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Strategic environmental assessment and monitoring: Arctic key gaps and bridging pathways

Juan Azcárate¹, Berit Balfors¹, Arvid Bring^{2,3} and Georgia Destouni^{2,3}

¹ Department of Sustainable Development, Environmental Science and Engineering, KTH Royal Institute of Technology, Teknikringen 76, SE-100 44 Stockholm, Sweden

² Department of Physical Geography and Quaternary Geology, Stockholm University, SE-106 91 Stockholm, Sweden

³ Bert Bolin Centre for Climate Research, Stockholm University, SE-106 91 Stockholm, Sweden

E-mail: azcarate@kth.se

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Abstract

The Arctic region undergoes rapid and unprecedented environmental change. Environmental assessment and monitoring is needed to understand and decide how to mitigate and/or adapt to the changes and their impacts on society and ecosystems. This letter analyzes the application of strategic environmental assessment (SEA) and the monitoring, based on environmental observations, that should be part of SEA, elucidates main gaps in both, and proposes an overarching SEA framework to systematically link and improve both with focus on the rapidly changing Arctic region. Shortcomings in the monitoring of environmental change are concretized by examples of main gaps in the observations of Arctic hydroclimatic changes. For relevant identification and efficient reduction of such gaps and remaining uncertainties under typical conditions of limited monitoring resources, the proposed overarching framework for SEA application includes components for explicit gap/uncertainty handling and monitoring, systematically integrated within all steps of the SEA process. The framework further links to adaptive governance, which should explicitly consider key knowledge and information gaps that are identified through and must be handled in the SEA process, and accordingly (re)formulate and promote necessary new or modified monitoring objectives for bridging these gaps.

Keywords: Arctic, strategic environmental assessment, hydroclimatic change, climate change, environmental change, environmental observation, monitoring, adaptive governance, adaptation, monitoring gaps, uncertainty

1. Introduction

Systems for environmental assessment and environmental monitoring are needed to understand the large ongoing

and future environmental changes in the Arctic, their impacts on society and ecosystems, and to decide on appropriate change mitigation and adaptation strategies and measures (UNEP 2007, Koivurova 2008, Casper 2009). With regard to policy and practice of environmental assessment, all Arctic states have in principle established national environmental assessment systems, and some have also signed international treaties on transboundary environmental assessment. Koivurova (2008), however,



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argues that the environmental assessment implementation varies considerably among Arctic states, is insufficiently applied across the region, and poorly considers specific Arctic characteristics.

With environmental *monitoring*, we refer to the ability to detect, understand and evaluate changes in the physical environment, within the framework of environmental assessment. Such monitoring in turn fundamentally relies on actual *observations* of the environment. Monitoring is explicitly recognized as a critical component of strategic environmental assessment (SEA) in relevant scientific literature (Thérivel and Partidário 1996, Partidário and Fischer 2004, Persson and Nilsson 2007) as well as in concrete SEA conceptualization and implementation, such as the European Union (EU) SEA Directive on the assessment of the effects of certain plans and programmes on the environment (OJEC 2001). SEA differs from environmental impact assessment (EIA) in that EIA regards individual projects (Wood 2003) while SEA regards higher-level development initiatives, i.e., overarching policies, plans and programmes (João 2005). Environmental monitoring has further been a fundamental component of SEA since its initial development stages (Lee and Walsh 1992, Thérivel and Partidário 1996), explicitly recognized as a good SEA practice principle (IAIA 2002) and an essential SEA tool for accountability and learning (Persson and Nilsson 2007). Legal provisions established in the EU SEA directive (OJEC 2001) and in several countries (Partidário and Fischer 2004) also formally require environmental monitoring within SEA. However, despite legal requirements and overall recognition of the importance of environmental monitoring in SEA, reporting or communication of SEA monitoring results are found to be absent in practice (Gacheciladze *et al* 2009, Lundberg *et al* 2010).

With regard to environmental changes that should be monitored as a main component of SEA application, water-related changes are essential for water and food security (Oki and Kanae 2006), environmental flows (Tharme 2003), and because water is a key integrating and change propagating-regulating factor for various other environmental changes. For example, water flow changes relate closely to changes in climate and in human land-use and water-use (Jarsjö *et al* 2012, Destouni *et al* 2013). Furthermore, water quality changes follow from activities in different human sectors, such as: agriculture (Basu *et al* 2010); mining (Banks *et al* 1997), waste disposal (Rosqvist and Destouni 2000); and several combined industrial and household activities (Baresel and Destouni 2005) along with climate change (Darracq *et al* 2005). Both water flow and water quality changes can in turn also affect climate change (Destouni and Darracq 2009, Destouni *et al* 2010a) and ecosystems (Poff *et al* 1997, Poff and Zimmerman 2010). These examples also highlight that observation systems must be in place in order for environmental monitoring to be feasible.

Such water and water-related changes, in the following referred to as hydroclimatic changes, are not least important in the rapidly changing Arctic region, where they are among the most recognized Arctic indications of environmental change.

They include, for instance, increasing river flows (Peterson *et al* 2002, 2006, McClelland *et al* 2006, Shiklomanov and Lammers 2009, Overeem and Syvitski 2010) and increased (Smith *et al* 2007) or changed seasonality (Frampton *et al* 2011, 2013) of the groundwater contribution to those flows, in addition to increased mass loss from glaciers (Kaser *et al* 2006, Gardner *et al* 2011), permafrost degradation (Hinzman *et al* 2005, Lyon and Destouni 2010, White *et al* 2007, Brutsaert and Hiyama 2012), shorter extent of snow cover season (Brown *et al* 2010, Callaghan *et al* 2011) and water-related ecosystem shifts in the Arctic landscape (Smol *et al* 2005, Karlsson *et al* 2011). Various water changes have also been identified as key indicators for Arctic food and water security (Nilsson and Evengård 2013, Nilsson *et al* 2013). However, with regard to the observation systems that are needed to monitor such important hydroclimatic changes in the Arctic, research shows decline and key deficiencies (Lammers *et al* 2001, Shiklomanov *et al* 2002). Particular gaps are for example found for observations of hydrochemistry in Arctic rivers (Bring and Destouni 2009), and for Arctic areas where ecological regime shifts have already occurred (Karlsson *et al* 2011) and future climate change is expected to be most severe (Bring and Destouni 2011, 2013).

With regard to the rapidly changing Arctic system, there are thus gaps in both the implementation of SEA (Koivurova 2008) and the observation systems required for the environmental change monitoring that should be part of that implementation. Furthermore, the literature proposes different approaches to required SEA monitoring (Partidário and Fischer 2004). As a starting step to address the inherent complexity in strategic decision-making and to systematically monitor its effects, Partidário and Arts (2005) articulate key monitoring concepts in a multi-track approach to SEA monitoring. Cherp *et al* (2011) build on this approach and integrate key elements of SEA ex post evaluation and management of strategic initiatives. Additionally, Persson and Nilsson (2007) suggest principles for SEA monitoring, emphasizing, among other issues, the importance of deciding if and when to link SEA monitoring with observation systems. Nilsson *et al* (2009) further introduce an analytical tool kit for SEA monitoring, proposed to serve as a systematic stand-alone monitoring framework. Moreover, Lundberg *et al* (2010) suggest how SEA monitoring processes can be linked to SEA processes for regional transport infrastructure plans, while Wallgren *et al* (2011) proposes how SEA monitoring can link to planning and programming processes, and Gacheciladze-Bozhesku (2012) explores the integration of stakeholder participation in SEA monitoring.

However, despite growing research on and application of strategic approaches to SEA (Azcárate and Balfors 2009, Partidário and Coutinho 2011, Teigão dos Santos and Partidário 2011, Azcárate and Balfors 2013, Partidário and Gomes 2013), project-based EIA-type of approaches still dominate SEA practice, with conspicuously missing strategic frameworks for the uncertainty monitoring that is needed to manage unexpected effects, address situations of uncertainty, and link to adaptive management (Partidário and

Fischer 2004, Partidário 2009). This letter focuses on such strategic gaps in SEA application for the rapidly changing, transboundary Arctic region, with particular regard to actual environmental observation systems in the region and their links to strategic uncertainty monitoring in regional SEA application. Based on a concrete gap analysis for the Arctic, the letter proposes an overarching framework for systematic consideration of available environmental observations and remaining key uncertainties in regional SEA application and monitoring. The framework departs from the EU SEA Directive as a model basis for introducing necessary strategic connections between SEA uncertainty monitoring and environmental observations, with the aim to improve both the regional SEA application and the environmental observation systems across the Arctic.

In the following, section 2 extends first the above general background and gap analysis for SEA and environmental monitoring (2.1), and continues with the corresponding specific background and gap analysis for the Arctic region (2.2). Section 3 outlines and discusses the proposed overarching framework for systematically linking and improving SEA application and environmental monitoring in the Arctic, and section 4 summarizes main conclusions from the study.

2. SEA and environmental monitoring

2.1. General background and gap analysis

Initial SEA development took place in the USA under the 1969 National Environmental Protection Act (NEPA) for strategic initiative assessment beyond the project-focused EIA (Glasson *et al* 2003). Since NEPA, SEA has been regulated in the legal systems of many countries (Fischer 2007), different approaches to SEA have been developed (Verheem and Tonk 2000), and SEA application has increased worldwide due to its promotion by international organizations such as the World Bank, Regional Development Banks, the United Nations and the European Union (Dalal-Clayton and Sadler 2005).

In Europe, discussions on the need of regulating environmental assessments of strategic initiatives started as early as 1975 (Thérivel 2004), with the EU SEA Directive (OJEC 2001) being a main current result of the further development after these early discussions. The SEA Directive is a procedural provision aiming to harmonize SEA processes in member countries. In particular, the monitoring requirements in the EU SEA Directive differ from those in the EU EIA Directive (OJEC 1985) where monitoring is not mandatory. However, even the SEA monitoring requirements are considered to be vague and minimum-level requirements (Partidário and Fischer 2004) that fail to provide concrete guidance on how to organize monitoring, carry out scoping for monitoring, and establish causality relations to monitored environmental impacts (Persson and Nilsson 2007, Hanusch and Glasson 2008). Perhaps as a consequence of vagueness and concretization failure, despite the explicit recognition and acceptance of the importance of monitoring in SEA, there is

limited literature on the subject and a general lack of practical application experiences (Partidário and Arts 2005).

Empirical evidence of SEA monitoring application, for instance in England, Germany and Canada, shows that the identification and evaluation of unforeseen, emerging and external issues have not been a focal point in SEA monitoring (Hanusch and Glasson 2008, Gacheciladze *et al* 2009). Moreover, in their studies of different regional planning schemes in Sweden, both Lundberg *et al* (2010) and Wallgren *et al* (2011) found that monitoring was limited to controlling if measures set out in strategic initiatives were implemented, completely overlooking the observations of the actual measured impacts on the physical environment. Overall, a lack of methodological application and formalized routines for monitoring and evaluating the effects of strategic initiatives has been found in the studies of concrete SEA monitoring applications (Gacheciladze *et al* 2009, Lundberg *et al* 2010, Wallgren *et al* 2011).

An additional issue that has been poorly considered in both SEA theory and practice is that of whether and how to link SEA monitoring with existing observation systems (Gacheciladze-Bozhesku and Fischer 2012). Linking SEA monitoring with existing observation systems is for instance recommended in the EU SEA Directive, stating that: '*existing monitoring systems may be used if appropriate, with a view to avoiding duplication of monitoring*' (OJEC 2001). As information availability is fundamental, and collecting such information and data requires considerable amounts of time, effort and investment, SEA monitoring should clearly make best possible use of already existing observation systems (Partidário and Fischer 2004). This means that there is a separation of responsibilities, with existing observation systems often operated and funded by long-term government programmes and agencies, whereas the direct interpretation of these observations and monitoring changes related to specific plans, programmes or policies rests with the institutional body that coordinates the corresponding SEA process. However, guidance on how these systems can and should be effectively connected to SEA monitoring is lacking, and various limitations and challenges exist in practice.

For instance, the available environmental observation system in Sweden is only weakly linked to the monitoring of strategic initiative effects due to analytical, organizational and institutional barriers (Wallgren *et al* 2011). In England and Germany, where SEA monitoring is based on existing environmental observation systems, it has further been found that available observation systems do not cover the information needs of SEA monitoring and that there are problems with data collection frequencies, scales and compatibilities (Hanusch and Glasson 2008). Also in Canada, similar challenges of linking SEA monitoring with existing environmental observations were found, for instance, in the forest sector due to inconsistencies between existing industry and government observing systems (Gacheciladze *et al* 2009).

2.2. Arctic background and gap analysis

All Arctic states, that is to say Finland, Sweden, Norway, Denmark (including Greenland and the Faroe Islands),

Iceland, Canada, the United States of America, and the Russian Federation, have adopted EIA and SEA provisions in their national legal systems (Koivurova 2008). As EU member states, Sweden and Finland have also adopted the environmental assessment requirements of the EU SEA Directive (OJEC 2001); Norway and Iceland have done the same even though they remain outside the EU. Greenland (Denmark) adopted its own environmental assessment regulations, Canada established SEA provisions through Cabinet Decisions, USA regulated SEA in its 1969 NEPA, and the Russian Federation established SEA-like provisions under its SER/OVO system (Wood 2003, Dalal-Clayton and Sadler 2005, Koivurova 2008).

In theory, by having adopted regulations for SEA in their national legal systems, Arctic states are obligated to carry out environmental assessments for overarching policies, plans and programmes that could potentially harm their Arctic environments. However, the established SEA legal systems vary among Arctic countries, as does also concrete SEA application (Koivurova 2008).

Through the Espoo Convention, the Arctic states agreed already in 1991 to carry out EIA on planned development projects taking place in transboundary contexts (UNECE 1991). Furthermore, as stated in Article 2.7 of the Convention, SEA should be carried out for policies, plans and programmes in transboundary contexts. However, the use of SEA for such strategic actions above the individual project level was here expressed as discretionary. Even though a specific protocol on SEA has thereafter been added to the Espoo Convention, and signed by the Arctic states of Norway, Finland, Sweden and Denmark (UNECE 2003, Koivurova 2008), the implementation of SEA in the Arctic has been limited by the discretion left to states to decide what are significant impacts (Hildén and Furman 2001, Bastmeijer and Koivurova 2008). In addition, SEA application limitations are due to differences in national environmental assessment systems (Hildén and Furman 2001, Koivurova 2005), needs for extensive collaboration between countries (Tesli and Husby 1999), and lack of institutional capacities (Kersten 2009).

With regard to environmental monitoring, it is an essential part of SEA for revealing, quantifying and following up the actual reality of historic, through ongoing, to future environmental variability and change, and the effectiveness of introduced policies, plans and programmes that aim specifically at controlling, mitigating or adapting to such variability and change. To achieve all this, SEA monitoring must rely on already available environmental observation systems, as discussed above in the general section, even though these systems may be broader and serve also other information goals than just SEA requirements. Thereby, SEA monitoring in the Arctic is faced with similar challenges and uncertainties as the currently operated environmental observation systems in the Arctic.

With regard to observations of environmental changes in the Arctic, hydroclimatic changes should be central, including hydrological, hydrochemical, water-related ecological, and water management changes, in addition to large-scale climate

change. All of these different aspects of hydroclimatic change are linked, for instance because both climate change and water management practices directly affect water flow changes, which in turn propagate the change effects to and partition them among different water subsystems (soil moisture, groundwater, stream networks, lakes, wetlands and snow–ice subsystems) and associated water fluxes in the landscape (Bosson *et al* 2012, Karlsson *et al* 2012). Moreover, water is a main carrier of different constituents (dissolved tracers and other chemicals, sediments, colloids), and the spatiotemporal concentration and mass-flux variability of these depend on the fluxes and partitioning of water (Cvetkovic *et al* 2012), in addition to the distribution of waterborne source inputs (Destouni *et al* 2010b) through the landscape. Changes to water in the landscape, and in the fluxes and concentrations of its constituents in turn affect Arctic ecosystems (Karlsson *et al* 2011), the Arctic Ocean (Cauwet and Sidorov 1996, Amon and Meon 2004, Dyurgerov *et al* 2010), and Arctic food and water security (Nilsson and Evengård 2013, Nilsson *et al* 2013).

In spite of such key roles for water in the landscape in multiple environmental changes, its observation in the Arctic has large gaps (Lammers *et al* 2001, Shiklomanov *et al* 2002, Hinzman *et al* 2005, Walsh *et al* 2005, Arctic-HYDRA consortium 2010), particularly regarding water chemistry (Bring and Destouni 2009) and hydrologically mediated ecological regime shifts (Karlsson *et al* 2011). Arctic hydrological observations have also declined the most, and is most deficient, in areas where future climate changes are expected to be the most severe (Bring and Destouni 2011, 2013). International assessments of the status of transboundary water management, latest in the Second Assessment of Transboundary Rivers, Lakes and Groundwaters (UNECE 2011), have further pointed out a lack of relevant water and water quality observations in Eastern Europe and Central Asia, which are parts of the pan-Arctic drainage basin. Furthermore, a global survey of UN-related international initiatives and programmes for water observations (FAO 2006), identified key problems of data quality, irregular data updates, limited data accessibility and data fragmentation, several of which also apply to the Arctic. With particular regard to Arctic food and water security, an international assessment has also recently called for urgent initiation of observations that underlie several, currently unmonitored, freshwater quantity and quality indicators in the Arctic (Nilsson and Evengård 2013, Nilsson *et al* 2013).

3. Linking and improving Arctic SEA application and environmental monitoring

We have in the above section identified and exemplified main gaps and limitations, which imply major improvement needs and challenges for both SEA application and relevant observations and monitoring of environmental change in the Arctic. Increased interest in the Arctic region is beginning to partly address these challenges. A main focal point for efforts to coordinate monitoring and assessment activities is then the Arctic Monitoring and Assessment Programme (AMAP),

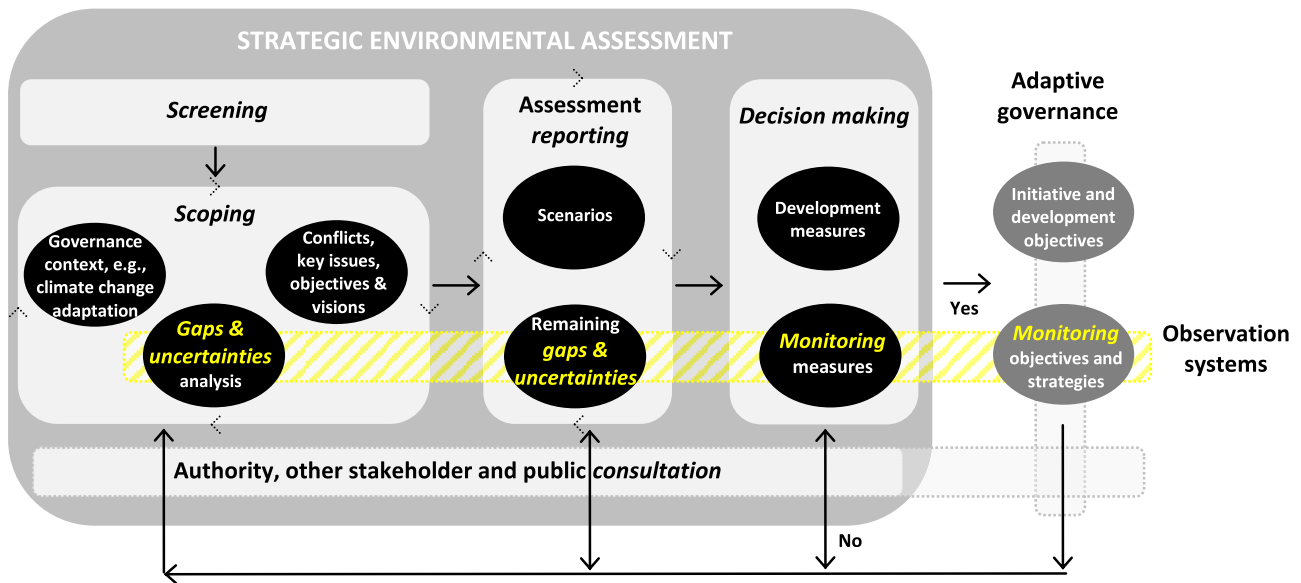


Figure 1. SEA adaptive governance framework for gap/uncertainty handling and environmental monitoring linked to observation systems.

established in 1991 and now a programme committee under the Arctic Council. AMAP was originally established to implement the Arctic Environmental Protection Strategy (AEPS), but has now a broader scope and is an umbrella for a range of programmes and assessments related to Arctic observations and monitoring. Recent examples of AMAP assessments include the snow, water, ice and permafrost in the Arctic (SWIPA) report (AMAP 2011a), and the assessment of mercury in the Arctic (AMAP 2011b). Under the umbrella of the Arctic Council and the International Arctic Science Committee (IASC), an effort at securing commitment to maintain the capacity of Arctic observation networks (the SAON process) has also recently been initiated. More generally within the UN framework, the Federated Water Monitoring System (FWMS) has been initiated to alleviate the particular problem of water data fragmentation (FAO 2006), which is also relevant for the Arctic.

However, even with such coordination initiatives in place, limited funding in combination with competing information goals still imply a critical need for prioritization and optimization of current and future observation systems in the Arctic. For example, regarding the key hydroclimatic change observations in the Arctic, Bring and Destouni (2013) have shown that global climate model (GCM) projections differ both from each other and from change observations in their indications of how (e.g., in which direction precipitation is/will be changing) and which Arctic areas will be most severely affected by climate change under current conditions and various future change scenarios. These differences imply that different observation improvement or optimization strategies are needed to meet competing information goals regarding Arctic hydroclimatic change. A rational strategy to improve observation systems based on the spatiotemporal severity distribution of hydroclimatic change is thereby currently not possible just by reconciliation of change observations and GCM projections. Instead, explicit decisions

are needed for which information goals should be prioritized for first fulfilment with limited observation system resources, along with a transparent basis for such decision-making.

We here propose that such a transparent and participatory decision-making basis can and should be developed as integral part of the SEA process, which has potential to link and improve both SEA application and environmental monitoring in the Arctic. We depart then from the EU SEA Directive as a starting model for achieving such connection. With regard to environmental monitoring, Article 10 of the SEA Directive states that ‘*Member states shall monitor the significant environmental effects of the implementation of plans and programmes, inter alia, to identify at an early stage unforeseen effects, and to be able to undertake appropriate remedial action*’ (OJEC 2001). SEA should further include the following main steps: *screening*, *scoping*, *reporting*, *consulting* and *decision-making*, in addition to *monitoring* (Wood 2003, Thérivel 2004).

The aim of the *screening* step is to determine the need to carry out an SEA for a strategic initiative, i.e. for an overarching national or international policy, plan or programme. *Scoping* deals with establishing the issues and the level of detail that should be addressed in the SEA for such a strategic initiative; the scope and level of detail of the SEA must be consulted with relevant authorities, as one *consulting* step. *Reporting* produces a written environmental assessment report that must also be reviewed in a *consulting* step by relevant authorities and the public. Additionally, the comments made by the consulted authorities and public should be included in the environmental assessment report with an account given as to how these comments influenced the *decision-making* on the assessed strategic initiative. Figure 1 illustrates the SEA process flow and the place of the different steps within it.

The *monitoring* requirement of the SEA Directive should further address the significant environmental impacts and

results expected from the assessed strategic initiative. If monitoring is then understood and introduced only as a last independent step, after decisions have been made, its function in SEA may be limited to only following up whether decisions are formally implemented (Lundberg *et al* 2010, Wallgren *et al* 2011). With regard to the actual environmental change that is affected by the assessed initiative, however, the example of hydroclimatic change observations shows that they are deficient, with the major gaps in and remaining uncertainties from such deficient observations limiting our ability to monitor actual environmental changes with some sufficient degree of accuracy and certainty. Such deficiencies apply to ongoing environmental changes, and even more so to the change development from past to present or from present to future environmental conditions, and to the environmental change effects of strategic national or international initiatives that require SEA application. Furthermore, because we cannot observe and have not observed everything everywhere and at every point in time, the interpretations and implications of data from even improved environmental observations will always be subject to some uncertainty and inaccuracy. To systematically consider, account for, and handle our knowledge gaps and uncertainties regarding actual environmental changes through the whole SEA process, uncertainty handling and monitoring components should be integral and interactive parts of all (other) steps in SEA application.

Figure 1 illustrates the overarching framework that we propose for explicit gap–uncertainty handling and monitoring parts (emphasized with italic and yellow text) within all the different steps of the SEA process. The gap–uncertainty handling and monitoring parts include explicit gap and uncertainty analysis in the *screening* and *scoping* steps of SEA, gap and uncertainty reporting in its *reporting* step, and gap and uncertainty communication and discussion in its *consultation* step, identifying through the latter also possible key stakeholder conflicts that result from such remaining gaps and uncertainties, which hinder decision agreements and could be resolved by improved availability to observational data and associated uncertainty reduction. They further include explicit monitoring decisions in the SEA *decision-making* step, about whether and which observation system addition or improvement measures are needed for potential approval of the assessed strategic initiative after bridging or reducing remaining critical knowledge gaps and uncertainties in a new SEA cycle (the ‘No’ pathway in figure 1). Moreover, explicit monitoring decisions should also be part of an adaptive governance process (figure 1, right). This should guide and inform the SEA process about main development and environmental objectives of the assessed strategic initiative, and main objectives and strategies of relevance for monitoring prioritization decisions within SEA. It should further also itself be guided by the SEA result (‘Yes’ or ‘No’ pathway in figure 1) with regard to new or modified monitoring objectives/prioritizations needed for reaching the environmental objectives of assessed strategic initiatives with sufficient accuracy and certainty. The yellow beam in figure 1 particularly illustrates the fundamental role of monitoring and

gap/uncertainty analysis, which must link to actual available observations of the concerned environment, across all main steps of the SEA process.

As an example, with regard to the previously identified gaps and uncertainties relating to hydroclimatic changes in the Arctic, consider a policy of changed forestry practices in a larger transboundary Arctic region. Already for the *scoping* step to be fulfilled in a satisfactory manner, a gap and uncertainty analysis is required to indicate possible critical needs for hydrological–hydrochemical observation improvements, to both project and follow up the effects of the new forestry policy on water quantity, quality and interactions with climate change in the region. Limited observations, and their influence on the ability to project and follow up such policy effects, should further be explicitly presented in the *consultation* and *reporting* steps, and considered in the *decision-making* step. In the latter, decisions must be made on whether the environmental observation systems will be improved to reduce key knowledge gaps and uncertainties. At any rate, decision makers must consider remaining gaps and uncertainties, even after possible observation improvement measures, as observation limitations may leave open a wider range of opportunities and risks associated with different policy options than those apparent from only some assumed scenario projection without explicit uncertainty consideration. Furthermore, after implementation of the assessed policy/plan/programme, environmental observation systems are key monitoring components for following up the resulting environmental change effects; especially observation of actual environmental changes that differ from those expected in the performed SEA provide then a basis for policy/plan/programme modification by *adaptive governance*.

We believe that the explicit gap and uncertainty handling in the proposed framework would improve SEA application by explicitly showing concrete observation limitations that are not necessarily related to institutional incapacity, political reluctance, or similar obstacles to successful SEA implementation. The shortcomings related to environmental observation limitations call for action to increase the capacity to observe the physical environment and systematically monitor its ongoing changes to reduce key knowledge gaps and uncertainties, with multiple benefits to be gained from this also for other sectors of public management. Examples of the latter may include mitigation of health risks relating to environmental conditions, and improved reliability of environmental projections for spatial planning, among other issues.

4. Conclusions

This letter has analyzed and elucidated critical shortcomings in the application of SEA, and particularly the environmental change and related uncertainty monitoring that should be part of this application, with focus on the rapidly changing transboundary Arctic region. Shortcomings in environmental monitoring have here been concretized by examples of main gaps in the monitoring of Arctic hydroclimatic changes reported in the scientific literature. For relevant

identification and efficient reduction of such gaps, and of remaining uncertainties under typical conditions of limited resources for observation systems and monitoring, we have proposed explicit gap/uncertainty handling and monitoring components, systematically integrated within all steps of the SEA process.

The fate and possible success of various coordination initiatives for environmental monitoring in the Arctic (such as AMAP and SAON specifically for the Arctic, and the general FWMS with Arctic relevance) may ultimately depend on the success of implementing such an overarching SEA framework that systematically links and consistently pursues clear goals of both environmental assessment and environmental change observations and monitoring. As suggested here (figure 1, right), such a framework also links to adaptive governance. This should explicitly consider key knowledge and information gaps that are identified through and must be handled in the SEA process, and accordingly (re)formulate and promote necessary new or modified observation objectives for bridging these gaps. The linked SEA and adaptive governance framework, which has here been proposed with an Arctic focus, is also relevant and should be useful for improved SEA and monitoring in other parts of the world.

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