

Review

# Rethinking Sustainability Monitoring in the Arctic by Linking Resilience and Sustainable Development in Socially-Oriented Observations: A Perspective

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**Abstract:** Monitoring of social-ecological systems dynamics and sustainability is of high importance in a rapidly changing Arctic. The goal of this essay is to discuss and articulate the principles for designing a suitable Arctic sustainability monitoring framework based on the convergence between resilience thinking and sustainable development paradigms. We propose to integrate sustainability monitoring into the socially-oriented observations (SOO) methodologies in order to design Arctic sustainability monitoring as a transdisciplinary participatory activity that results in both co-production of sustainability knowledge and building more sustainable and resilient Arctic social-ecological systems by enabling continuous observation and informed decision-making. Special attention is given to approaches for developing sustainability indicators to monitor trends in Arctic social-ecological systems. It is argued that sustainability monitoring is a valuable component of the Arctic sustainability knowledge system that integrates social and natural sciences and engages Indigenous, local, and traditional knowledge, entrepreneurship, education, and decision-making. Bringing together diverse knowledge systems is the primary route to collectively pursue sustainability in a holistic, polycentric, multifaceted, participatory, and knowledge-driven manner. Transdisciplinary SOO approaches and methods are specifically discussed.

**Keywords:** Arctic; sustainability; monitoring; social-ecological system; indicators; transdisciplinary approaches; socially-oriented observations



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## 1. Introduction

The Arctic is facing rapid, simultaneous, and interlinked changes, in both social and natural systems [1,2]. The outcomes of many of these changes are rather uncertain and difficult to predict. Yet, the desirable trajectory of change in Arctic social-ecological systems (SES) is the adaptation to the ongoing transformations that also supports SES sustainability in a long run [3]. Thus, the long-term monitoring of Arctic SES and their sustainability, focusing on transformations and adaptations as attributes of SES sustainability, appears to be of high importance [4–6]. Conceptually, SES sustainability monitoring can be accomplished through the integration of the resilience approach and the sustainable development principles (and Sustainable Development Goals (SDGs) in particular), which, we argue, collectively give us new instruments for monitoring Arctic sustainability.

It is important to remember that the theory of resilience emerged in the natural sciences, as described by Holling in 2001 [7]. In the Arctic, it was further developed with the input from scientists representing a wide range of human and social sciences fields. The result was a useful framework for understanding the dynamic relationship between humans and the environment, and that also provides models for increasing the society's capacity to manage change in coupled systems [8–10].

This paper aims to discuss the principles for designing a suitable Arctic sustainability monitoring framework based on the convergence between resilience thinking and sustainable development paradigms, and elucidate potential approaches and methods to define sustainability indicators. We develop the principles for designing such an Arctic sustainability monitoring framework and describe pathways for setting the process for continuous development and observation of indicators.

The Arctic is a region of special importance for understanding sustainability [11]. First of all, it is one of the most rapidly and radically changing parts of the planet that, in turn, exerts considerable influence over global processes. This is true in terms of climate and environment [1], as well as in respect to socioeconomic systems [2]. Particular vulnerability of Arctic social-ecological systems to such rampant change is well recognized [1]. However, our understanding of the responses, resilience, and adaptive capacities in changing Arctic SES are still fragmentary. The lack of data, limited observations, and long-term monitoring in particular are significant impediments to improving our knowledge of these processes. The insufficient and inequitable engagement of Indigenous and local knowledge is also a formidable obstacle in attaining this task [12]. Yet, sustainability is well aligned with the way Arctic Indigenous communities have been living for millennia and a consensus future goal among all Arctic stakeholders [13]. Thus, understanding and monitoring sustainability of the Arctic SES systems is of paramount importance for the Arctic and for the entire globe.

We consider Arctic sustainability monitoring as a transdisciplinary activity that results in both co-production of sustainability knowledge and in building more sustainable and resilient Arctic SES. First, we discuss the meanings of sustainability in the Arctic. Then, after an overview of existing efforts of sustainability monitoring in the Arctic, we propose to re-think social-ecological systems (SES) sustainability monitoring based on converging sustainable development and resilience concepts. We then delineate the main principles and approaches of the SES sustainability monitoring and discuss the process of designing the indicators. Finally, we outline possible implementation strategies of such monitoring using socially-oriented observations (SOO) principles.

## 2. Defining Arctic Sustainability

There are a variety of ways to define sustainability and Arctic sustainability in particular. In fact, a regional Arctic sustainability science is an emerging and rapidly growing body of knowledge [10]. Examining various possible definitions, Graybill and Petrov [11] emphasize that sustainable development in the Arctic should be viewed first of all from a human perspective and be localized and operationalized through the notion of social-ecological systems (SES). They recommend using the following definition of Arctic sustainable development: “development that improves the health, well-being and security of Arctic communities and residents while conserving ecosystem structures, functions, and resources” [11] p. 12. Building on Agyeman et al. [14], they point out that this “Arctic-specific definition includes a more explicit engagement with ecology, socioenvironmental justice, and equity issues, while recognizing the need to live within the supporting ecosystem’s limits.” It also recognizes the importance of social, environmental and economic pillars of sustainability in the Arctic. Yet they warn that Arctic sustainability cannot be conceived solely as a Western concept, but must include avenues for Indigenous epistemologies and methodologies to be a part of a “decolonial” notion of sustainability.

Keeping in mind these perspectives, it could be argued that integrating the concepts of sustainable development and resilience is key to understanding sustainability. The possibilities of such integration were discussed during the Arctic Resilience Forum held in 2018 in Rovaniemi, Finland and published on the website of the Arctic Council Sustainable Development Working Group [6]. In this context, Arctic sustainability can be defined as the capacity of SESs at different spatial, temporal, and organizational scales to transform or proactively adapt to impacts and processes (both external and internal, fast and slow) by increasing human, social, and cultural capacities, societal benefits, and ecosystem services,

thus facilitating resilience building and sustainable development of such capacities, services, and benefits.

A holistic, polycentric, multifaceted, participatory, and knowledge-driven approach to building sustainable Arctic SESs does not assume putting all elements of sustainability in one basket and mixing them. Rather, it calls for a systematic application of concepts and related inter- and transdisciplinary approaches, such as the ecosystem services concept, the driver-pressure-state-impact-response framework, a resilience view of the SES transformations, the adaptive cycle in socio-ecological system dynamics, and Indigenous knowledge [15–17]. In other words, this definition connects sustainability to the well-being or “thrivability” of humans and ecosystems [18].

There is a broad consensus that sustainability must be addressed using interdisciplinary approaches [10]. However, disciplinary silos remain entrenched in science knowledge production. To an extent it is natural given the dissimilarities between natural and social sciences. Critiques vary from complaints that natural systems “have no purpose”, while social systems may be “goal-oriented and politicized” [19]. However, there is a recognized urge to bridge these divides.

According to J. Kim, the science of sustainability “transcends disciplinary boundaries and focuses increasingly on understanding the dynamics of SES” [20]. We find there are divergent understandings of what sustainability science means [21–24]. According to Komiyama and Takeuchi [25], it can be defined as a science that examines sustainability focused on real-world problems, purposes, and goals, and recommends possible solutions for the sustainability transition, i.e., a “transformational change” [26]. Nevertheless, although the history of sustainability science dates back a number of decades, it has struggled to find well-operationalized ways to solve real-world problems mainly due to a “wicked” and complex nature of driving forces and their interactions [27–29]. Moreover, the sustainability of coupled human-natural systems (i.e., SES) remains an elusive concept.

Why are scientific approaches alone unable to overcome barriers to address many urgent sustainability challenges? Kauffman and Arico contend that this highlights the issue of the disconnect between the science and society [30]. If sustainability scientists wish to support a transformative change leading to sustainable development, they must break away from their professional comfort zones and conventional modes of science-making. A higher level of knowledge integration and collaborative work between the knowledge producers and users are required to deal with these challenges. We argue that a transdisciplinary approach to Arctic sustainability science that integrates science, local/traditional/Indigenous knowledge, entrepreneurship, education, and decision-making, and is based on interdisciplinary linkages between social and natural sciences, will be instrumental in building the Arctic sustainability knowledge system.

### **3. Existing Observing Frameworks with Connections to Sustainability Monitoring**

Sustainability monitoring in the Arctic to date has been largely compartmentalized into projects that pursued distinct conceptual and disciplinary meanings of sustainability. The majority of Arctic monitoring programs engaged with sustainability originated from natural science initiatives and focus on the natural components of social-ecological systems and their resilience. For example, the Circumpolar Biodiversity Monitoring Program (CBMP) established by the Arctic Council and maintains biodiversity indices and indicators that target biodiversity components and services that are globally significant, critical to the resiliency of Arctic ecosystems, and of vital importance to northern communities. However, only a few indicators are connected to social systems, thus providing a limited account of sustainability processes and outcomes. A number of monitoring programs engage local residents and knowledge holders in observations and knowledge co-production. In North America, the Local Environmental Observer (LEO), Exchange for Local Observations and Knowledge of the Arctic (ELOKA), and SmartICE projects work with local community members to collect and share observations. The input of the Indigenous knowledge holders is central to these efforts, but they often emphasize observing rather than knowledge

co-production for understanding or response. The Rapid Assessment of Circum-Arctic Ecosystem Resilience (RACER) project [31] uses the biological productivity and diversity of SES to assess ecosystem resilience. While RACER relates to human systems through harvestable species and other community-relevant resources, it does not clearly consider social and economic factors. The experiences of monitoring projects using a single disciplinary lens (or knowledge system) may create solutions that dismiss alternative options, potentially resulting in unintended consequences [32].

More inclusive and transdisciplinary assessment projects with some monitoring components are the Adaptation Actions for a Changing Arctic (AACA) (AMAP 2017) and the Arctic Resilience Report (ARR) [8,9]. Both employ the concepts of ecosystem services, social-ecological systems, and SES governance to assess resilience and sustainability. Although based on vast volumes of observations and abundant with methodologically-rich monitoring approaches, AACA and ARR are not sustainability monitoring programs, but largely science-driven snapshot assessments.

In the Arctic, monitoring platforms that originated from social sciences and sustainable development thinking gained momentum in the last two decades. Primary examples include the Arctic Council Sustainable Development Working Group projects such as the Arctic Human Development Report (AHDR) [33,34], and Arctic Social Indicators (ASI) reports [35,36]. Both AHDR and ASI made particular references to sustainable development and designed their assessments to characterize human systems in their connection with nature and through contribution to human development. For example, ASI indicators were developed within six domains: (1) Fate control and/or the ability to guide one's own destiny; (2) cultural wellbeing and cultural integrity or belonging to a viable local culture; (3) contact with nature or interacting closely with the natural world; (4) material well-being; (5) education; and (6) health and population.

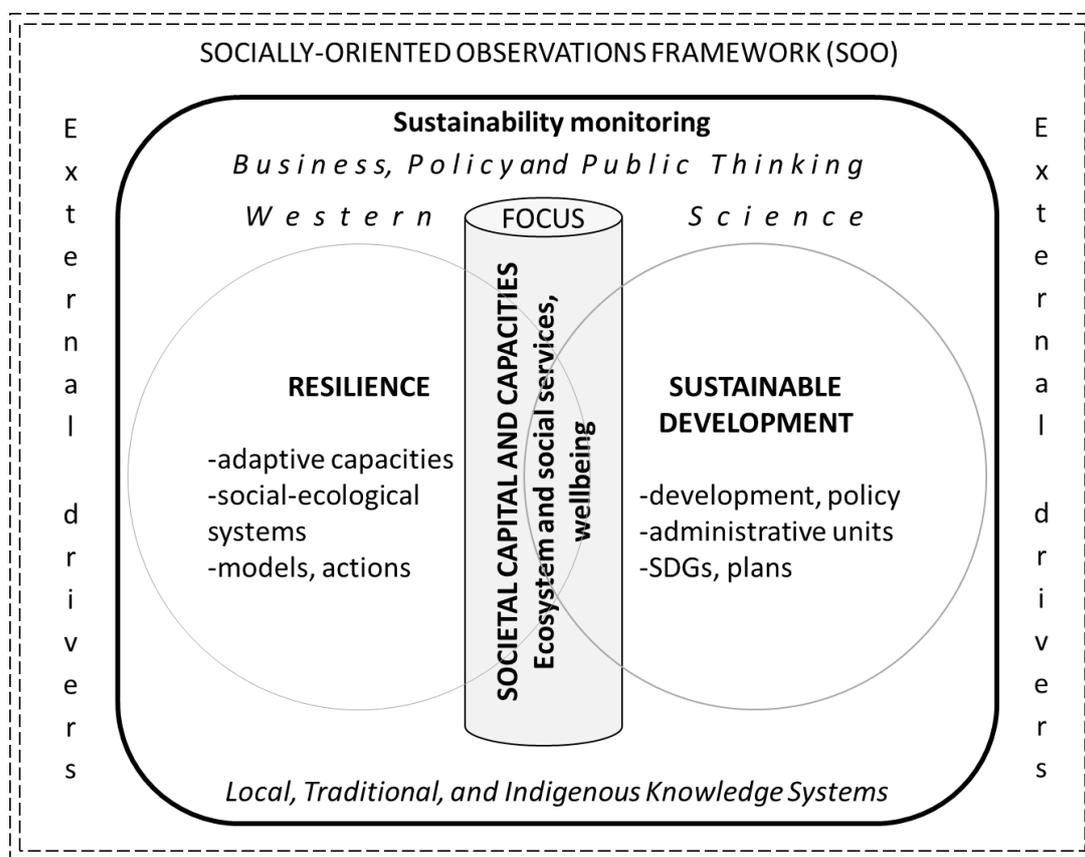
Other prominent social sciences-driven efforts in observing Arctic human systems include ReSDA [37], SLiCA [38], and Arctic Observing Network Social Indicators Project [39]. Despite being instrumental in revealing changes and challenges faced by Arctic communities, they largely do not bridge with natural sciences to account for connectivity between social and environmental domains of sustainability. They are also mostly focused on the circumpolar, national, and regional scales, while missing local processes that are only described through scattered case studies. As many of these efforts are data-driven, they rely on limited datasets and thus tend to omit important components relevant to SES sustainability, such as mixed and subsistence economies, sharing of harvest, Indigenous knowledge transfer, and the extent of and communities' capacity for self-organization and fate control.

Most recently, the progress in sustainable development monitoring has been propelled by United Nations (UN) initiatives such as the Millennium Development Goals and SDGs [40]. The SDGs have an elaborate system of monitoring, and are proliferated globally, including in many Arctic countries, and seemingly entered the mainstream of decision-making processes [40,41]. The direct application of SDGs to the Arctic and their advantages and limitations are discussed in several recent papers [42–44]. While the SDG framework may be usable in the Arctic, to be truly valuable it must be localized, linked to local and Indigenous knowledge, embedded in local capacity-building, and substantially transformed to accommodate participatory and bottom-up information flows. The pitfalls associated with SDGs are also considerable, including a misuse and misinterpretation of indicators, potential political and special interest influences, and a possible onset of managerialism and neocolonial governance tendencies [41,45]. Still, the localized and interlinked use of the SDG indicators may be appropriate, especially in conjunction with other forms of monitoring, as argued below.

#### **4. Sustainability Monitoring through Linking Resilience and Sustainable Development**

Given that we are still searching for a suitable theoretical and methodological platform for Arctic sustainability monitoring, we propose to converge resilience and sustainable de-

velopment thinking, disciplines, and knowledge systems to develop an integrated approach that can be effectively deployed within existing or emerging monitoring frameworks. We view sustainability monitoring as an activity that can help bridge knowledge across and between social and natural sciences, as well as between Western science and Indigenous knowledge systems. Arctic sustainability monitoring will thus be a transdisciplinary activity that leads to a co-produced knowledge and building more sustainable Arctic SESs. As written in the Intergovernmental Panel on Climate Change (IPCC) Special Report on the ocean and cryosphere in a changing climate, the practice of knowledge co-production would gain from further methodological innovations and better training of researchers [1]. In this context the Socially-Oriented Observations (SOO) [46] as a participatory, integrated observing framework has been specially highlighted by the IPCC Report [1]. As a part of SOO, sustainability monitoring could be constructed by focusing on the convergence between resilience and sustainable development concepts (Figure 1) and broad and diverse stake-, rights-, and knowledge-holder participation in the sustainability indicators identification.



**Figure 1.** Sustainability monitoring under socially-oriented observations (SOO).

ARR (2016) [9] defined resilience as the capacity to cope with stresses and shocks by responding or reorganizing in ways that maintain identity, function, and structures, as well as the ability to deal with transformational change. In this report, special attention was given to the concept of social-ecological resilience, so that residents are empowered to make deliberate choices concerning rapid changes in the Arctic [9,47]. This concept is instrumental for developing shared understandings among relevant actors and institutions and useful in respect to channelizing information flows for decision makers.

The Arctic is changing more rapidly than other regions of the planet and the external and internal forces of change affect both ecological and social components of SES. Since the uncertainty of the outcomes is high, it is crucial “to empower deliberate choices” that can

mold the changes and facilitate adaptation and transformation [47]. Taking into consideration the close connections between human activities with the environment in the Arctic, the following definition of Arctic SES resilience can be used in sustainability monitoring: the human capacity to obtain, share, and utilize knowledge of systems' functions and linkages, enabling communities to engage in fostering adaptive or transformative change to respond to disturbances, or to strengthen the system, or to avoid unwanted changes, or to attain a more desirable set of arrangements [46]. This definition emphasizes the role of "agency and actors" and strengthens the importance of a SES approach to resilience by focusing on the co-evolution of social and ecological SES components.

Resilience monitoring is concerned with capturing and understanding adaptive capacities of SES. On this basis, the three key elements for measuring resilience could be defined as "diversity", "knowledge/learning capacity", and "capacity for self-organization". Measuring these three elements by constructing indicators through a process of knowledge co-production enables several advancements in Arctic sustainability science and practice, namely: (a) strengthening the understanding and monitoring change in the Arctic; (b) facilitating transformation by improving public awareness and building shared understandings among stake- and knowledge-holders about challenges and possible solutions; and (c) providing decision-makers with information on complex issues and supporting strategic planning. The spatial unit of analysis for resilience monitoring is a SES, which does not easily fit into political or jurisdictional boundaries used for policymaking and policy action, thus making resilience more elusive for implementation.

In turn, the vast literature on sustainable development highlights what is often conceptualized as "pillars" of sustainability: environment, society, and economy, but presents them in an interrelated manner (e.g., [48]). It has been well established that social systems are dependent on the benefits provided by biogeophysical systems through ecosystem services. Key elements of social activity, such as economic exchange, knowledge production, and choice, are viewed as representing of different societal domains. Societies are reliant on natural resources, yet at the same time they influence nature [9]. Interrelationships among environment, society, and economy are becoming more evident through transdisciplinary activities, including sustainable development monitoring. Yet, sustainable development as a concept deals with development and is inherently policy-oriented, normative, and spatially bound to fit policy-jurisdictional boundaries (such as countries, provinces, districts, etc.). Resultantly, sustainable development monitoring, such as SDGs indicators, focuses on attaining certain objectives (e.g., improving health, well-being, and security of Arctic communities while preserving ecosystems) within predefined, largely political, boundaries [11,40].

In order to effectively monitor sustainability in the Arctic, we need to develop approaches that ensure the complementarity of these two fundamental concepts: sustainable development (including the SDGs), which arose largely from the social sciences, and ecosystem/socio-ecological system resilience, which originated in the natural sciences. Such a convergent approach articulates a new vision of harnessing science and other knowledge systems for a transition towards sustainability. It also represents an attempt to strengthen the dialogue between science and society. While sustainable development focuses on desirable outcomes through planning the implementation of the SDGs, resilience thinking is concerned with maintaining system dynamics, self-organization capacities, adaptation, and sources of resilience in SESs. Both concepts are important and necessary for integrating natural and social indicators within sustainability monitoring.

Desired integration cannot be achieved within the science alone and should be based instead on an interaction between several knowledge systems: Western science, local/traditional/Indigenous knowledge, and business/policy/public thinking [49,50]. This interaction could occur in sustainability monitoring activities, as designed by the SOO, which couples together sustainable development goals and resilience assessment in defining and observing sustainability indicators (Figure 1).

## 5. Engaging SOO for Sustainability Monitoring: Methods and Good Practices

The SOO conceptual framework has been developing since 2013 [5]. The main approaches of SOO which could be used in sustainability monitoring are described below. “Participatory approaches to community engagement” is based on the engagement of diverse individuals and groups, especially local and Indigenous knowledge holders. Going beyond observations using conventional social science approaches, these people are considered active agents who can shape changes and enable transformations. Various decision-making institutions and other relevant organizations are also actively involved [46].

A “problem and solution-oriented approach” will enable not only identifying of key issues, but, concurrently, a search for solutions by the stakeholders. Under the SOO framework, this is viewed as an open-ended process with a dynamic agenda, including constant and purposeful redefinition of key problems and solutions and redesign of indicators for long-term monitoring. Social, environmental, economic, political, and spiritual-cultural challenges and changes not easy to pinpoint or timestamp. Many exist without being foreseen by the majority of scientists. Moreover, when scientists and communities identify topics of concern, politicians and decision makers often fail take these findings into consideration soon enough or at all. That is why there is a need to use the problem and solution-focused SOO approaches, which will enable us not only to detect the main problems and driving forces impacting SES sustainability, but also to inform decision makers as soon as possible. This will help to devise knowledge-driven solutions considering available alternatives and recommendations from different social groups, experts, and stakeholders [5].

The original SOO framework has been concerned with monitoring quality of life conditions (QLC) domains—social, economic, environmental, governance, and spiritual-cultural. It is articulated that QLC must be analyzed using the concept of ecosystem and social services, broadly utilized in natural and social sciences [5]. SES sustainability monitoring instead focuses on “societal capital and capacities (SCC)” that are at the core of and closely linked to both resilience and sustainable development (Figure 1) while underpinning other QLC domains. Societal capital includes all capitals possessed by a community and its members: human, social, cultural, civic, etc., that underpin the system’s diversity, knowledge/learning capacity, and capacity for self-organization.

It should also be recognized that a SES exist under the pressure from external driving forces, such as climate change, human activity, and decisions made by actors external to SES. Multi-scale approach is important for identifying key issues and indicators for Arctic sustainability monitoring. This means that the indicators need to be carefully examined at different cross-interacting spatial levels. Scales to consider include global, circumpolar, zonal (e.g., coastal or tundra zone), ecosystem, and administrative (regional, municipal, or local communities). The “top-down” indicators developed by social and biogeophysical scientists are valuable for the Arctic sustainability monitoring, but in SOO they must be combined with the “bottom-up” indicators. The “bottom-up” component incorporates indicators developed by local people while the “top-down” system relies on scientists and government authorities.

According to the SOO experience from the Russian, Canadian, and Norwegian Arctic, methods from social and natural sciences can be integrated within the sustainability monitoring process: secondary data, scientific literature review, interviews, observations, content analysis of social media (especially local), documents, maps, images, and repeat photography [51]. Indigenous knowledge must also be engaged on the equitable basis. For understanding quality of life conditions and their impacts on societal capital and capacities, standard natural science methods can also be used, such a chemical analysis of drinking water and food sampling for pollutants. It is recommended to engage local people’s knowledge about the quality of water and food they consume with the results of performed laboratory analyses (which may differ). It is important to make local people and decision makers aware of the observations to design workable and timely solutions. The results of SOO application in the Russian North [5,46] show that abrupt changes in

SCC and QLC impacting both ecosystem and social services (including overall wellbeing, health, migration, employment, participation in decision-making, uneven distribution of incomes, environment pollution, etc.) are becoming key impediments for attaining SES sustainability.

Monitoring of existing and newly emerging problems and challenges gives new possibilities to find integrative solutions to the complex issues facing SES, and move towards improving quality of life and societal capital. The adaptive and transformative capacities and creativity of local communities play a decisive role in fostering sustainability. In this context, sustainability monitoring may help to identify and assess the process of implementing local sustainable development strategies as well as assist in devising scenarios for the future.

Scenarios approach and the use of narratives [52] can serve as one of the effective communication methods in SOO and sustainability monitoring in particular. It can assist in engaging with information initially not framed in scientific language, including the knowledge of local and regional actors, and can facilitate the translation of local knowledge into policy-relevant, problem- and solution-oriented information.

## **6. Principles for Developing Integrated, Transdisciplinary Sustainability Indicators in SOO**

Monitoring, including SOO, is dependent on selecting appropriate indicators. Given the complexity of SES, a multifaceted nature of sustainability and the need to converge resilience and sustainable development thinking, designing sustainability indicators is especially challenging [41,48]. Similar to social indicators, sustainability indicators must be measurable, indicative, easily interpreted, and attainable for collection (cost effective) [45]. The UN SDG system of indicators is one example, but it is top-down and overly quantitative, which limits its applicability to the Arctic SOO [53,54], although appropriate regional adjustments are possible [41].

In contrast, SOO builds on a number of different principles that reflect its transdisciplinary and participatory nature. SOO indicators are problem-/solution-focused, i.e., oriented to simultaneously monitor sustainability challenges and policy responses or adaptations, observe both processes and outcomes of sustainability, track trends and implementation of solutions, and help in developing scenarios. A transdisciplinary framework through the process of negotiations and co-production between multiple disciplines and knowledge systems is instrumental in completing this task. Problem-/solution-focused sustainability indicators help capture not only interactions, but the disconnect between social and ecological sub-systems. Both availability and accessibility of ecosystem and social services indicators are important to consider. For example, in assessing food security (one of the SDGs) it is important to incorporate not only indicators of food availability, but also to food accessibility that depends mostly on the performance of socio-economic services, such as infrastructure and market development, as well as technologies to adapt to ecological and social crises.

As mentioned, societal capital and capacities (SCC) development is a top concern for sustainability monitoring in the Arctic. In the Anthropocene, human capacities to manage SES sustainability are becoming critically important, especially in the Arctic [55]. Sustainability depends upon individual human capacities (e.g., fate control, education, creativity, mental and physical health, material well-being, etc.), as well as on community capacities, including social capital, well-being, social connectedness, and organization. Social connectedness can be defined as the strength, extension, and quality of community networks. Social capital and well-being are determined by collective social and natural environment, where human needs are met, where individuals and groups can act meaningfully to pursue their (sustainability) goals, and where they are satisfied with their way of life and well-being [56].

In terms of social organization, equity constitutes an important theme [57]. It could be assessed using diversity indicators, such as community members engaged in governance, the autonomy in relation to land and resource management, and gender equity in decision-

making. Other types of indicators assess whether decision-making and planning processes involve diverse perspectives and cultural polycentrism, the extent to which governance systems are culturally appropriate and the effectiveness of laws governing natural resources management. Social participation and leadership could also appear in sustainability indicators frameworks, notably through social self-organization. Examples of operational indicators showing performance of social participation may include the share of community members who actively manage their natural resources, the number of active community organizations, and the percentage of community members who are members of multiple community organizations.

Indicators tracking education and social learning are also very important for monitoring Arctic sustainability. They were broadly discussed by the Arctic Social Indicators project [58]. Such indicators can be either qualitative or quantitative. Examples of operational quantitative indicators focus either on educational attendance or attainment, and may include secondary school completion, prevalence of post-secondary training, and attainment of advanced degrees [59]. However, many such indicators are unable to relay sufficient information about the transmission of traditional and local knowledge in a community. That is why participatory activities involving Indigenous and local perspectives and knowledge are needed.

Knowledge transmission and experiential learning constitute another important element in sustainability indicators frameworks, especially indicators of traditional learning. Such indicators could encompass access to and exchange of knowledge on biodiversity and its management, ways of transmitting traditional knowledge from the elders, parents, and peers to young people in a community, engagement in traditional land- and sea-based activities, exchange of local and Indigenous knowledge about landscapes, use of the local vocabulary or Indigenous language, and knowledge about traditional food and its use.

Diverse communities and social groups (age, gender, ethnic, professional, etc.), government and non-government organizations may have distinct views and diverging options with respect to Arctic SES sustainability. The polycentrism is linked to the heterogeneity and multi-functionality of SESs. SES sustainability deals with ecological, socio-cultural and economic diversities as they are intrinsically interconnected. As a cross-cutting indicator system, sustainability monitoring can take aim at assessing the diversity of quality of livelihood options that offer the best opportunity for local community's adaptation to disturbances, whether natural or social.

In order to monitor biocultural, sociocultural, and economic diversities, we propose focusing on several key groups of indicators. These include indicators measuring the accessibility of market and non-market (subsistence) food, water, and energy sources, and indicators characterizing a mixed economy, in particular the mix of household cash income and non-market (subsistence) activities (these are difficult to capture because of the lack of readily available data, therefore the percentage of households engaged in two or more income generating activities, and the diversity of employing industries are possible proxy indicators). Another group incorporates indicators of diversity of the ecosystem and social services, and the geographical heterogeneity of land use and of the local community's landscape management. These indicators could show whether land management practices maintain a heterogeneous landscape composed of different land use types, from home gardens, pastures, and cultivated fields to urban landscapes and protected areas. The third group is indicators of knowledge systems' polycentricity that provide a variety of options to navigate the change in building sustainable SESs by capitalizing on the diversity of cultures, languages, and knowledge systems.

Bringing all indicator groups together, the process of developing specific, regional, and community-based integrated sustainability indicators should be based upon co-production between all rights-, stake-, and knowledge-holders, scientists, and decision makers. Such co-production will enhance the transdisciplinary and decolonial nature of the indicators development process and catalyze societal learning to facilitate a pro-active adaptation to the change in a number of ways: first, by broadening the problem definition

and ensuing co-production by engaging multiple disciplinary perspectives and knowledge systems; secondly by using scenarios construction through the participatory methods to explore alternative policy options including adaptation to climate and biodiversity changes; thirdly, by developing inclusive information flows and mapping tools that foster trust among stakeholders and build broad support for action; and finally, by testing the developed understandings of changes and adaptation alternatives through comparative analysis, experimentation, and adaptive management.

Building trust between decision makers, scientists, knowledge-holders, and stakeholders through negotiations will also assist in instituting effective governance mechanisms to implement potential solutions, create opportunities for leadership and respect, and promote social networking that will enable bridging communication and accountability gaps. This will also provide an overlap in responsibility among organizations to allow the redundancy in policy implementation [9,10].

Finally, the sustainability indicators should interconnect different scales (from global to local and vice-versa). The need for revealing cross-scale linkages is particularly important in the Arctic, given that most of the Arctic is dominated by larger nation-states whose government centers are located in the south. Yet, communities are exposed to and affected by global processes, whether biogeophysical or social in nature [60]. The actions taken at the regional, national, or global scales can directly affect the resilience of Arctic communities, ecosystems, and the entire SESs sustainability [60].

Moreover, the role of climate, food, and energy policies around the world in shaping the Arctic's future is considerable. Connecting the Arctic and non-Arctic regions through informal and formal networks, can establish new information flows that increase sustainability in the Arctic and globally [60]. Thus, the indicators of external connectedness, for example, the number of individuals within the community who represent the community and manage relationships with external organizations, or the percent of community members who have access to external media sources, can be valuable in showing the interconnections between different scales.

## **7. Conclusions: Towards Arctic Sustainability Monitoring and the Arctic Sustainability Monitoring Network**

Diverse transdisciplinary practices of sustainability knowledge co-production, including monitoring, in the Arctic are emerging, but urgently need to be developed further [4,54]. These practices must be based on an equitable engagement of Western science on one hand and rich knowledge, traditions, activities (actions), and problem-solving approaches of the local communities and Indigenous peoples, on the other. For this purpose, co-production creates and maintains a "space for societal learning" [61]. In general, sustainability knowledge co-production can be understood as a collaborative, creative activity of societally relevant knowledge production, transformative action, and new social relations building through a participatory and equitable process. In addition, a "successful transdisciplinary approach must create a space where science and policy can meet and interact in equal terms" [62] p.11.

In the Arctic the holistic thinking and ways of knowing of Indigenous and local communities, as well as intergenerational transmission of their knowledge, culture, and skills are the main sources of community resilience and SES sustainability in many remote settlements. Western science, which is highly discipline-based, is sometimes incapable of grasping SES as a whole or identifying complex drivers and consequences of change and predicting them. That is why it is important to bring together Indigenous, traditional, and local knowledge and Western science in order to collectively pursue sustainability, in a holistic, polycentric, multifaceted, participatory, and knowledge-driven manner. One of the ways to attain this goal, as discussed in the paper, is by linking sustainable development and resilience thinking to form an integrated conceptual foundation for the monitoring system that embraces diverse understandings of sustainability. In doing so, the framework proposed here appears to be positioned to become one of the possible solutions for the lack of simultaneous engagement of Indigenous and local knowledge, rights- and stakeholders,

science experts from various disciplines, and policy makers in sustainability monitoring, because it focuses on SES (i.e., coupled natural-human systems) and is relevant to scientists, communities, and policy makers alike.

This goal necessitates systematic indicator design, when diverse knowledge flows support the selection and continuous monitoring of key sustainability indicators. Such indicators should be both qualitative and quantitative. This is especially important in the Arctic, where quantitative social data are often not readily available [51]. In addition, the indicators should be easy to understand and use by all stakeholders and provide a common language unambiguously interpretable by decision makers.

One possible way forward to implementing these approaches is to develop the Arctic Sustainability Monitoring Network (ASMON). It will embrace principles outlined in this paper and capitalize on the experiences of the SOO, Arctic Social Indicators, and other initiatives, such as the Circumpolar Biodiversity Monitoring Program and Arctic Resilience Report, with the aim to design a transdisciplinary monitoring system for building Arctic sustainability. ASMON could be developed and implemented under the auspice of the international organizations, such the Arctic Council, in close collaboration with Indigenous communities and science coordinating bodies (e.g., International Arctic Science Committee (IASC) and International Arctic Social Sciences Association (IASSA)), and become a part of the Sustaining Arctic Observing Networks (SAON) and other monitoring and knowledge engagement initiatives deployed in the Arctic now and in the future.

One opportunity is to connect ASMON with the SAON's Roadmap for Arctic Observing and Data Systems. The Arctic Observing Summit 2020 (AOS, 2020) prioritized identifying essential and shared Arctic variables by working with diverse knowledge holders, information user groups, stakeholders, and applications, a task that is well-aligned with establishing the ASMON. Another important idea that may propel sustainability observations in various Arctic regions could come from the IASC and IASSA in a form of an "H-MOSAIC" (i.e., Human MOSAIC) initiative that will entail an extended period of coordinated observations of human systems using compatible, co-productive methodologies, where approaches disused in the paper could play a key role. This work may also lay the foundation for planning integrated, sustainability-oriented activities for the possible large-scale knowledge production programs in the Arctic, such as the next International Polar Year. Furthermore, the Arctic, where sustainable development is complicated by rapid climate change and dramatic socioeconomic transformations, could be a good testbed for developing and implementing sustainability monitoring that could be later transferred to other regions of the world.

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