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Ecosystem services in the Arctic: a thematic review

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ABSTRACT

The study presents the first systematic review of the existing literature on Arctic ES. Applying the Search, Appraisal, Synthesis and Analysis (SALSA) and snowballing methods and three selection criteria, 33 publications were sourced, including peer-reviewed articles, policy papers and scientific reports, and their content synthesised using the thematic analysis method. Five key themes were identified: (1) general discussion of Arctic ES, (2) Arctic social-ecological systems, (3) ES valuation, (4) ES synergies and/or trade-offs, and (5) integrating the ES perspective into management. The meta-synthesis of the literature reveals that the ES concept is increasingly being applied in the Arctic context in all five themes, but there remain large knowledge gaps concerning mapping, assessment, economic valuation, analysis of synergies, trade-offs, and underlying mechanisms, and the social effects of ES changes. Even though ES are discussed in most publications as being relevant for policy, there are few practical examples of its direct application to management. The study concludes that more primary studies of Arctic ES are needed on all of the main themes as well as governance initiatives to move Arctic ES research from theory to practice.

1. Introduction

The concept of ecosystem services (ES) presents a useful way of thinking about the relationship between human welfare and nature, with the literature on ES having grown exponentially since the 1990s (Costanza et al., 2017; Costanza and Kubiszewski, 2012; Droste et al., 2018; McDonough et al., 2017). The popularity of the concept grew further through the publication of the seminal Millennium Ecosystem Assessment (2005) and research platforms such as The Economics of Ecosystems and Biodiversity (TEEB) and the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), which have sought to mainstream ecosystem service valuation into decision-making. The fact that the number of scientific peer-reviewed articles containing the words 'ecosystem services' in their title have grown from less than 10 in the 1990s to 2800 in 2016 alone (Costanza et al., 2017), illustrates this point. This rapidly-growing body of literature contains analysis from all types of ecosystems and includes a wide range of topics, including ecological analysis, valuation, biodiversity conservation, and management (Abson et al., 2014; Droste et al., 2018).

Despite the growing attention to ES and its practical applications, the concept has, in certain remote parts of the planet, failed to attract widespread public attention. One such region is the Arctic, also known as the 'refrigerator of the world', referring to the global importance of climate regulation services that it provides together with the Antarctic region (Chapin et al., 2005; Walker, 2007). The extent and importance of the vast array of services that Arctic sea ice, marine and terrestrial ecosystems provide on global, regional and local scales was not recognised until fairly recently. Scientific research, changing weather patterns and improved understanding of Earth's geological cycles in the twentieth century made apparent that not only the four million Arctic inhabitants depend on Arctic ecosystem services, but so do the rest of the Earth's inhabitants. As natural resources become scarce globally, the attention of political leaders has turned to the Arctic, where climate change makes some more accessible. Like everywhere else in the world, trade-offs occur when extracting natural resources in the Arctic and

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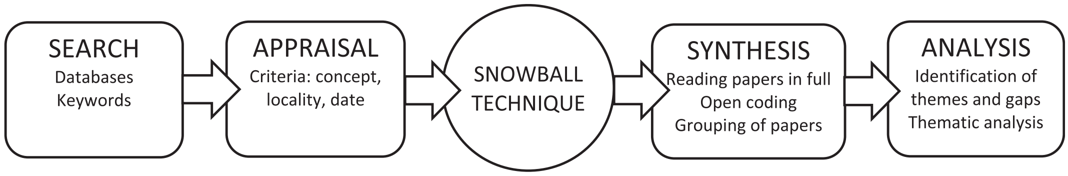

Fig. 1. Framework used for the meta-synthesis: a combination of SALSA and snowballing technique.

increasing global interest in the region means that this is no longer an Arctic-only issue. Global forums, such as the Arctic Circle Assembly, which involve actors from a wide array of sectors and geographical locations outside of the Arctic, and the fact that global powers like China and the European Union have their own Arctic policies, are indicative of this impression (Young, 2010, 2016).

In few places on Earth are the consequences of climate change more apparent than in the Arctic (Arctic Council, 2004; Viñas, 2018; Wang and Overland, 2012). A warming climate has left increasingly large areas of the Arctic Ocean ice-free in summer, which, together with thawing of permafrost and rising temperatures on land and water, is changing the ecosystems in unprecedented and unpredictable ways (IPCC, 2014; O'Garra, 2017; Wang and Overland, 2012; Whiteman et al., 2013). With landscape and ecosystems, societies that depend on them are also changing: Arctic populations are confronted with challenges as well as opportunities presented by climate change, having to adapt to changes quickly to remain resilient (Arctic Council, 2013b, 2016; Chapin et al., 2015; Kaltenborn et al., 2017). The notion of ecosystem services, with its perspective focused on the benefits derived from human-ecosystem interactions, provides a platform for examining the impacts of changes that are taking place in the Arctic (Arctic Council, 2016; Costanza et al., 2017; Potschin and Haines-Young, 2017). However, literature connecting the ES concept, especially its practical applications to Arctic policy-making, is still scarce. This paper provides a meta-synthesis of the existing literature that applies the ES concept in an Arctic context. Its principal objective is to map out existing publications on the subject since 2005 and list the main re-emerging themes and gaps in the research so far. To the best of the authors' knowledge, this meta-synthesis is the first attempt to provide a comprehensive overview of the existing literature on Arctic ES, and its outcomes will represent an orientation point for the commencement of future Arctic ES research projects.

The paper is organised as follows. Section 2 presents the methods used in the literature review, including publication sourcing techniques, article selection rationale, and thematic analysis. Section 3 lays out the synthesis of the main findings according to the five recurring themes identified in the literature. Section 4 presents the discussion of the results, and Section 5 concludes the paper by outlining the practical implications of this review with regards to research and sustainable development policy in the Arctic.

2. Methods

2.1. SALSA framework

In order to locate and synthesise the existing literature on ecosystem services in the Artic to date, the meta-synthesis method (Cronin et al., 2008; Polit-O'Hara and Beck, 2006) was applied using the Search, Appraisal, Synthesis and Analysis (SALSA) framework (Cronin et al., 2008; Grant and Booth, 2009) (Fig. 1). 'Meta-synthesis involves analysing and synthesising key elements in each study, with the aim of transforming individual findings into new conceptualisations and interpretations' (Grant and Booth, 2009, p. 6). SALSA framework has its roots in health sciences but is applicable to any discipline due to its simplicity and logical sequence of steps for conducting a literature review. It is an approach that has frequently been applied in ES research without a specific reference to the SALSA framework (Mastrangelo et al., 2015; Yang et al., 2018). Due to a small number of identified relevant scientific articles, a 'snowballing' method (Creswell, 2007) was applied between the Appraisal and Synthesis stages to expand the list of publications relevant to the topic.

2.2. SALSA and snowballing steps

2.2.1. Step 1: search

Four academic databases – Science Direct, Scopus, Web of Science and Google Scholar – were searched to identify relevant publications that applied the concept of ecosystem services in an Arctic context between 2005 and 2018. Firstly, the search keywords 'Arctic' and 'ecosystem services' were used to find the relevant literature using a Boolean search string 'Arctic AND 'ecosystem service$[1]'', with entire texts interrogated in all four databases. All the resulting publications from Scopus (n = 121) and Web of Science (n = 107) were then taken to the Appraisal stage. The pool of results from the Science Direct and Google Scholar academic search engines were initially very large – 2686 and 13,000 respectively – and the overwhelming majority were not relevant for this Arctic-specific ES literature review. To narrow these down, the term 'ecosystem services' was replaced in both search engines with the terms 'environmental services', 'nature's services' and 'natural capital' and complemented with additional search words 'valuation', 'mapping', 'economics' and 'subsistence resources', using Boolean search string: 'Arctic AND ('nature's services' OR 'natural capital') AND ('valuation' OR 'mapping' OR 'economics' OR 'subsistence resources'). This new search sourced four additional publications from Science Direct and five from Google Scholar. Some articles appeared in more than one academic search engine and these were not counted twice. Overall, two hundred and thirty-seven papers were sourced from the four databases.

2.2.2. Step 2: appraisal

The abstracts of all the papers sourced from the four databases in the Search phase were read in full to determine their suitability to be included in the review using three criteria: use of ES concept, locality, and date of publication. The first criterion required that the concept of ES is applied in a meaningful way and not simply as a buzzword, the second criterion – that the content is discussed in relation to the Arctic, and the third – that the date of publication is 2005 or later. The reason for the latter criterion is that the seminal Millennium Ecosystem Assessment (MEA) synthesis report was published in 2005 containing a chapter on Polar Systems, and it has been credited for spawning multiple lines of ES research due to its popularisation of the concept (Chapin et al., 2005; Chaudhary et al., 2015; MEA, 2005). After reading the abstracts, eighteen of the two-hundred and thirty-seven publications were deemed suitable for this literature review.

2.2.3. Additional step 3: snowballing technique

An additional step was added to the SALSA framework to identify more relevant articles. 'Snowballing technique' refers to pursuing references provided in citations of selected publications, a method that has proved to be particularly useful for 'identifying high-quality sources

[1] "$" stands for zero or one character in Boolean search (Malkamäki et al., 2017)

in obscure locations' (Greenhalgh and Peacock, 2005, p. 1065). Its successful applications range from literature reviews in health sciences (ibid.), social science and education (Tess, 2013), computer science (Radjenović et al., 2013), and environmental science and policy studies (Binder et al., 2013; Spruijt et al., 2014). Applying this technique resulted in 15 additional articles and allowed for the inclusion of a wider range of publications, such as intergovernmental bodies (e.g. the Arctic Council and its expert working groups) and non-governmental organisations (e.g. the World Wildlife Fund). It also enabled the triangulation of data sources and representation of the viewpoints of different stakeholders. Appendix 1 presents the final list of 33 publications sourced from each search engine and using the snowballing technique in the chronological order of sourcing.

2.2.4. Step 4: synthesis

All the papers sourced in the first three steps using a combination of SALSA framework and snowballing technique were read in full and analysed with a purpose of identifying the main analytical focus, methods and themes related to Arctic ES. The papers were categorised according to publication types: academic peer-reviewed articles (n = 20), reports and studies published by inter-governmental forums, such as the Arctic Council and the Nordic Council of Ministers (n = 10) and other sources – an NGO publication, a book chapter and a conference proceeding (n = 3). Then the publications were grouped according to the Arctic biomes discussed: terrestrial, sea-ice and marine (O'Garra, 2017).

2.2.5. Step 5: analysis

The thematic analysis was conducted in accordance with the six-stage framework outlined by Braun and Clarke (2006), which has been applied in a wide variety of qualitative research contexts. This process has its methodological foundations in grounded theory (Guest et al., 2012; Strauss and Corbin, 1990), whereby coding and the formation of identified research themes involve a bottom-up inductive process that is emergent from the data. The six phases in the framework are as follows: (1) familiarisation with data; (2) generation of initial codes; (3) searching for themes; (4) reviewing themes; (5) defining themes; and (6) analysis and writing up. With regards to the initial generation of codes in stage 2, an open coding approach was applied, ensuring that codes were developed and modified as the coding process progressed. Initially, the coding of the 33 selected articles was carried out manually, before utilising qualitative data analytic software MAXQDA. In stage 3, the codes were grouped into five distinct themes, which were then reviewed for consistency in stage 4 to ensure that there was no or very limited overlap between them, and then each theme was defined in stage 5. Stage 6 involved a quantitative appraisal of the extent to which each theme appears in the Arctic ES literature, from which research gaps emerged. In this paper, observations of research gaps made by the authors of the respective Arctic ES publications are also referred to as a reinforcement of our own conclusions.

3. Results

3.1. General findings

Arctic ecosystems and ES are typically classified into three biomes: terrestrial, sea-ice and marine (O'Garra, 2017). From the 33 publications sourced for this meta-synthesis, eleven discuss all three biomes, eight – terrestrial, two – sea-ice and ice, and twelve – marine ecosystems. Appendix 1 contains more detailed information about each paper, including the publication type and date, themes and biomes discussed, and methods used. As Table 1 indicates, most of the literature is concerned with the marine biome or discusses all three biomes, whereas terrestrial and sea-ice biomes receive relatively less attention. The tendencies are similar in peer-reviewed academic literature, with terrestrial and marine ES being more widely discussed than the Arctic sea-ice biome.

Table 1
Number of publications concerned with Arctic ES in different biomes

Biome	Terrestrial	Sea-ice	Marine	All three	Total
Number of publications	8	2	12	11	33
Number of peer-reviewed articles	6	2	5	3	16

Even though scarce, the literature on Arctic ecosystem services has been growing steadily over the last few years. Out of 33 publications identified for this review, 27 were published in 2013 or later. One possible explanation for this increased attention is that two influential publications came out around that time – the Arctic Biodiversity Assessment (ABA) in 2013 and The Economics of Ecosystems and Biodiversity (TEEB) scoping study for the Arctic in 2015 – which strengthened the ES agenda in the region. At the same time, Arctic issues started to be discussed with increased frequency in international forums, such as the Arctic Circle Assembly and global climate negotiations (Duyck, 2015), and Arctic-focused research programmes are growing in number as a result of this increased attention.

Despite the relatively large number of documents found on academic search engines that contain the words 'Arctic' and 'ecosystem services', only a few of them actually focus on ES. For example, the total number of such documents on the Scopus database (on April 15, 2018) was 121; among them only seven had Arctic ES as their main topic, but in 68 articles the term 'ecosystem services' was used in the abstract, most often in relation to threats of their loss if Arctic ecosystems are further degraded by the changing climate and human activities. This observation exposes the tendency in the ES literature to use the term as a buzzword for sustainability research justification but without exploring it in any real depth (Abson et al., 2014; Droste et al., 2018).

3.2. Main themes

Five key themes emerged through the thematic analysis: (1) general discussion of Arctic ecosystem services; (2) Arctic social-ecological systems; (3) economic (monetary and non-monetary) valuation of ES and/or potential for it; (4) identification and general discussion on ES synergies and/or trade-offs; (5) integrating the ES concept into Arctic resource management. The main themes are listed in Table 2, together with brief explanations and numbers of corresponding publications. The themes are discussed in more detail in the remainder of this section with references to the literature. The themes discussed in each publication sourced for this review are listed in Appendix 1, along with a brief outline of their analytical approach.

3.3. General discussion on Arctic ES

More than half of the publications (17 out of 33, or 52%) include general discussions on Arctic ES, in addition to explanations concerning the concept and its relevance for the Arctic. This fact indicates that there is a perception of novelty in this research area and a need to provide some background. The main focus points of each publication that includes this theme are listed in Table 3. Publications are listed in the same order as in Appendix 1.

The discussion starts with general attempts to apply the ES concept, list and classify Arctic ES using the most common typologies, such as the Millennium Ecosystem Assessment (MEA) and The Economics of Ecosystems and Biodiversity (TEEB) (Arctic Council, 2013b, 2016; CAFF, 2015; Chapin et al., 2005; Gundersen et al., 2016; Huntington, 2013; WWF, 2015). The Economics of Ecosystems and Biodiversity (TEEB) scoping study by the Biodiversity Working Group of the Arctic Council Conservation of Arctic Fauna and Flora (CAFF) (CAFF, 2015) gives an extensive overview of Arctic ES and indicates the potential for

Table 2
Five main themes emerging from the literature on Arctic ES

Theme	Explanation	Number of publications
1. General discussion on Arctic ES	General discussion of Arctic ES up to the point of (but not including) spatial mapping.	17
2. Arctic social-ecological systems	Social-ecological systems as a conceptual model for thinking about nature-human interactions in the Arctic.	12
3. Valuation of Arctic ES	Discussion and application of ES monetary and non-monetary valuation methods in the Arctic.	18
4. Synergies and/or trade-offs between Arctic ES	Discussion and/or assessment of synergies and/or trade-offs between different Arctic ES.	10
5. Integrating ES into management	Application of ES concept into the management of Arctic natural resources and socio-ecological ecosystems.	23

spatial mapping, valuation and application in the management of natural resources. The Arctic Biodiversity Assessment (ABA) (Huntington, 2013) reviews four provisioning and one cultural ES, providing an overview of the key stakeholders, trends and future concerns. The MEA (Chapin et al., 2005) provides a general discussion on the status, trends, and drivers of change in the Arctic ES as well as implications for human well-being. The stated purpose of these Arctic-wide studies is to prepare the ground for future ES research and its conceptual application in Arctic sustainable development policy.

Some of the more focused studies also provide a general discussion of the ES concept before applying it to a specific context. They attempt to list, describe and discuss its potential applications in the research and management practices of different Arctic biomes, e.g. coastal ecosystems and kelp forests (Gundersen et al., 2016; Smale et al., 2013), cold water corals (Armstrong et al., 2014), sea-ice ecosystems (Eicken et al., 2009; Euskirchen et al., 2013), boreal forests in Arctic Finland (Vihervaara et al., 2010) and Alaska (Chapin et al., 2006), and a combination of biomes (Chapin et al., 2015; Jansson et al., 2015). In some cases, the ES concept is applied in relation to other sustainability concepts, such as ecosystem stewardship and resilience. Chapin et al. (2015) discuss the applicability of the ES concept to Arctic conservation through an ecosystem stewardship framework that integrates social and ecological dimensions of conservation across different spatial scales. Similarly, the Arctic Resilience Report (Arctic Council, 2013b, 2016) conceptualises the occurrence of ES as an interplay between social and ecological systems, using the term to discuss the resilience of ecosystems and communities to fast-paced environmental and social change. The ES concept in these studies provides a framework for conceptualising, quantifying and managing human-nature interactions in the Arctic.

3.4. Arctic social-ecological systems

In relation to sustainability, the term 'social-ecological system' (SES) is used to highlight the interdependence of humans and nature and diminish boundaries between social and natural sciences in sustainability research and management (Berkes et al., 2000). SES is defined by the Arctic Council (2016, p. 17) as 'an integrated system that includes human societies and ecosystems. The functions of such a system arise from the interactions and interdependence of the social and ecological subsystems. Its structure is characterised by reciprocal feedbacks.' As Table 4 indicates, the term is predominantly used in a conceptual way to emphasise the need for a holistic inter- and transdisciplinary approach to Arctic sustainable development.

The SES concept is discussed in relation to ES in 12 publications out of 33 (36%), and it has been applied to the whole of the Arctic (Arctic Council, 2016; CAFF, 2015; Chapin et al., 2015), separate biomes (Eicken et al., 2009; Jansson et al., 2015), regions (Jansson et al., 2015) and species (Mosbech et al., 2018). The SES concept lies at the heart of the Arctic resilience debate, being used to study how changes in one part of a system affect its resilience and to emphasise the interdependence of social and natural domains. The Arctic Resilience Report (Arctic Council, 2013b, 2016) discusses in depth how different components of these sub-systems are affected by the physical changes in the Circumpolar North and what policy actions have a potential to enhance their resilience. This holistic approach resonates with the Sustainable

Table 3
Main points of focus in general discussion on Arctic ES.

Publication	Focus
O'Garra, 2017	Discusses the importance of Arctic ES globally, presents a framework for ES valuation and identifies the threat that many services may soon be lost due to climate change.
Armstrong et al., 2014	Presents the ES concept and applies it to the management of a cold-water coral reef.
Chapin et al., 2015	Provides ES definition and briefly discusses it in relation to an ecosystem stewardship conservation framework.
Anisimov et al., 2017	Aims to improve understanding of climate change effects on societies in the Arctic through changes in ES supply.
Eicken et al., 2009	Discusses ESs of the sea-ice biome, referring to them as sea-ice system services (SISS) and classifies them using the MEA framework.
Mosbech et al., 2018	Presents ES concept and applies it to a single species of Little Auk to highlight the multiple ways, in which Arctic communities benefit from ES.
Chapin et al., 2006	Integrates ES in a framework for analysing directionally changing social-ecological systems, applying this approach to Alaskan boreal forests.
Jansson et al., 2015	Presents the ES concept and uses it to estimate the societal effects of future climate change in northernmost Europe in terms of changes in terrestrial and freshwater ES.
Vihervaara et al., 2010	Presents, discusses and applies the ES conceptual tool in analysis of human-environment systems in Finnish Forest Lapland.
Smale et al., 2013	Applies the ES notion to highlight the ecological and societal importance of kelp forests and the threats of climate change.
Huntington, 2013	Discusses four provisioning and two cultural ES in the Arctic using available data.
Arctic Council, 2016	Provides a theoretical analysis of links between ecosystem properties and attributes of social systems with a resilient supply of ES, beginning to examine possible impacts of climate change on Arctic ES.
Gundersen et al., 2016	Uses MEA classification to list and explore ES of four defined coastal ecosystems: kelp forests, eelgrass meadows, blue mussel beds, and shallow bays and inlets.
Chapin et al., 2005	Provides a wide-ranging and detailed review of polar ES according to the MEA classification, and considers ES contribution to human wellbeing, possible climate change effects and management interventions.
CAFF, 2015	Presents a scoping and thematic study of main Arctic ES and provides guidance and policy focus areas that could be further refined and assessed using TEEB methodology.
Magnussen and Kettunen, 2013	Through scoping study, highlights the socio-economic importance of the marine ES in the Barents Sea and Lofoten Islands and how they might be affected by oil and gas drilling in the area.
WWF, 2015	Provides a summary and professional review of the TEEB scoping study by selected contributors, highlighting the multiple values of Arctic ES.

Table 4
Main points of focus on social-ecological systems.

Publication	Focus
Chapin et al., 2015	Discusses how the warming climate in the Arctic interacts with socio-economic changes to reduce subsistence activities in rural communities; examines the contribution of Arctic ES to human well-being and identifies the main drivers of ES changes.
Eicken et al., 2009	Describes sea ice as a geophysical phenomenon within a social-ecological system and draws out a framework for identifying and meeting the information needs of sea-ice users in Arctic Alaska.
Mosbech et al., 2018	Examines the ES provided by the little auk in Northwest Greenland from ecological, socioeconomic and cultural perspectives, highlighting the variety of reciprocal interactions of a single species with multiple components of a SES.
Chapin et al., 2006	Using a case study of Alaskan boreal forests, draws on the dynamics of social-ecological systems that are subject ed to directional changes to identify policy strategies for addressing their sustainability.
Jansson et al., 2015	Uses the SES concept for analysing the occurrence of and projected changes in ES provision in northernmost Europe, concluding that adaptation strategies must take into account the complexities of social and ecological responses to change.
Vihervaara et al., 2010	Using the case study of Finnish Forest Lapland, introduces a methodology and databases for the sustainable management of ES.
Arctic Council, 2013b	Presents an Arctic resilience framework as an integrative approach for assessing SES changes across spatial and temporal scales, identifying the risk of threshold effects and building response capacity.
Koenigstein et al., 2016	Integrates stakeholder perceptions of ES changes with available scientific information to study climate change effects on SES in the Barents Sea region and identify appropriate adaptation actions.
Kaltenborn et al., 2017	Explores through an ES lens human-nature interactions and local notions of human well-being in the SES of a small community in the Lofoten Islands.
Huntington, 2013	Discusses interdependence of social and ecological subsystems of SES in the Arctic through the supply of provisioning and cultural ES.
Arctic Council, 2016	Bases the concept of Arctic resilience on reciprocal feedbacks between social and economic SES components and their ability to bounce back from shocks and adapt to change.
CAFF, 2015	Uses SES to describe reciprocity between Arctic societies and ecosystems, providing examples from different biomes. Suggests applying the SES concept for analyses of ES provision and change.

Development Goals (SDGs) of the United Nations that address human and ecological dimensions simultaneously. For instance, promotion of sustainable communities in the Arctic (SDG 11) through climate action (SDG 13) and responsible use of natural resources that enhance the sustainability of marine (SDG 14) and terrestrial (SDG 15) ecosystems (Nilsson et al., 2016; UN, 2016). The all-encompassing nature of the SES concept and its applicability to policy-making, guided by the SDGs, at least partly explains its fast-growing popularity.

Not unlike the SDGs, despite its seemingly high applicability for policy, the SES debate in the literature remains somewhat ambiguous and conceptual, which is a common difficulty with broad concepts. Having said that, there are examples of how the SES notion has been employed to provide concrete management suggestions. In focused studies, it enables researchers to model and quantify the interactions and flows of ES between components of SESs, bringing forward policy needs in specific contexts. Eicken et al. (2009) describes sea ice as a geophysical phenomenon within an SES and refers to the benefits derived from it by people as sea-ice system services (SISS). Regulating, provisioning and cultural SISSs are co-created and utilised by different user groups who constantly observe sea-ice, adjusting their activities accordingly. To identify the priorities of different SISS users and meet their information needs, the study suggests a consortium-based approach, where scientists and resource users work closely together. Chapin et al. (2006) present a framework for assessing the sustainability of SESs undergoing directional changes and apply it to boreal forest management in Alaska. Using criteria based on human-ecosystem interactions and resulting ES, the authors highlight the policy strategies that are most likely to enhance the sustainability of this SES. Vihervaara et al. (2010) translate different land uses of Finnish Forest Lapland into relevant ESs, map them and assess the impacts of different land uses on ES provision and SES, combining ecological, economic and sociological data. A similar approach was applied by Jansson et al. (2015), who analyse feedback mechanisms between SES components to project future changes in ES supply in the European Arctic.

Arctic societies and ecosystems have coexisted in a relative balance for millennia, but the climatic and physical conditions are changing more rapidly now than ever, threatening species, landscapes and ways of life in the region. The SES concept presents a new approach to conservation and environmental management as it removes the nature-culture separation, focusing instead on the synergies between human well-being and environmental protectionism. Chapin et al. (2015) propose an 'ecosystem stewardship' approach to Arctic conservation, whereby human activities are considered to be an integral part of ES co-production and management. On the same note, Koenigstein et al. (2016) advocate an integrated approach to research that involves stakeholder-informed ecosystem modelling.

The SES notion underpins the multiplicity of values resulting from interactions between humans and nature. The literature includes examples of how one component of SES, e.g. a single species, can influence multiple aspects of social, economic and cultural life in Arctic communities. Mosbech et al. (2018) look into the ES provided by the little auk, a small seabird with breeding grounds in Northwest Greenland, and describe it as a social and ecological 'engineer' that has influenced the livelihoods and cultural practices of local communities and functioning of local ecosystems for millennia. Other 'social engineers' in the literature include the walrus, a keystone species in Alaskan Inuit communities (CAFF, 2015, p. 38), reindeer in Arctic Eurasia, and caribou in North America; the species that are central to the cultural identities of communities expressed through traditional art and storytelling (CAFF, 2015, p. 89; Huntington, 2013; Jansson et al., 2015). Marine resources, including fish and marine mammals, play a dominant role in many Arctic coastal communities' social and cultural lives through monitoring, harvesting and sharing activities (CAFF, 2015; PAME, 2013). Kaltenborn et al. (2017) describe the relationship between communities and local ecosystems as important in terms of provisioning ES, but also as components of what constitutes a 'good life' – a sense of well-being.

3.5. Valuation of Arctic ecosystem services

Putting the ES concept into practice often implies carrying out an ES valuation, the results of which can be communicated to decision-makers in monetary (Cook et al., 2016; Costanza et al., 2017; Hauck et al., 2013) or non-monetary (Kelemen et al., 2014; Maestre-Andrés et al., 2016; Castro Martínez et al., 2013) terms. Few primary valuation studies of Arctic ES have been carried out to date, despite the increasing attention to ES globally and the efforts of the TEEB scoping study for the Arctic in this regard (CAFF, 2015). Table 5 lists 13 publications from the literature that are concerned with monetary valuation and 5 that provide non-monetary analyses of Arctic ES values.

A recent study by O'Garra (2017) provides a preliminary assessment of the quantity, distribution and economic value of the key Arctic ES and geological resources using the benefit transfer method and total economic value (TEV) framework. The author combines secondary

Table 5
Main points of focus on valuation of Arctic ES.

Publication	Focus
Monetary perspective	
O'Garra, 2017	Application of benefit transfer approach for estimation of the economic value of key Arctic ES.
Aanesen et al., 2018	Using discrete choice experiments (DCE), reveal households' preferences related to commercial developments and recreational activities in coastal zones in Northern Norway.
Hasselström et al., 2017	Cost-benefit analysis of reducing the probability of a major oil spill in Lofoten-Vesterålen in northern Norway, finding that improving maritime safety is economically profitable for society in terms of the avoided costs of ES loss.
Goldstein et al., 2014	Provides a replacement cost calculation for the subsistence harvest of northern pintail by indigenous communities in North America.
Euskirchen et al., 2013	Attempts to monetise the climate regulation ES of the Arctic cryosphere by examining how physical changes and feedback mechanisms may affect global CO2 emissions up to the year 2100 and, using the social cost of carbon, calculates the expected economic damage.
Noring et al., 2016	Contingent valuation study of ES at risk from potential oil spills in the Lofoten Islands, finding a high perception of risk and preference for preventive over reactive measures for reducing the ecological damage of oil spills.
Aanesen et al., 2015	Uses a discrete choice experiment (three protection scenarios) to elicit the economic values of ES provided by cold water corals in Northern Norway.
Hasselström et al., 2012	Background desk-based study using secondary sources to estimate the threats to and values of ES in the Lofoten Islands and the Barents Sea likely to be affected by an oil spill in the area.
Huntington, 2013	Cites different valuation studies of Arctic ES, stressing the need for value pluralism and need for primary studies.
CAFF, 2015	Cites ES valuation studies from around the Arctic, giving examples of methods and different types of ES values.
Magnussen and Kettunen, 2013	Cites economic valuation studies of provisioning and cultural ES provided by Norwegian fisheries.
WWF, 2015	Reviews the TEEB scoping study, outlining examples of different ES values and emphasising plurality.
Navrud et al., 2017	Presents a contingent valuation study of coastal ES potentially lost due to oil spills in Arctic Norway.
Non-monetary perspective	
Mosbech et al, 2018	Applies an interdisciplinary perspective, assessing in non-monetary terms the economic, socio-cultural and ecological importance of the little auk in Northwest Greenland.
Koenigstein et al., 2016	Uses stakeholder consultation to inform ecosystem modelling in terms of the socio-economic impacts of ocean warming and acidification in the Barents Sea region.
Kaltenborn et al., 2017	Examines the role of ES and cultural values in the well-being of a small community in Northern Norway.
Brinkman et al., 2016	Uses qualitative data from semi-structured interviews with subsistence resource harvesters in four indigenous communities in Alaska to identify their perceptions of climate change effects on the availability of provisioning ES.
Alessa et al., 2008	Provides analysis of the perceptions of change in the quality and availability of freshwater provisioning ES in a remote community in the Steward Peninsula, Alaska, and the role of Traditional Ecological Knowledge for resilience.

biophysical and economic data from existing studies (not all Arctic-based) and arrives at an aggregate estimate of around \$281 billion (in 2016 prices) worth of ES per year derived from food, mineral extraction, oil production, tourism, hunting, existence values, and climate regulation. The paper sends a strong message, comparable to those of Costanza et al. (1997) and Costanza et al. (2014), drawing public attention to the economic value of ecosystem services and the costs of their loss if climate change predictions for ice-free summers in the next two decades turn out to be accurate (IPCC, 2014; Wang and Overland, 2012; Whiteman et al., 2013).

In an attempt to monetise the cost of lost climate regulation services in the Arctic by combining climate modelling and the social cost of carbon, Euskirchen et al. (2013) arrive at an estimate that between 2010 and 2100 the annual costs from extra climate warming add up to a societal cost ranging from USD 7.5 trillion to USD 91.3 trillion, with the large range resulting largely from the choice of discount rate. For comparison, the highest estimate exceeds global GDP in 2013, which was around USD 77 trillion, and the low estimate is in excess of every nation's GDP that year apart from the US (USD 16.7 trillion) and China (USD 9.6 trillion) (World Bank, 2018).

Several ES valuation studies in the literature translate concerns over possible oil spills in the Arctic into economic values, arguing for a precautionary approach in hydrocarbon exploration. They reveal significant negative effects of potential oil spills on individual well-being through loss of ES, warning that the costs of such spills are much higher than preventive measures (Hasselström et al., 2012, 2017; Magnussen and Kettunen, 2013; Noring et al., 2016) and, in some cases, even the economic gains from drilling (Kotchen and Burger, 2007; Magnussen and Kettunen, 2013). A contingent valuation study estimated that US households' willingness to pay (WTP) to prevent a similar oil spill to the Exxon Valdez in 1989 aggregated to \$2.8–7.16 billion (1990 USD) (Carson et al., 2003) and to USD 10.87 billion (2005 USD) according to a later estimate by Kotchen and Burger (2007). In Norway, a nationwide pilot contingent valuation study on hypothetical oil spills in Northern Lofoten reveals significant non-use values attached to coastal ES, with an average WTP per household per year for a ten-year period to avoid marine and coastal ecosystem service (ES) loss/damage from an oil spill ranging between NOK 1165 and NOK 1192 nationally and NOK 1330 and NOK 2387 by Lofoten residents (Navrud et al., 2017). Another study estimated that people were willing to pay between EUR 274 and EUR 287 to avoid a loss of ES provided by cold water corals (Aanesen et al., 2015).

There are, as of yet, very few valuation studies focusing on ES of a single species in the Arctic. Focused studies, however, have the potential to improve understanding of nature-human interactions and values that are generated through them in different place-specific contexts. In one such study, Goldstein et al. (2014) use a replacement cost method to estimate the cost of replacing a year's worth of subsistence harvest of northern pintail by indigenous communities in North America using chicken as the most viable alternative. The authors determine a mean estimate of the total replacement cost for the annual subsistence harvest of ~15,000 pintails to be ~\$63,000 per year (2010 USD), with sub-regional values ranging from \$263 yr^{-1} to \$21,930 yr^{-1}. Mosbech et al. (2018) apply a non-monetary analysis of the value of the little auk in Inughuit communities in Northwest Greenland and find multiple ecological, socio-cultural and economic aspects, in which the species help to sustain the socio-ecological systems in the region.

Socio-cultural analyses of non-monetary ES values address the main criticism of monetary valuation of ES – that it fails to capture the multiple values and valuation languages (Huntington, 2013; Kumar and Kumar, 2008; Martinez-Alier et al., 1998). For Inupiat communities in the Seward Peninsula in Alaska, this mismatch, combined with the loss of traditional knowledge transfer systems, means that the younger generations are less aware of the extent of ES changes and, therefore, less able to adapt to them (Alessa et al., 2008). A study by Brinkman et al. (2016) adds a socio-cultural dimension to climate change projections by integrating the perceptions of local subsistence resource users in four Alaskan indigenous communities. A study by Koenigstein et al. (2016) also attempts to integrate stakeholders' perceptions into ES models for the Barents Sea region by combining preference assessment surveys with predictive ecosystem modelling. The authors argue that their process-based integrated ecosystem model captures ecological complexity and place-specific societal values of ES and is, therefore, better-equipped to inform adaptive governance than models based on only physical data. An evaluation by Kaltenborn et al. (2017) examines the contribution of cultural and provisioning ES to human well-being in the small Røst community in northern Norway through local stakeholders' narratives, which they later synthesise into the localised concept of a 'good life'. This approach highlights the importance of scale and context in socio-cultural assessments of ES as they provide the basis for social cohesion and shared values in communities.

3.6. Synergies and trade-offs

An important topic in the ES literature that transpires in the Arctic context is the discussion of synergies and trade-offs between different ecosystem services. According to Openness' (Operationalisation of Natural Capital and Ecosystem Services) project definition, an ES trade-off is 'a situation where the use of one ES directly decreases the benefits supplied by another' and a synergy is 'a situation where the use of one ES directly increases the benefits supplied by another service' (Turkelboom et al., 2016, p. 2). Synergies and trade-offs are addressed in only 10 out of 33 publications (20%) as there are few primary ES assessments and valuation studies to date that could inform this discussion. They are, however, important to consider as no ES exists in isolation and use of one service is likely to impact on the availability of others (Arctic Council, 2016; Jansson et al., 2015; Martín-López et al., 2014; Martín-López et al., 2012). The publications that report on synergies and trade-offs are listed in Table 6.

The supply of ES is not necessarily one-directional or static and may form multiple and multidirectional synergies and trade-offs at the same time, depending on the local ecological, social and cultural context (de Groot et al., 2010; Koenigstein et al., 2016; Martín-López et al., 2012). For instance, some Arctic studies show clear trade-offs between provisioning and cultural services in marine, sea-ice and terrestrial biomes (Aanesen et al., 2018; Gundersen et al., 2016; Huntington, 2013; Vihervaara et al., 2010), while others point to an important synergy linking regulating, provisioning and cultural ES (Chapin et al., 2005). The cold climate in the Arctic resulted in limited industrial activity, which forced local populations to adapt to the harsh conditions through harvesting provisioning ES and preserving traditional ways of life through cultural ES, such as spiritual enrichment and aesthetics. These two categories of ES are reported as being closely interlinked as subsistence harvesting activities play an important role in many communities' social and cultural lives and identity (Huntington, 2013; Kaltenborn et al., 2017; Koenigstein et al., 2016; Mosbech et al., 2018).

Some studies point out the fundamental trade-off between industrial development in the Arctic and ES bundles associated with environmental protection (Aanesen et al., 2018; Armstrong et al., 2014; Chapin et al., 2005). Jansson et al. (2015) briefly consider trade-offs between the cultural, provisioning, and regulating ES of terrestrial and freshwater ecosystems in Northern Europe and find that they are numerous and multidirectional, especially when climate change effects and adaptation strategies are taken into consideration. Another common trade-off identified in the literature is between regulating and provisioning marine ES: important fish habitats provided by cold water corals and kelp forests in the Northeast Atlantic are often degraded by the harvesting of marine resources, notably commercial fishing (Aanesen et al., 2015; Armstrong et al., 2014; Smale et al., 2013). A trade-off that causes considerable tension among groups of Arctic ES users is between provisioning and cultural services provided by marine mammals, e.g. through whaling and whale-watching in the town of Húsavík in northern Iceland (Arctic Council, 2016).

Although abiotic flows are not typically counted as ES, significant trade-offs between biotic and abiotic flows are important to consider in environmental management (O'Garra, 2017; van der Meulen et al., 2016). This is reflected in the literature on ES in the Arctic, where hydrocarbon exploration is discussed as an important driver of change. Trade-offs between Arctic ES and hydrocarbon exploration are central to an ongoing debate and have been observed between oil and gas drilling and cultural, regulating and provisioning ES in North America (Carson et al., 2003; Kotchen and Burger, 2007) and the Barents Sea (Hasselström et al., 2012, 2017; Magnussen and Kettunen, 2013). While considering synergies and trade-offs between different ES reduces the risk of double-counting benefits in valuation studies and allows for better modelling of multiple socio-ecological interactions, it makes the picture of Arctic ES much more complex (Arctic Council, 2016; Jansson et al., 2015; Vihervaara et al., 2010).

3.7. Integrating ES concept into Arctic natural resource management

Even though it could be argued that all ES research is aimed at informing policy, it is debatable when the ES concept is integrated into management and when it is merely discussed. In this review, the criteria for inclusion of papers in this category is that (i) integration of the ES concept into the management of Arctic environmental policy is discussed in some detail and (ii) concrete suggestions for policy are

Table 6
Main points of focus on synergies and trade-offs between Arctic ES.

Publication	Focus
Aanesen et al., 2018	Applying DCE, reveals trade-offs between cultural and provisioning coastal ES in northern Norway.
Hasselström et al., 2017	Touches upon potential trade-offs between hydrocarbon exploration and ES provision in Northern Norway, which are partly preventable if appropriate safety measures against oil spills are applied.
Jansson et al., 2015	Discusses cause and effect relationships between ES under changing climate conditions, without using the specific terms of synergies and trade-offs.
Vihervaara et al., 2010	Identifies trade-offs between provisioning and cultural ES in the Finnish Boreal Forest.
Koenigstein et al., 2016	Identifies synergies between provisioning and cultural ES in the Barents Sea region, where harvesting of marine resources is central for social cohesion and the sense of local identity.
Kaltenborn et al., 2017	Discusses synergies and trade-offs between cultural and provisioning ES that are important for human well-being.
Aanesen et al., 2015	Briefly describes the trade-off between provisioning ES (commercial fishing) and regulating ES (fish habitat provided by cold water corals).
Huntington, 2013	Gives examples of synergies and trade-offs between provisioning and cultural ES in the Arctic, especially through indigenous subsistence and commercial harvesting, and how they form additional synergies with regulating ES and identifies trade-offs between provisioning ES and extraction of non-renewable resources.
Arctic Council, 2016	Reflects on trade-offs between the cultural and provisioning services of marine mammals. ES synergies and trade-offs are considered as a result of multiple interactions within a SES.
Chapin et al., 2005	Describes synergies between regulating, provisioning and cultural ES, synergies and trade-offs between subsistence and cash economies in ES utilisation, as well as synergies and trade-offs between industrial development and cultural ES.

Table 7
Main points of focus on integrating the ES concept into management.

Publication	Focus
Armstrong et al., 2014	Proposes ES-based management of cold-water corals.
Chapin et al., 2015	Proposes an ecosystem stewardship framework that integrates social and ecological processes and ES for Arctic conservation.
Hasselström et al., 2017	Assesses the economic costs of oil drilling and potential oil spills, and how these should be considered when making decisions about new hydrocarbon exploration in the Arctic.
Anisimov et al., 2017	Analyses projected changes in ES provision due to climate change, providing guidance for land use planning in the Arctic.
Eicken et al., 2009	Proposes a framework for addressing the information needs of sea-ice users based on the concept of sea-ice services.
Chapin et al., 2006	Proposes an ES-based framework for management of Alaskan boreal forest.
Jansson et al., 2015	Sets out possible strategies for climate change adaptation based on changes in ES provision and societal responses.
Vihervaara et al., 2010	Outlines an ES-based framework for Finnish boreal forests.
Arctic Council, 2013a	Proposes Ecosystem-Based Management (EBM) as a preferred environmental management model for the Arctic.
Arctic Council, 2013b	Suggests taking a participatory approach and including traditional knowledge of SES and ES into Arctic governance.
Koenigstein et al., 2016	Integrates stakeholder perspectives of ES use into ecosystem modelling to improve governance.
Kaltenborn et al 2017	Includes social and built capital and their dependence on local natural capital into ES management frameworks.
Brinkman et al 2016	Includes perceptions of ES users into adaptation strategies to ensure access to resources.
Huntington, 2013	Proposes integration of ES and stakeholder perspectives into Arctic environmental management.
Arctic Council, 2016	Proposes a holistic and systematic approach for enhancing the resilience of Arctic SES, where ES flows are a result of human-ecosystem dynamics and can be used for diagnosing as well as addressing system disturbances and shocks.
Gundersen et al., 2016	Provides a conceptual model of the effects of human activities on ES and management actions to mitigate them.
Chapin et al., 2005	Gives an overview of the treaties governing Arctic ES, identifies some institutional trade-offs and opportunities for stakeholder-focused ES management.
CAFF, 2015	Discusses various Arctic ES governance and valuation aspects, providing examples of policy focus areas where the TEEB methodology can be applied.
Magnussen and Kettunen, 2013	Discusses the impact of prior ES assessments on marine planning policy in Norway, e.g. establishment of the Norwegian Ecosystem Service Expert committee, and argues for better integration of ES values in environmental management decisions, e.g. through cost-benefit analysis.
PAME, 2013	Recommends monitoring Arctic marine ecosystems, valuing their ES and managing human activities to minimise negative effects on ES provision.
PAME, 2015	Proposes an EBM framework for the management of the Arctic Ocean.
WWF, 2015	Calls for the inclusion of ES values in decision-making, using examples from around the Arctic.
Navrud et al., 2017	Suggests ES valuation as a method for making environmental management decisions more transparent.

made. 23 out of 33 (70%) publications include suggestions of how to apply the ES concept in management, offering varying levels of practical policy guidance. These contain mainly general discussions of the applicability of the concept to management, as Table 7 indicates. The seminal reports – the MEA (2005), TEEB Scoping Study (2015) and Arctic Resilience Report (2016) – discuss the relevance of ES for management of Arctic natural resources and promote an integrated approach to ES governance, where ecological objectives and interests of different stakeholder groups are reflected in environmental policy planning and implementation (Arctic Council, 2016; CAFF, 2015; Chapin et al., 2005; Chapin et al., 2015; Huntington, 2013).

The overarching recommendation in the literature is that human activities should be considered a part of socio-ecological system dynamics rather than operating separately from nature. Ecosystem-based management is one such approach, defined by the Arctic Council (2013a, p. 1) as a 'comprehensive, integrated management of human activities based on best available scientific and traditional knowledge about the ecosystem and its dynamics, in order to identify and take action on influences that are critical to the health of ecosystems, thereby achieving sustainable use of ecosystem goods and services and maintenance of ecosystem integrity'. In the literature, EBM is most extensively discussed in the context of marine management. The Arctic Council's Working Group on Protection of the Arctic Marine Environment (PAME) applies an ecosystem approach in their proposed framework for the management of marine protected areas (MPA[2]) in the Arctic and stresses the importance of 'long-term conservation of nature with associated ecosystem services and cultural values' (PAME, 2015, p. 11). Arctic Ocean Review (PAME, 2013) provides recommendations for identifying and monitoring Arctic marine ecosystems, valuing their ES and managing human activities that may affect them. Gundersen et al. (2016) suggest that employing the ES approach in the management of the Nordic coastal zones, part of which are in the Arctic, would enable policy-makers to combine social preferences and ecological principles, and Smale et al. (2013) advocate EBM of kelp forests in the northeast Atlantic.

Focused ES assessments and valuation studies provide policy recommendations based on their outcomes. In the terrestrial biome, Anisimov et al. (2017) assess the projected effects of the warming climate on permafrost and terrestrial vegetation in the first half of the 21st century using mathematical models, foreseeing that this information would be useful for land use planning and management in the region. ES-based frameworks were proposed for the management of Alaskan and Finnish boreal forests (Chapin et al., 2006; Vihervaara et al., 2010), adaptation to climate change in terrestrial and freshwater ecosystems in the European north (Jansson et al., 2015), conservation of migratory species in the Arctic and sub-Arctic North America informed by economic values of ES provided by northern pintails (Goldstein et al., 2014), and future research and protection of the little auk in northwest Greenland (Mosbech et al., 2018).

Another key issue that transpires in the literature is the role of resource users in Arctic ES management. Including stakeholder perspectives and Traditional Ecological Knowledge (TEK) in environmental policy frameworks is being increasing widely advocated worldwide (Gómez-Baggethun et al., 2013; Reed et al., 2009). Scale and context are of great importance here as panaceas are rarely effective in environmental governance (Ostrom, 2007; Young et al., 2018). Localised ES assessments that combine scientific information and traditional knowledge are suggested as a climate adaptation strategy in the Arctic. Eicken et al. (2009) analyse how different stakeholders perceive, measure and use sea ice in Arctic Alaska, and how this knowledge can be used in climate adaptation. Socio-cultural analyses of Arctic ES suggest including the perspectives of local ES beneficiaries in research, monitoring and management, and adjusting the spatial and temporal scales so that they are relevant to stakeholders (Alessa et al., 2008;

[2] MPA is 'A clearly defined geographical space recognized, dedicated, and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values.' (PAME, 2015, p. 11)

Huntington, 2013; Kaltenborn et al., 2017; Koenigstein et al., 2016).

A major purpose of economic valuation of ES is to inform policy decisions. This information can be incorporated into decision-making when determining which set of actions is likely to be most beneficial in a particular socio-ecological context. Some of the monetary valuation studies provide an economic rationale for the sustainable management of Arctic ES from a cost-benefit analysis perspective, demonstrating that welfare losses are associated with unsustainable management practices (Aanesen et al., 2015; Armstrong et al., 2014; Goldstein et al., 2014; Hasselström et al., 2012, 2017; Navrud et al., 2017). Other studies contend that the loss of vital regulating Arctic ES may be irreversible, leading to dire and unpredictable consequences and that these losses should be prevented through strict environmental policies (Anisimov et al., 2017; Euskirchen et al., 2013; O'Garra, 2017).

4. Discussion

4.1. Research gaps

During the synthesis of the main themes in the literature on Arctic ES, some significant research gaps emerged. The most frequent were as follows:

(i) a need for a better inventory of Arctic ES through collection of biophysical, socio-cultural and socio-economic data;
(ii) a dearth of detailed and focused analysis of mechanisms and feedbacks of social-ecological interactions;
(iii) a lack of primary monetary and non-monetary Arctic ES valuation studies;
(iv) a shortage of analysis of interactions between ES bundles in terms of synergies and trade-offs;
(v) a lack of examples of concrete strategies for integrating ES into Arctic policy and natural resource management.

Given the novelty of the subject, it is unsurprising that most of the literature addresses general discussions of how the ES notion could be applied in an Arctic context. The first step towards addressing the gaps in Arctic ES research demand a comprehensive inventory and classification of ES in all biomes (Aanesen et al., 2015; CAFF, 2015; Chapin et al., 2005; Huntington, 2013; Smale et al., 2013). This work was started by the MEA and the scoping study by TEEB, but large gaps remain. Secondly, spatial mapping of Arctic ES on different scales containing bio-physical as well as socio-cultural and economic information is necessary for analysing and modelling the effects of rapidly changing climate conditions on ecosystems and societies (Armstrong et al., 2014; CAFF, 2015; Eicken et al., 2009; Huntington, 2013; WWF, 2015).

The SES concept is discussed predominantly on conceptual and theoretical levels, with a few exceptions where interactions between social and ecological components are described in detail using case studies. There is a general consensus that the SES concept is useful for examining human-nature interactions, yet its practical application is lacking. There is a need for in-depth primary studies exploring risks, causalities and feedbacks between societies and ecosystems that could provide guidance for effective policy interventions (Arctic Council, 2016; Hasselström et al., 2017; Kaltenborn et al., 2017; Koenigstein et al., 2016; Vihervaara et al., 2010). This kind of research requires a transdisciplinary approach, collaboration between different disciplines and inclusion of local perspectives, such as TEK. Future studies on SES resilience in the Arctic should include analysis of different ES management and governance regimes, allowing for comparisons and cross-regional learning (Aanesen et al., 2018; Chapin et al., 2006; Chapin et al., 2015). Social sustainability, equity and gender-related effects of Arctic ES changes and distribution across stakeholder groups are also under-researched (Arctic Council, 2016; CAFF, 2015; Hasselström et al., 2017; Jansson et al., 2015).

As Arctic ES is a relatively new area of research, there is a lack of primary ES valuation studies in all biomes, and it is important that a pluralistic view is applied when interpreting results and using them to inform policy (Alessa et al., 2008; Arctic Council, 2016; Huntington, 2013). The aim of this perspective is to ensure that relevant value domains are accounted for in each case. A worry shared by many ES researchers is that monetary ES valuation techniques are not equipped to capture the full value of environmental services, especially in indigenous contexts (Chan et al., 2012a,b; Kumar and Kumar, 2008; Martín-López et al., 2014; Satz et al., 2013). There is a danger that non-use values and cultural ES are omitted or poorly captured in one-dimensional monetary ES valuations that do not account for the multiplicity of values and valuation languages (Chan et al., 2012b; Huntington, 2013; Kotchen and Burger, 2007; Castro Martínez et al., 2013). This problem is not unique to the Arctic and has been discussed in other contexts (Chan et al., 2012a; Kelemen et al., 2014; Maestre-Andrés et al., 2016). The literature on Arctic ES calls for more primary economic (CAFF, 2015; Gundersen et al., 2016; Magnussen and Kettunen, 2013; O'Garra, 2017), socio-cultural (Alessa et al., 2008; Huntington, 2013; Kaltenborn et al., 2017; Vihervaara et al., 2010) and integrated (Brinkman et al., 2016; Huntington, 2013; WWF, 2015) valuation studies.

Utilisation of one ES often affects the availability of others, and while some synergies and trade-offs are identified in the literature, the discussion of the underlying mechanisms is largely missing. To eliminate this knowledge gap, interactions between different Arctic ES and ES bundles need to be studied together with human activities that affect their provisioning. A prerequisite for that is filling in the first two gaps in research – mapping and inventory, and assessment of feedback mechanisms between SES components and ES valuation. The literature highlights the need for dynamic modelling that would facilitate analyses of trade-offs and synergies between different uses of Arctic ecosystems on varying spatiotemporal scales (Arctic Council, 2016; CAFF, 2015; Gundersen et al., 2016; Huntington, 2013; Jansson et al., 2015; Navrud et al., 2017; O'Garra, 2017; Vihervaara et al., 2010). This requires a good understanding of the different uses of Arctic ES and advanced technical skills on the part of researchers, as well as improved models and software. Provisioning and cultural ES form a synergy with climate regulating ES in the Arctic and are sensitive to climate change, so better modelling and, ultimately, conservation policies that produce climate regulation benefits are likely to enhance provision across all three types of ES (Chapin et al., 2005; Huntington, 2013; Jansson et al., 2015; Watson et al., 2003).

Despite the widespread discussion in the literature on mainstreaming ES into Arctic sustainability policies, description of concrete policy tools and strategies is largely missing. In most papers, the ES concept is applied in a general way with no step-by-step practical guidance. This observation coincides with one made by McDonough et al. (2017), who suggest that ES-based management strategies should recognise their limitations of applicability, e.g. to one research field, to prevent bias in quantification as knowledge is shared. The next steps, following the initial description of Arctic ES and scoping exercises presented in this synthesis review, involve filling in the research gaps and integrating that knowledge into resource management. For this purpose, additional resources, expertise and governance mechanisms are required, as well as inclusive decision-making frameworks. An example of such improvements is the European Union's effort to develop ES research and mainstream it into policy, such as through the EU Biodiversity Strategy 2020 and Mapping and Assessment of Ecosystems and their Services (MAES).

4.2. Comparison to other ES literature reviews

The research gaps identified in this literature review on Arctic ES coincide with some of the previous observations of similar globally focused reviews of ES research, such as the recent study by Costanza et al. (2017) that highlights the need for integrated ES inventory and valuation, analysis of trade-offs and dynamic modelling, and context-specific bundling and scaling of ES to address local management needs. Balvanera et al. (2012) find similar knowledge gaps in ES research in Latin America, pointing to a need for better ES inventory, assessment and modelling of synergies and trade-offs that are relevant to resource users. Malinga et al. (2015) emphasise the global need for improved mapping of heterogeneous landscapes with multiple ES on all scales, since this would enable researchers to assess spatial-temporal dynamics of human-nature interactions as well as ES bundles, synergies and trade-offs. The interdisciplinary necessities in ES research and evolving recognition of multiple perspectives and types of values associated with ES observed in this meta-synthesis was also noted by Droste et al. (2018). The tendency for descriptive rather than normative and action-oriented analysis of human-nature interactions in ES literature was pinpointed by Abson et al. (2014) and Milcu et al. (2013), corresponding with the observation in this study that discussion of Arctic ES at this stage remains rather conceptual, lacking scientific detail and practical guidance for application to management and policymaking.

The emphasis on the need to move away from single-point ES valuation towards integrated approaches and non-economic deliberative techniques highlighted in this study is also reported in the global ES literature (van den Belt and Stevens, 2016), particularly in the context of cultural ES (Dickinson and Hobbs, 2017; Droste et al., 2018; Milcu et al., 2013). This would be a welcome development towards comprehensive assessment of Arctic ES, ensuring the inclusion of different worldviews and value domains, especially when valuing cultural ES. A pitfall to look out for in future ES research is the tendency to focus on the most obvious and quantifiable cultural ES that fit neatly into utilitarian value frameworks, such as recreation and tourism, while less tangible ES, such as the sense of identity and spiritual enrichment, receive less attention (ibid.). Another common concern, which coincides with the observations of this study, is over-prioritisation of economic ES values over socio-cultural and ecological ones (Chaudhary et al., 2015; van den Belt and Stevens, 2016).

The ES concept presents an opportunity for a holistic approach to Arctic sustainable development that integrates social and natural sciences. Involvement of a wider array of social science researchers, activists and policy makers is required to bridge knowledge gaps and increase policy relevance (ibid.). However, it is also important that they work together to avoid compartmentalising ES research into separate disciplines or policy agendas (Abson et al., 2014; Droste et al., 2018; Milcu et al., 2013). Having been dominated by ecology and economics since its conception, the ES literature has under-emphasised social issues. The involvement of social science and humanities in shaping the ES discourse is essential, so that the issues of development, social justice, equity, gender equality, welfare of future generations, governance, ethics, social-environmental interactions and co-production of ES are addressed (Chaudhary et al., 2015; Daw et al., 2011; Dickinson and Hobbs, 2017; Fisher et al., 2013; van den Belt and Stevens, 2016).

4.3. Limitations

This study presents the first reproducible attempt to assess the current state of knowledge on Arctic ES using research methods commonly applied in meta-syntheses of literature. It is not, however, without limitations. Firstly, as noted by Milcu et al. (2013) in the context of cultural ES, there is likely to be a parallel body of research that is concerned with the topic without using ES terminology. We included a few publications sourced through 'snowballing' technique that examine nature-human interactions and associated values through an ES lens (Alessa et al., 2008; Kaltenborn et al., 2017; Mosbech et al., 2018), but there are likely to be more studies in the Arctic that examine similar issues without specifically referring to ES. The second limitation is associated with qualitative aspects of the methodology – publication selection bias and subjectivity when interpreting the results of the thematic analysis. Finally, the ES research environment is rapidly changing with new research constantly being published through various outlets and in different languages, e.g. Russian research focused on Arctic issues that did not come up in our academic database search, and it is unavoidable that some relevant publications were overlooked.

5. Conclusions

To the best of our knowledge, this thematic review is the first attempt to systematically review the literature on Arctic ecosystem services to date. This synthesis of 33 publications on Arctic ES indicates that the ES concept is being applied in the Arctic with potential implications for research and policy, although it is limited in scope and depth at the moment. The number of publications sourced for this review went from an average of 0.75 per year between 2005 and 2012 to around 4.5 between 2013 and the beginning of 2018. That the vast majority (27 out of 33, or 82%) of publications sourced for this review were published in 2013 or later suggests that the body of literature on Arctic ES is growing rapidly, as are general academic, economic and political interests in the region. As the global focus shifts to the Arctic, owing to rapid climate change with resulting environmental challenges and economic opportunities, this trend is likely to continue. Many of the reviewed publications cross the boundaries of scientific disciplines and contain multiple themes, which confirms that ES research continuously crosses disciplinary boundaries, bringing about new opportunities for cooperation as well as methodological challenges. Discussion of Arctic ES research is still relatively novel and limited, and there is an apparent need for further research in all thematic areas identified in this literature review.

With intensifying climate change and its uncertain effects on Arctic ecosystems and societies, it is particularly important to estimate trade-offs between different ES and conduct primary valuation studies (monetary and non-monetary) in order to estimate those effects and determine appropriate policy responses. Moreover, a closer examination of human-ecosystem dynamics and various natural resource management scenarios is needed to enable incorporation of Traditional Ecological Knowledge and other locally-based strategies into climate change resilience planning in the Arctic. The broad areas of future study identified in this meta-synthesis will require resources and innovation as well as the willingness of scientists, policy makers and communities to cooperate. Even more importantly, future research on Arctic ES should be aimed at informing policy and incorporating the ES perspective into the management of natural resources, as is required by the EBM framework favoured by the Arctic Council.

Appendix 1. Sourced publications on Arctic ecosystem services

Appendix 1
Sourced publications on Arctic ecosystem services (in chronological order of sourcing).

Nr.	Source	APA Reference	Type	Methods and type of data	**Biome**	**Themes**
1.	Science Direct	O'Garra, T. (2017). Economic value of ecosystem services, minerals and oil in a melting Arctic: A preliminary assessment. *Ecosystem Services*, 24, 180-186.	Article	Economic ES valuation; benefit transfer method; secondary data.	all	1,3
2.	Science Direct	Aanesen, M., Falk-Andersson, J., Vondolia, G. K., Borch, T., Navrud, S., & Tinch, D. (2018). Valuing coastal recreation and the visual intrusion from commercial activities in Arctic Norway. *Ocean & Coastal Management*, 153, 157-167.	Article	Economic ES valuation; discreet choice experiment with three scenarios; primary data.	marine	3,4
3.	Science Direct	Armstrong, C. W., Foley, N. S., Kahui, V., & Grehan, A. (2014). Cold water coral reef management from an ecosystem service perspective. *Marine Policy*, 50, 126-134.	Article	Desk-based review of literature and management; draws policy implications.	marine	1,5
4.	Science Direct	Chapin, F. S., Sommerkorn, M., Robards, M. D., & Hillmer-Pegram, K. (2015). Ecosystem stewardship: A resilience framework for arctic conservation. *Global environmental change, 34*, 207-217.	Article	Desk-based overview of the concept; discussion of its applicability for Arctic ES management.	all	1,2,5
5.	Scopus	Hasselström, L., Håkansson, C., Noring, M., Soutukorva, Å., & Khaleeva, Y. (2017). Costs and benefits associated with marine oil spill prevention in northern Norway. *The Polar Journal, 7*(1), 165-180.	Article	Cost-benefit analysis of two scenarios using secondary data.	marine	3,4,5
6.	Scopus	Anisimov, O., Kokorev, V., & Zhiltcova, Y. (2017). Arctic Ecosystems and their Services Under Changing Climate: Predictive-Modeling Assessment. *Geographical Review, 107*(1), 108-124.	Article	Predictive mathematical modelling ES changes using secondary data.	terrestrial	1,5
7.	Scopus	Goldstein, J. H., Thogmartin, W. E., Bagstad, K. J., Dubovsky, J. A., Mattsson, B. J., Semmens, D. J., Diffendorfer, J. E. (2014). Replacement Cost Valuation of Northern Pintail (Anas acuta) Subsistence Harvest in Arctic and Sub-Arctic North America. *Human Dimensions of Wildlife, 19*(4), 347-354.	Article	Primary economic ES valuation using replacement cost method.	terrestrial	3
8.	Scopus	Euskirchen, E., Goodstein, E. S., & Huntington, H. P. (2013). An estimated cost of lost climate regulation services caused by thawing of the Arctic cryosphere. *Ecological Applications, 23*(8), 1869-1880.	Article	Calculation of added warming effects of thawing Arctic ice and associated economic costs of ES loss to year 2100 using integrated assessment models and secondary data.	sea-ice	3
9.	Scopus	Eicken, H., Lovecraft, A. L., & Druckenmiller, M. L. (2009). Sea-Ice System Services: A Framework to Help Identify and Meet Information Needs Relevant for Arctic Observing Networks. *Arctic, 62*(2), 119-136.	Article	Framework for addressing information needs of ES users based on primary data from case studies.	sea-ice	1,2,5
10.	Web of Science	Mosbech, A., Johansen, K. L., Davidson, T. A., Appelt, M., Grønnow, B., Cuyler, C. & Flora, J. (2018). On the crucial importance of a small bird: The ecosystem services of the little auk (Alle alle) population in Northwest Greenland in a long-term perspective. *Ambio*, *47*(2), 226-243.	Article	Analysis of sociocultural and ecological ES values applying a multi-method approach; primary and secondary ecological and ethnographic data.	terrestrial	1,2,3
11.	Web of Science	Noring, M., Hasselström, L., Håkansson, C., Soutukorva, Å., & Gren, Å. (2016). Valuation of oil spill risk reductions in the Arctic. *Journal of Environmental Economics and Policy, 5*(3), 298-317.	Article	Primary ES valuation using contingent valuation method and two scenarios.	all	3
12.	Web of Science	Chapin, F. S., Lovecraft, A. L., Zavaleta, E. S., Nelson, J., Robards, M. D., Kofinas, G. P., Naylor, R. L. (2006). Policy strategies to address sustainability of Alaskan boreal forests in response to a directionally changing climate. *Proceedings of the National Academy of Sciences, 103*(45), 16637-16643.	Article	Sustainability policy framework developed and applied to the case study, uses secondary data to draw policy strategies.	terrestrial	1,2,5
13.	Web of Science	Jansson, R., Nilsson, C., Keskitalo, E. C. H., Vlasova, T., Sutinen, M.-L., Moen, J., Aspholm, P. E. (2015). Future changes in the supply of goods and services from natural ecosystems: prospects for the European north. *Ecology and Society, 20*(3).	Article	Analysis of projected changes in ES via expert panels and literature review.	terrestrial	1,2,4,5
14.	Google Scholar	Vihervaara, P., Kumpula, T., Tanskanen, A., & Burkhard, B. (2010). Ecosystem services–A tool for sustainable management of human–environment systems. Case study Finnish Forest Lapland. *Ecological Complexity, 7*(3), 410-420.	Article	Development of methodology for ES research; examples of various primary and secondary data sources.	terrestrial	1,2,4,5
15.	Google Scholar	Smale, D. A., Burrows, M. T., Moore, P., O'Connor, N., & Hawkins, S. J. (2013). Threats and knowledge gaps for ecosystem services provided by kelp forests: a northeast Atlantic perspective. *Ecology and Evolution, 3*(11), 4016-4038.	Article	Extensive literature review synthesising existing knowledge and drawing recommendations.	marine	1
16.	Google Scholar	Arctic Council, A. (2013). Summary for policy-makers. Arctic Resilience Interim Report 2013.	Report	A brief summary of the report for policy makers.	all	2,5
17.	Google Scholar	Koenigstein, S., Ruth, M., & Gößling-Reisemann, S. (2016). Stakeholder-informed ecosystem modeling of ocean warming and acidification impacts in the Barents Sea region. *Frontiers in Marine Science*, *3*, 93.	Article	Combination of stakeholder perceptions and ecosystem modelling to evaluate societal effects of ES changes.	marine	2,3,4,5

(*continued on next page*)

Appendix 1 (*continued*)

Nr.	Source	APA Reference	Type	Methods and type of data	**Biome**	**Themes**
18.	Google Scholar	Kaltenborn, B. P., Linnell, J. D., Baggethun, E. G., Lindhjem, H., Thomassen, J., & Chan, K. M. (2017). Ecosystem Services and Cultural Values as Building Blocks for 'The Good life'. A Case Study in the Community of Røst, Lofoten Islands, Norway. *Ecological Economics*, *140*, 166-176.	Article	Analysis of ES cultural values through ethnographic observations, in-depth interviews, and a participatory scenario workshop; primary data.	all	2,3,4,5
19.	Snowball Method	Aanesen, M., Armstrong, C., Czajkowski, M., Falk-Petersen, J., Hanley, N., & Navrud, S. (2015). Willingness to pay for unfamiliar public goods: Preserving cold-water coral in Norway. *Ecological economics, 112*, 53-67.	Article	Economic ES valuation – discreet choice experiment using three scenarios; primary data.	marine	3,4
20.	Snowball Method	Brinkman, T. J., Hansen, W. D., Chapin, F. S., Kofinas, G., BurnSilver, S., & Rupp, T. S. (2016). Arctic communities perceive climate impacts on access as a critical challenge to availability of subsistence resources. *Climatic Change*, *139*(3-4), 413-427.	Article	Semi-structured interviews eliciting local perceptions of ES changes linked to climate predictions; primary and secondary data.	all	3,5
21.	Snowball Method	Alessa, L., Kliskey, A., Williams, P., & Barton, M. (2008). Perception of change in freshwater in remote resource-dependent Arctic communities. *Global environmental change, 18*(1), 153-164.	Article	Primary qualitative and quantitative data from semi-structured interviews and questionnaires used to elicit stakeholders' perceptions of ES changes in the case study area.	terrestrial	3
22.	Snowball Method	Hasselström, L., Cole, S., Håkansson, C., Khaleeva, Y., Noring, M., & Soutukorva, Å. (2012). *The value of ecosystem services at risk from oil spills in the Barents Sea.* Paper presented at the The ISEE conference, Rio de Janeiro.	Conference paper	Discussion of ES values based on secondary economic data.	marine	3
23.	Snowball Method	Huntington, H. P. (2013). Provisioning and cultural services. Chapter 18 of the Arctic Biodiversity Assessment (ABA). Status and trends in Arctic biodiversity. *Conservation of Arctic Flora and Fauna (CAFF), Akureyri, Iceland*, 593-626.	Report	General overview and case study approach; a mixture of desk studies and comprehensive literature review.	marine	1,2,3,4,5
24.	Snowball Method	Arctic Council. (2016). *Arctic Resilience Report*. Stockholm Environment Institute and Stockholm Resilience Centre.	Report	Literature review and stakeholder engagement, leading to case study approach. Case studies selected and data coded by experts using qualitative comparative analysis.	all	1,2,4,5
25.	Snowball Method	Gundersen, H., Bryan, T., Chen, W., & Moy, F. E. (2016). *Ecosystem Services: In the Coastal Zone of the Nordic Countries*: Nordic Council of Ministers.	Report	General overview and case study approach; mixture of desk studies and comprehensive literature review.	marine	1,5
26.	Snowball Method	Chapin, F. S., Berman, M., Callaghan, T. V., Convey, P., Crépin, A.-S., Danell, K., McGuire, A. D. (2005). Polar Systems. In *Millennium Ecosystem Assessment.*	Report	Broad overview of polar ES and their management using wide range of secondary data and case studies.	all	1,4,5
27.	Snowball Method	CAFF. (2015). Conservation of Arctic Flora and Fauna (CAFF). The Economics of Ecosystems and Biodiversity (TEEB) for the Arctic: A Scoping Study. Stockholm Environment Institute and Stockholm Resilience Centre.	Scoping study	Scoping study synthesising the existing knowledge through lit. review, case study approach, and development of research and policy frameworks.	all	1,2,3,5
28.	Snowball Method	Magnussen, K., & Kettunen, M. (2013). Marine ecosystem services in the Barents Sea and Lofoten Islands, a scoping assessment. *Nordic Council of Ministers, Copenhagen*.	Scoping assessment	Scoping assessment of ES values using secondary data from previous studies.	marine	1,3,5
29.	Snowball Method	Arctic Council, A. (2013). *Ecosystem-based management in the Arctic*.	Report	An overview report by an expert group using secondary data, outlining research and policy needs.	all	5
30.	Snowball Method	PAME. (2013). *The Arctic Ocean Review Project, Final Report.*	Report	Desk-based review of policy instruments; recommendations for future management.	marine	5
31.	Snowball Method	PAME. (2015). *Framework for a Pan-Arctic Network of Marine Protected Areas*.	Report	An overview of ES values and management needs; MPA framework.	marine	5
32.	Snowball Method	World Wildlife Fund (WWF). (2015). Valuing Arctic Ecosystems and Biodiversity. WWF Global Arctic Programme. Ottawa, Canada.	Magazine	Professional review of TEEB Scoping Study and commentary by selected contributors.	all	1,3,5
33.	Snowball Method	Navrud, S., Lindhjem, H., & Magnussen, K. (2017). Valuing Marine Ecosystem Services Loss from Oil Spills for Use in Cost-Benefit Analysis of Preventive Measures. *Handbook on the Economics and Management of Sustainable Oceans*, 124-137.	Book chapter	Presents non-market ES valuation and its implications for policy using an example of a primary contingent valuation study with three scenarios.	marine	3,5

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