase harvest and production of crowberry's juice and liquor, which are favoured by the Nordic market (though we found no economic research regarding this gastronomy benefit of *E. nigrum*). Another example is that more carbon can be captured by crowberry encroachment, just because its wooden roots grow horizontally and vertically (Silvola and Hanski 1979, Ylanne et al. 2015). Without the recognition of the term EDS, one can only see the beneficial impacts of crowberry to humans, leaving its detrimental effects on the local ecosystem untouched. Yet, as mentioned before, this allelopathic encroachment can affect the local ecosystems and the local people in both direct and indirect ways. This case study, therefore, strengthens the argument that identification and evaluation of indirect EDS/ negative regulating NCP are important to achieve complete species assessments.

Furthermore, it is of importance to underline species abundance in species assessments, since species impacts can influence ecosystem functions and processes at different levels of magnitude (since not all impacts have linear effects), which, in turn, may influence critically and unexpectedly other ES-EDS/NCP. The affected ES-EDS/NCP can further influence the stability of the native ecosystems and impact on people's way of life. These feedback processes of impacts between nature and humans not only highlight the ambiguous tangle between supporting and regulating ES (internalised in NCP), but also underline the importance of indirect ES-EDS/NCP. Although species abundance may regulate beneficial and detrimental impacts on the local ecosystem, quantification issues have, as far as we are aware, largely not been addressed in relation to the ES-EDS and NCP concepts, though both MAES/CICES and IPBES frameworks acknowledge the dynamics of ecosystem processes and functions. Species abundance, hence, should beneficially be recognised as an element dynamically regulating their own ES-EDS/NCP.

Though NCP can be thought of as a slightly more flexible and comprehensive concept than ES, in practice, it is not the case. Combination of supporting and regulating ES into regulating NCP may lead to double counting in the valuation phase. Values should only

be assessed once; for instance, in the case of *E. nigrum*, values of berries are recognised as provisioning NCP. Yet, if researchers additionally evaluate values of crowberry as habitat, which can be recognised as indirect regulating NCP, then this entails the risk of double counting (Fu et al. 2011). In these specific situations, researchers can divide NCP into sub-groups, such as direct-indirect subgroups for higher degree of clarification as we have done in this analysis. The CICES framework’s hierarchical structure also clearly enables the evaluation of these impacts.

Although we aimed to achieve a comprehensive analysis, some limitations were unavoidable. Since *E. hermaphroditum*, a species now considered synonymous with *E. nigrum* (Royal Botanic Gardens 2022) was not considered a keyword, some publications may have been left out. Studies comparing both subspecies concluded that they primarily possess the same morphological and phenological characteristics (Nilsson et al. 2000, Altan and Özdemir 2004), though the negative impact of *E. hermaphroditum* is stronger in some specific situations (Nilsson et al. 2000). Another limitation comes from the exclusion of languages of nations and regions in which *E. nigrum* plays an important role in the local communities, such as in Norwegian – “krekling” or “krøkebær”, in Russian – “вороника”, in Finnish – “variksenmarja”, Swedish – “kråkbär” or other indigenous languages such as the Sámi in Fennoscandia – “čáhppesmuorji”. Thus, further systematic literature reviews of *E. nigrum* specifically, or other environmental issues, should consider including non-English keywords to embrace diverse worldviews and context-specific perspectives. Last, but not least, it is worth noting that, amongst 251 articles, only one belongs to social sciences (Hupp et al. 2015), implying that this native invader has largely not been investigated by social scientists before. Further research about *E. nigrum* would beneficially focus more on its socio-economic impacts.

Conclusions

This study provides a comprehensive assessment of the beneficial and detrimental impacts of *Empetrum nigrum* in Arctic socio-ecological systems, emphasising its complex impacts on human well-being. By applying the frameworks of Ecosystem Services (ES), Ecosystem Disservices (EDS) and Nature's Contributions to People (NCP), we categorised *E. nigrum* beneficial and detrimental impacts to provide a comprehensive understanding of its multifaceted impacts on Arctic ecosystems and human well-being. Our findings underscore that, while *E. nigrum* offers some direct positive impacts to humans, its indirect detriments, particularly through its impacts on vegetation stands and biodiversity, may be significant. The analysis revealed that the CICES framework enables clearer categorisation of crowberry’s ES, though it currently lacks specific differentiation between benefits, such as food and medicinal uses. A notable limitation of CICES is its ignorance of ecosystem disservices, which are crucial for a holistic assessment of crowberry's impacts. Therefore, we propose that the EDS concept should be systematically integrated into the CICES framework, classified in a manner parallel to its existing ES categories. The NCP concept does not offer a more inclusive lens for assessing these multifaceted impacts as the IPBES framework claimed, especially due to

its inherent misalignment between its theoretical definition and its practical application. The positive and negative effects of invasive species are often treated as exogenous factors influencing other NCPs rather than being integrated as endogenous contributions or disservices directly from the invasive species themselves. Therefore, we also suggest the NCP concept to improve the neutrality of the subcategories' names and adopt an endogenous perspective in assessing nature's contributions to people. Ultimately, based on different research purposes, one may prefer one concept over the other.

Hosting institution

UiT The Arctic University of Norway

Author contributions

PN and CA designed the study. CA, KB and MT conducted literature cross-reading. MT assisted in data analysis. The first draft was written by PN and CA and all authors contributed to the final version.

Conflicts of interest

The authors have declared that no competing interests exist.

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Endnotes

*1 Regarding the topic of invasive species, IPBES addresses invasive species as a significant topic for assessment, but the comprehensive thematic report on the topic is yet to be finalised.

*2 The term «NCP» and «contributions» are used interchangeably in the NCP literature.

*3 This bioeconomic perspective was chosen to effectively illustrate the direct and indirect impacts from nature to humans.