ARCTIC
VOL. 77, NO. 4 (DECEMBER 2024) P. 346–359
https://doi.org/10.14430/arctic81476

The Potential of DPSIR Framework to Develop a Holistic Picture of Arctic Industries and Livelihood—A Scoping Review

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(*Received 5 January 2024; accepted in revised form 27 September 2024*)

ABSTRACT: The Arctic and its resources are becoming a hotspot of increasing political, environmental, and social conflict. The Driver-Pressure-State-Impact-Response (DPSIR) framework can be a useful tool when trying to disentangle the complex issues affecting the region and organize their fundamental components along a causal chain, thus promoting a much-needed integration between social and environmental sciences on one hand and science and policy making on the other (especially when a participatory approach is pursued). The aim of this article is to facilitate and improve future applications of the DPSIR framework in the Arctic context. This is pursued through a comprehensive literature review of the use of the DPSIR framework in the Arctic, with a focus on five of the most important economic sectors in the Arctic economy: aquaculture and fisheries, mining, forestry, tourism, and Indigenous livelihoods. In order to promote the most accurate and balanced approach to the DPSIR framework, its main criticisms and variants are also discussed. The article provides a summary of indicators used in Arctic case studies and focuses on the relevance of the framework as a tool for both local stakeholder involvement and participative policy-making processes. It also provides a general model for application of the DPSIR framework in the Arctic context and, when Arctic examples are not available, a summary of relevant examples outside the Arctic area.

Keywords: stakeholder involvement; interdisciplinarity; indicators; socio-environmental sustainability; fisheries; mining; forestry; tourism; Indigenous livelihoods

RÉSUMÉ. L'Arctique et ses ressources deviennent progressivement un enjeu clé dans les conflits politiques, écologiques et sociaux qui se multiplient. Le cadre Forces motrices-Pressions-États-Impacts-Réponses (Driver-Pressure-State-Impact-Response en anglais, abrégé en DPSIR) peut s'avérer un outil utile pour comprendre les enjeux complexes d'une région et pour organiser ses composantes fondamentales sous la forme de chaîne causale. Cela favorise une intégration essentielle entre les sciences sociales et environnementales d'une part et la formulation de politiques, d'autre part (en particulier lorsque la démarche est participative). Cet article vise à simplifier et à améliorer l'utilisation future du cadre DPSIR dans le contexte de l'Arctique. Pour atteindre cet objectif, nous avons mené une étude détaillée de la littérature examinant l'utilisation du cadre DPSIR dans l'Arctique, en nous concentrant sur cinq des secteurs économiques les plus importants de la région : l'aquaculture et la pêche, l'exploitation minière, l'exploitation forestière, le tourisme et les moyens de subsistance autochtones. Pour favoriser une utilisation juste et équilibrée du cadre DPSIR, nous explorons également ses principales critiques et variantes. Cet article résume les indicateurs utilisés dans les études de cas de l'Arctique. Il met aussi l'accent sur la pertinence du cadre comme outil facilitant la participation des parties prenantes locales et les processus participatifs d'élaboration des politiques. Il propose une approche générale de l'application du cadre DPSIR dans le contexte arctique. Lorsque des exemples propres à l'Arctique font défaut, il fournit un aperçu d'exemples pertinents se rapportant à des régions en dehors de l'Arctique.

Mots-clés : participation des parties prenantes; interdisciplinarité; indicateurs; durabilité socioenvironnementale; pêche; exploitation minière; exploitation forestière; tourisme; moyens de subsistance autochtones

Traduit pour la revue *Arctic* par Nicole Giguère.

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INTRODUCTION

The need for holistic approaches—capable of producing meaningful results and relevant for effective decision-making—that face social and environmental challenges has long been recognized as crucial in land use, sustainable development planning, and natural-resource conflict resolution (Jerneck et al., 2011). Even though social sciences and environmental sciences have different, sometimes divergent, ontologies and epistemologies (Jerneck et al., 2011) and use different terms, they are both trying to come up with tools, models, frameworks, and theories that will allow for a better understanding of the system as a whole, for instance, the socio-ecological system in the social sciences and the coupled human and natural system in the environmental sciences. The Driver-Pressure-State-Impact-Response (DPSIR) framework is one of various models and frameworks that encourage integrated research (e.g., Lewison et al., 2015; Dietz, 2017). The DPSIR framework structures the relationship between human activities, their effects on the natural environment, and the consequent impacts on societies through a causal chain, allowing for a clear interpretation of the selected issues and the development of possible actions to address them. This is extremely important in the Arctic context. The Arctic is emerging as an area of growing interest in and conflicts over natural resources and as a fundamental and vulnerable part of the ecosystem that must be managed for the sake of environmental conservation and social justice. We believe that, if properly applied, the DPSIR framework could be a useful tool to guide both researchers and decision-makers who are addressing the numerous challenges that this region faces.

Considering that the Arctic is under increasing political, environmental, and social pressures, the overall aim of this article is to facilitate and improve future applications of the DPSIR framework in the Arctic area both for research and for policy-making processes. To do this, two subobjectives are pursued: 1. We summarize the current state of the use of the DPSIR framework in Arctic case studies through a comprehensive literature review. More specifically, we analyze the use of the DPSIR framework in five of the most important economic sectors in the Arctic: aquaculture and fisheries, mining, forestry, tourism, and Indigenous livelihoods (Glomsrød et al., 2017). 2. We also discuss relevant case studies about the same economic sectors outside the Arctic area, since a very limited number of Arctic studies appear to be available.

DPSIR Framework: History and Definitions

The DPSIR framework is a causal one, intended to show the cause-effect relationship between five elements—Drivers, Pressures, State, Impact and Responses—to highlight the effects of anthropogenic activities on both the ecosystem and the social system (Gari et al., 2015). The five elements (Figs. 1, 2), or categories, are measured or described through specific indicators.

Built on previous models, the DPSIR framework was developed by European Environmental Agency (EEA) in the mid-nineties as a simple and effective conceptual and communicative framework to manage complex information and a large number of indicators from a variety of disciplines, ranging from social and political sciences to environmental sciences (Wolfslehner et al., 2008; Rounsevell et al., 2010; Tscherning et al., 2011; Gari et al. 2015; Lewison et al., 2015). The DPSIR framework was originally intended to organize the results of analyses to gain a holistic perspective, facilitating communication between the humanities/social sciences (economics included) and environmental sciences and among different actors (researchers and experts, policy makers, and the general public). Its final goals are to support decision makers in evidence- and science-based policy design and implementation and to identify the best strategies to achieve sustainable development of socio-ecological systems (EEA, 1999; Tscherning et al., 2011; Gari et al. 2015; Lewison et al., 2015).

Consistently, DPSIR has been defined as a problem structuring method (PSM) offered to different actors to facilitate the shared understanding of a common and complex problem and negotiations (Wolfslehner and Vacik, 2011). According to this definition, the DPSIR framework is not a tool to solve problems per se (Gomes Jùnior et al., 2022). Furthermore, Bell (2012) shows how DPSIR can organize indicators produced through a participative process, offer a wider and shared understanding of common problems, make the indicator-based decision-making process more democratic, and identify relevant factors and causal relationships with a plurality of perspectives.

According to the typology structured by Binder et al. (2013), the DPSIR framework is, in essence, a policy framework with the following meanings:

* The interaction between Society and Environment is univocal and proceeds from S to E (human actions affect the natural sphere). Proper feedback is not taken into consideration, but changes in the environment can impact societies.
- It has an anthropocentric perspective: the ecological system is seen as provider of services for human well-being.
- The social system is considered only on the macro level (societal structure determines individual behaviours).
- It aims to provide policy-relevant information, so it is appropriate to develop action-oriented strategies to reduce the impacts of human activities on the ecological system.

DPSIR Framework: Critical Issues and Possible Solutions

Since the DPSIR framework first came into being, it has been revised, modified, and integrated in a variety of ways to deal with its analytical and conceptual limits. Table 1 summarizes the main modified versions of the

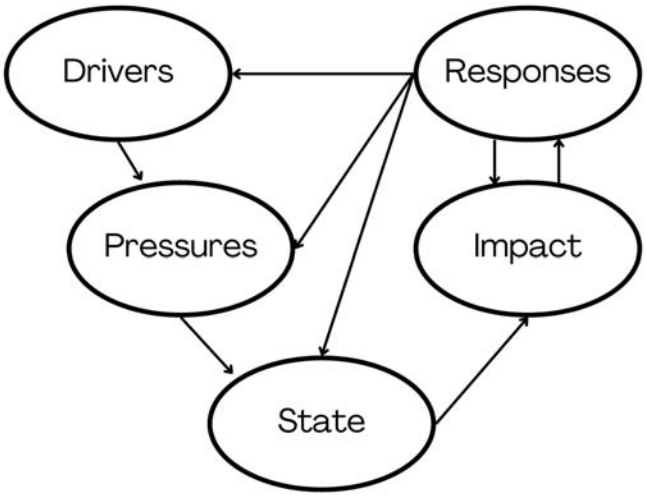

FIG. 1. The DPSIR Framework for Reporting on Environmental Issues (EEA, 1999).

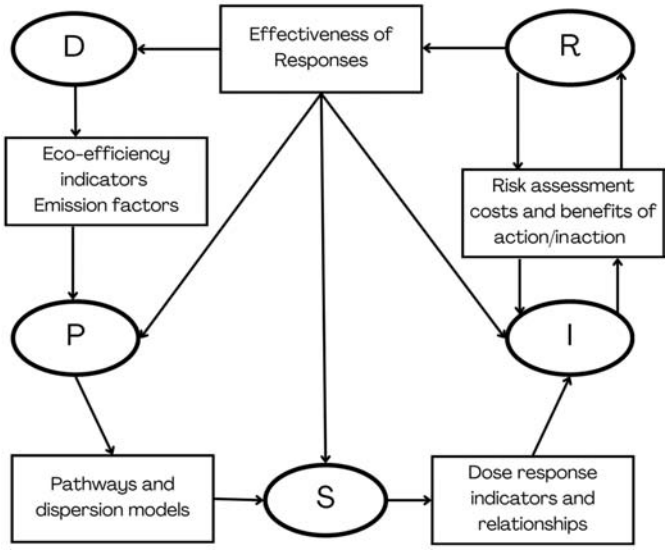

FIG. 2. Indicators and information linking DPSIR elements (EEA, 1999)

DPSIR frameworks. One of the major challenges in the effective application of the DPSIR framework is its excessive simplification of causal relationships: it's difficult to consider the feedback and complex interactions that constitute the rule and not the exception in socio-environmental dynamics (Niemeijer and de Groot., 2006; Wolfslehner and Vacik, 2008; Potschin et al., 2009; Tscherning et al., 2011; Gari et al., 2015; Lewison et al., 2015). Paillet et al. (2021) stress that the strong anthropocentric perspective of the framework prevents researchers from considering ecological resilience as part of its Response factor, focusing instead on just the political dimension. Consequently, by ignoring ecosystem feedbacks and complex dynamics, the framework promotes an instrumental view of nature. To respond to these limitations, Niemeijer and de Groot (2006) proposed a modified DPSIR framework: the Enhanced DPSIR (eDPSIR). It is meant to address the complex interactions between indicators and environmental problems that are usually studied and politically addressed separately, leading to limited understanding and ineffective solutions. A simple causal chain was considered inadequate, so the authors suggest a causal network structure instead. In addition to improving the representation and understanding of complex socio-environmental interactions, the eDPSIR framework allows its users to identify key indicators, helping them to focus on the most significant ones.

Another difficulty in applying the original DPSIR framework is defining the scale and boundaries of the system. This affects how DPSIR categories are defined and, therefore, how indicators are selected and allocated to them. For example, a system's border definition is crucial in identifying how all the interested parties are affected by changes in ecosystem services (ES; provisioning services, cultural services, regulating services, and supporting services; Reid et al., 2005), or in distinguishing between Drivers and Pressures and identifying the effective Response level and targets. However, this is not an easy step, since some system boundaries (for example, in fisheries) are quite hard to identify precisely. One possible way to clarify the border definition is provided by the modified version of the framework proposed by Rounsevell et al. (2010): the Framework for Ecosystem Services Provision (FESP). It allows for a clearer distinction between exogenous (Drivers) and endogenous (Pressures) factors that affect the State, and thus determination of the consequential Impacts. The distinction between exogenous and endogenous factors depends on the definition of the system boundaries, and thus identification of effective Responses, since it is assumed that actors included in the system can modify only endogenous factors and do not have much power over the external ones. Ecosystem services beneficiaries are different social groups who are part of the same system but prioritize different ES according to their interests and needs, potentially creating conflict: often, trade-offs and synergies between different ES (and related benefits for different actors) have to be found. This is a matter of political choice—but to identify the most balanced strategy, the framework must consider multiple ES and their interactions.

Another critical aspect, related to the previous one, was addressed by the creation of the DAPSI(W)R(M) framework (Elliott et al., 2017), in which *"A"* indicates Activity, *"W"* stands for Welfare, and *"M"* for Measures. This modified version of the DPSIR framework addresses the need for differentiation between Drivers (for example, food production) and the following human Activity (in case of salmon farming); between Impacts on environmental elements and, as a consequence, Impacts on human Welfare; and between Responses and specific management Measures (for example, modifying legislation).

The absence of clear rules in attributing indicators to categories and defining categories themselves is hard to address, since there cannot be univocal rules and definitions, and many indicators could be included in one

TABLE 1. Summary of standard and modified DPSIR main features.

	Standard DPSIR	eDPSIR (enhanced DPSIR)	FESP (Framework for Ecosystem Services Provision)	Resilience DPSIR	DAPSI(W)R(M) (Driver-Activities-Pressures-State-Impacts on human Welfare-Responses as Measures)	Equity DPSIR
Main feature	Causal chain	Causal network to deal more effectively with complexity of real-world interactions	Improved definition of boundaries and scale	Integration of DPSIR categories and resilience constitutive elements to study indigenous communities and their traditional livelihoods	Developed mostly for marine environment management according to Ecosystem Approach	Integration of equity and justice issues in the definition of categories and indicators
Proposed by	EEA (1999)	Niemeijer & de Groot, 2006	Rounsevell et al. (2010)	Sarkki et al. (2016)	Elliott et al. (2017)	Gupta et al. (2020)
D – Driver	Social, demographic and economic developments and the corresponding changes in lifestyles, consumption and production	Not redefined	Underlying causes of environmental change: exogenous to the system	Driver and Pressures together (political, economic, ecological, demographic and social factors that lead to direct pressures on livelihoods) answer to the question: resilience to what?	Basic human needs: biological and physiological needs, safety needs, love and belonging needs, esteem needs and self-actualization needs (Maslow, 1943)	How do Drivers result from, mitigate or exacerbate inequalities?
A – Activity	–	–	–	Definition of the socio-ecological system upon which resilience is examined. Resilience of what?	Human actions that compose economic sectors active in a certain system	–
P – Pressure	Emissions, physical and biological agents, use of resources and of land	not redefined	Endogenous variables that quantify the effect of Drives within a system	Effects of pressures on livelihoods or changes in the interactions between ecosystem and livelihood. Resilience for whom?	Result of one or more Activities that can result in changes to the natural system (State changes) and subsequently the social system (Impacts on human Welfare)	Who uses and pollutes resources and sinks?
S – State	Quantity and quality of physical, biological and chemical phenomena	Not redefined	Sensitivity of the system to the Pressures variables	How to enhance resilience	Changes in the natural environment (physico-chemical variables and health of all levels of biological organisation)	How is the exposure to benefits and risks distributed?
I – Impact	Negative changes in ecosystem services and their consequences on society	Not redefined	Measure of whether the changes have a negative or positive effect on individuals, society and environmental resources		Consequence on the societal Welfare (W) of the changes in the natural system	How are Impacts distributed? Who is able to adapt; who pays for residual damages?
R – Response	Actions taken by groups, individuals or governments to prevent, compensate, ameliorate or adapt to changes in environment	Not redefined	Policies and management actions that aim to minimise negative Impacts or maximise positive Impacts		Actions taken (Measures – M) from a governance background that is linked to political landscape, policies, administration and legislation required.	How do Responses redistribute rights, risks and responsibilities?

category or another (Anastasopoulou et al., 2007; Vacik et al., 2007; Paillet et al., 2021). Indeed, the definition of which variables should be included in each category is highly contextual and depends on the identification of system boundaries, policy objectives, actors' interests, and so forth. At the same time, the absence of common rules makes comparison impossible. To compensate for the subjectivity of the definition, a clear context and method description is required (Tscherning et al., 2011; Gari et al., 2015; Lewison et al., 2015). Furthermore, even when the same variables are considered, they are often referred to by different terms or measured in different ways, generating inconsistency even within the same discipline (Maxim et al., 2009; Martins et al., 2012; Gari et al., 2015).

The constructivist criticism of the DPSIR framework should also be carefully considered. The framework implies a strong positivist and realist view of knowledge: it is argued that it does not account for different discourses and narratives, and that it implies the existence of one scientific, neutral truth (Svarstad et al., 2007; Tscherning et al., 2011; Gari et al., 2015). As pointed out by Svarstad et al. (2007), this could lead to significant biases, as discourses are an important part of the social construction of reality and shape the way information is interpreted, strongly limiting, or even impeding, the possibility to see alternative interpretations. This occurs with the DPSIR framework, too: the authors (Svarstad et al. 2007) considered four discourses related to biodiversity and showed how only one of them fully fit in the DPSIR framework. Another was partially represented, while the other two could not fit at all into the structure of the framework—and virtually disappeared along with their specific issues and point of views. Contrary to how the framework is generally perceived, the results visualized through the DPSIR framework were shown not to be a neutral and a realist reflection of reality. Hence, the DPSIR framework tends to follow and reproduce some specific discursive positions and thus needs to incorporate a more complex representation of socio-cultural issues (Svarstad et al., 2007).

The importance of incorporating multiple discourses and narrative in the DPSIR analysis, to avoid biases and to avoid misrepresenting ongoing conflicts over a resource, is stressed by Benjaminsen et al. (2008), who described the main narrative features of the opposition of local people to dogsledding in a Norwegian mountain area. The Benjaminsen study provides a good Arctic example, even though the researchers did not apply the DPSIR framework. The authors found that only some of the elements that constituted the opposition's narrative (such as the migration of moose) were directly related to the activity per se and its impacts on the ecosystem. Indeed, other features are related to wider, and perhaps deeper, issues such as the perceived loss of power of local communities over traditional resources and urban-rural conflict. These elements of local understanding could, at first glance, seem less relevant or even unrelated when the aim of an exercise is to address the sustainable management of dogsledding, and could, therefore, be excluded from a hypothetical DPSIR-based analysis. Nevertheless, they are crucial, since they structure the whole interpretation of the activity from the perspective of important local stakeholders and, if not properly considered, they could hinder or even jeopardize the effective implementation of the identified Responses.

Political criticism of the use of the DPSIR framework is also quite substantial. In a widely quoted paper by Carr et al. (2007), the framework is said to implicitly maintain the traditional hierarchical relationship between developers and the underdeveloped. The framework is also said to maintain and perpetuate privileges and power relations that have historically structured development policies and led to their failure. Those who can act upon the Drivers, such as governments of industrialized countries, big NGOs, international organizations, and so forth, stay on the top of the analytical hierarchy and are the only actors that can address the roots of the problems through Responses. Poor and marginalized people, on the contrary, are considered only in relation to Impacts and their knowledge. Responses and individual choices, which could, on an aggregate level, become Pressures or even Drivers themselves, are mostly ignored (Carr et al., 2007; Gari et al., 2015). The latter element is defined by Ehara et al. (2018:228) as "maladaptive coping strategies," which are actually the trade-offs local people make when reconciling immediate needs and long-term development. For instance, fishers who are affected by tourism and marine recreation activities can decide to shift their work to deeper water or expand their plot. It's not easy to incorporate the strategies in a DPSIR framework, but they can have an important effect on Pressures or even Drivers and should be considered.

Similar claims about the need to incorporate local knowledges, practices, and interpretations of resources' value specifically in the Arctic context have been brought up by Lovecraft and Meek (2019). Gupta et al. (2020) go further, bringing into light the importance of integrating equity issues, which have been traditionally marginalized in the DPSIR framework. This is crucial, since the DPSIR framework is often applied to identify Responses for sustainable development, which in turn cannot be achieved without a substantial consideration of social justice and equity, setting aside the risk that Responses themselves may create further injustice. Individuals are unequally responsible and affected by environmental problems. Furthermore, inequalities must be considered from an intersectional perspective. However, since the DPSIR framework relies mostly on aggregated data, inequalities and distributional aspects are hidden, and it becomes difficult to identify the structural factors causing both inequalities and environmental degradation. Because of this, the DPSIR framework is unable to address problems in a differentiated manner, therefore perpetuating inequalities even through the marginalization of different systems of knowledge. Consequently, the authors propose a modified DPSIR framework in which equality issues are integrated.

DPSIR Framework in the Arctic

The Arctic is usually understood and depicted as a singular and peripheral space (Dittmer et al., 2011). However, there is great diversity in the Arctic, and local and regional actors and processes are increasingly emphasizing a multitude of meanings and elements that are and can be linked to the place called the Arctic (Saarinen and Varnajot, 2019). The term Arctic can be tied to physical, symbolic, or political boundaries (Lovecraft and Meek, 2019). Different environmental, cultural, and political definitions set the border for the Arctic area in different ways. Based on environmental features, the border can be identified according to average temperature, treeline, and isotherm, or by the southern limit for midnight sun and polar night (Arctic Council, 2013). The Arctic states and other geopolitical actors determine political borders (Dittmer et al., 2011). According to the cultural dimension and Indigenous understanding of borders, we get a third set of definitions—all of which demonstrates that the Arctic context is highly complex. The area lacks a homogeneous governance, being subject to different countries' jurisdiction, but is also managed through international organizations such as the Arctic Council. Furthermore, its natural resources are exposed to conflicts between different Arctic actors (such as Indigenous communities, local people, governments, and businesses) and non-Arctic actors (e.g., global companies and international governance and agreements).

Finally, climate change is drastically affecting the Arctic (Horejsova and Paris, 2013; Cole et al., 2014; Cole et al., 2016; Lovecraft and Meek, 2019). It's therefore crucial to increase the understanding of how the different anthropogenic activities impact the Arctic's vulnerable environment and how environmental changes affect the different social groups relying on Arctic resources. Effective and well-balanced policies that can identify better trade-offs between different stakeholders' needs, views, and desires are needed to build a fair and sustainable socio-ecologic system in the Arctic.

All this considered, the DPSIR framework can be useful to structure indicators and data in a causal relationship between human pressures over the environment and the consequent societal impacts in the complex Arctic context, especially considering the modifications that have been made to address its problematic aspects. The final goal is to identify shared and balanced responses that include the different and often conflicting interests of Arctic and non-Arctic stakeholders. Nevertheless, the application of the framework in the Arctic context has been scarce to date.

METHODS

The aim of the present research is to conduct a scoping review on the applications of the DPSIR framework in the Arctic and some of its main industries: fisheries and aquaculture, tourism, forestry, mining, and Indigenous economies. The number of available case studies is limited: to provide more resources that can be used as examples, a brief summary of selected papers is attached as an appendix. Two categories of papers are included in that section: case studies from the Arctic area (though not related to the selected industries) and articles addressing issues related to the selected industries from other geographic areas.

Considering the lack of any current article about DPSIR applications in the Arctic context, this method was chosen because it allows for the broadest possible collection of papers. In addition, the review of the available literature could be used as basis for researchers and practitioners working in the field, facilitating further application of the DPSIR framework or its modified versions.

Because of the complex context of the Arctic, no specific definition of Arctic was applied; this allows a broader sample to be included. All the definitions adapted by the authors were considered valid. When using countries' name as keywords, the political definition of the Arctic—i.e., membership in the Arctic Council—has been applied. Thus, a tourism case study set in Vancouver Island was able to be included (that should have been excluded according to a climatic or environmental model). Most of the case studies are from the European Arctic, possibly because the original model was proposed by the EEA.

The main criteria for the identification of selected livelihoods were economic and social relevance in the Arctic region (Glomsrød et al., 2017), conflict that they generate to gain access to and exploit natural resources according to the different interests and values of each user category, and significant environmental impact they generate locally and globally. Clearly, there are important regional differences in the prominence of one sector or the other: most new mines are planned in northern Finland, Sweden, and Norway. Finland and Sweden are the most forested countries in Europe and are greatly investing in new biorefineries. Tourism is an important economic activity in Iceland and northern Finland, and the cruise sector is highly relevant in Norway, Iceland, and Greenland. Aquaculture and fisheries are practised in Norway, Faroe Islands, and Iceland and have created conflicts between countries, too. In addition, Indigenous Peoples constitute an important part of Arctic cultures, traditions, and herding practices.

The selected papers were found using five of the main databases for peer-reviewed literature: JSTOR, Web of Science, ProQuest, Scopus, and Google Scholar. The first four allow for advanced searches and the following keywords were used through different combinations (function AND) and in different fields (title, abstract, keywords, full text): Arctic, polar regions, Finland, Sweden, Norway, Svalbard, Greenland, Iceland, Russia, Faroe Islands, Canada, Alaska, DPSIR framework, mining, fishery, fish farming, aquaculture, forest, forestry, tourism, Indigenous issues, oil, gas, coal. Google Scholar was

used mainly to look for the most recent studies, using the cited-by function. No time frame was indicated, but only peer-reviewed English literature was taken into account. The collection was conducted from November 2021 to January 2022, with a second search in June 2022, which added only one paper: Reckermann et al, 2022. Table 2 presents a collection of all the articles considered in this review according to six categories and whether the study was located in the Arctic or not: non-industrial case studies, with examples of the application of the DPSIR framework in an Arctic or sub-Arctic context but not in relation to the selected industries (six articles); aquaculture and fisheries, forests, tourism, mining, and Indigenous livelihoods identify examples of DPSIR application in the selected industries (five articles related to Arctic, twelve outside). For a discussion of DPSIR frameworks in in selected industries outside the Arctic and in non-industrial case studies, see Appendix 1.

RESULTS

DPSIR Framework in the Arctic Industries

At least one example of the application of the DPSIR framework is available for each of them, except for mining.

Aquaculture and Fisheries: The only case study available for these sectors is about the fisheries on the Grand Banks, Canada (Dempsey et al., 2017). In the study, indicators for fisheries were selected and then organized through the DPSIR framework. The area is considered to be a socio-ecological system that has historically been a highly productive fishing ground until the collapse of the major fish stocks in the early 1990s because of heavy fishing pressure and an environmental regime shift. These collapses were addressed through fishing moratoria and, even though positive signs are visible in some stock, the recovery is diversified and different from the precollapse conditions. Socio-economic Impacts on fishers are also described. They range from targeting different species to catch, retiring from the industry, or moving to find employment elsewhere. The authors note that the DPSIR framework can be limited when it comes to representing the complex ecosystem dynamics and that the attribution of indicators is not straightforward, since, for instance, some components of the State can be either Pressures or Impacts. They deal with the latter issue by adding a state-to-state arrow in the framework. They also suggest categorizing indicators as exogenous/unmanageable and endogenous/manageable, as this makes the indicators less ambiguous compared to Drivers and Pressures.

Forests: In their study, which included some Arctic localities, Kyriazopoulos et al. (2017) interestingly summarize the main Drivers, Pressures, State, Impacts, and Responses that affect the treeline ecosystem in Europe. Their main assumption is that altitudinal and polar treeline ecotones are primarily controlled by climate, but centuries of human disturbances have altered the climatic position of treelines. Furthermore, subalpine and subarctic forests close to the treeline provide several resources and ecosystem services for local communities with traditionally low land-use intensity. However, the access to exclusive and non-exclusive ESs may cause conflicts if some stakeholders overuse them and cause degradation or losses that affect other stakeholders. The results (with Arctic and subarctic localities) are shown on an aggregate level in Appendix Table S1. The general findings show that climate change, land-use change, and (specifically for Iceland) volcanic activity are the main Drivers of the tree ecotone dynamics. The authors also note that land-use changes in treeline areas have been strongly linked to the dynamics of the socio-economic systems in Europe over the last century. They proceed to organize Pressures according to the Driver behind them and assess that land-use change is the most relevant Pressure. Together with tourism and industrial development, both abandonment of traditional pastoral activities and overgrazing have significant impacts on the treeline. For example, in the northern Scandes (mountain range), on the subarctic mountain plateau Finnmarksvidda in Norway, and in adjoining areas in Finnish Lapland (Kevo), birch forests above the conifer treeline have been partially overgrazed by domestic reindeer in the last 50 years, reducing lichen cover. Furthermore, because of climate change, birch forests are increasingly subject to attacks by various moth species. Main Impacts of both climate change and land-use change are wind, wildfires, grazing, and loss of biodiversity, followed by avalanches, root diseases, and bark beetle outbreaks. The authors note that Responses were generally scarce. Mitigation and adaptation measures and governance and political instruments specific for treeline ecosystems' restoration or adaptation to change were uncommon in any of the case studies. Their findings are summarized in a table with a brief list of Pressures, State, Impacts, and Responses.

Tourism: The DPSIR framework has been widely applied in the tourism sector to understand crucial issues related to sustainable development of the industry, and we can find examples from the Arctic too. Ólafsdóttir (2021) focusses on the participatory process to select indicators to address tourism in Snæfellsjökull National Park, Iceland. According to the author, all three pillars of sustainability must be considered in the analysis of the tourism sector. Social sustainability is about balancing the needs of the local community with those of tourists, fairly distributing benefits, and avoiding negative effects on residents; environmental sustainability is crucial, especially when it comes to nature-based tourism and tourism in protected areas (as is often the case with Arctic destinations); economic sustainability is needed to guarantee revenues and income, especially for local enterprises and workers. The author stresses that, together with the involvement of local stakeholders in the selection and evaluation of indicators, the use of the DPSIR framework describes the causality between environmental impacts and tourism that

TABLE 2. List of articles reviewed in the present study

Category	Arctic	Non-Arctic
Non-industrial case studies	Alexander et al., 2015 Barton et al., 2016 Bölter et al., 2016 Kruse, 2016 Lovecraft et al., 2019 Reckermann et al., 2022	–
Aquaculture and fisheries	Dempsey et al., 2017	Marín et al., 2021 Martins et al., 2012 Mozumder et al., 2019 Sanon et al., 2020
Forests	Kyriazopoulos et al., 2017	Paillet et al., 2021 Vacik et al., 2007 Wolfslehner et al., 2008
Tourism	Ólafsdóttir, 2021 Rempel, 2012	Mandić, 2020 Mustika et al., 2017 Ruan et al., 2019
Mining	–	Chen et al., 2020 Spitz et al., 2008
Indigenous livelihoods	Sarkki et al., 2016	–

is relevant in addressing sustainable-development issues. The framework is therefore used to identify the relationship between the selected indicators.

Another example comes from North Vancouver Island, Canada. Like Òlafsdòttir (2021), Rempel (2012) engages with sustainable development in tourism, starting from the assumption that community residents must be involved in tourism management. The area is suitable for nature-based tourism and for wildlife-related activities such as hunting, fishing, and wildlife watching. All these activities are also practised by local communities, and the economy of the area is based on natural resources extraction, such as fishing, mining, and forestry. These industries are currently declining, and tourism could be an interesting and sustainable sector to "diversify and improve local economy" (Rempel, 2012:586), but planning is needed to minimize potential negative impacts on the natural environment and local communities and cultures. The author stresses the importance of involving First Nations and calls for training programs to help people obtain, for example, driver's licences, boat operator certification, and first aid certification. In this study, the DPSIR framework is considered useful in "decision-making by identifying clear steps where the causal chain can be broken by policy action" (Rempel, 2012:595). Two modifications were developed: first, the author includes socio-cultural and economic dimensions of sustainability in the domains of Pressures and State, but according to the standard definition, these two categories are related to the ecosystem dimension; second, the author includes positive impacts. When the Driver is mass tourism, the Impacts are negative; when the Driver is sustainable management, positive Impacts are included. The process for the selection of indicators is also methodologically interesting. After determining Impacts through rapid rural appraisal, a web-based survey, and interviews with key informants, factor analysis was applied to determine and cluster the most important elements to include in the framework.

Indigenous Livelihoods and Cultures: The direct application of the DPSIR framework to local and Indigenous communities' issues is quite rare. However, Indigenous issues have been shown to be a crucial element in a significant number of the studies selected for mining, tourism, forestry, and fisheries.

The study conducted by Sarkki et al. (2016) is about reindeer herding in northern Finland and the challenges that come from land-use changes, conflicts with other human activities, and from climatic variation. The DPSIR framework was applied to better understand threats, economic and cultural impacts, and responses developed by herders—both Finns and Saami. DPSIR categories were combined with resilience categories, as reported in Table 1. The authors provide two frameworks: a general overview of DPSIR factors related to the main land uses that affect reindeer herding and a specific DPSIR framework focused on reindeer herding. Note that there is not a specific land use that challenges reindeer herding. The difficulty arises from the combination of different pressures and their cumulative effects. Furthermore, according to Sarkki et al. (2016), herders are often accused of overgrazing, leading to an inaccurate representation of reindeer herders as a threat to sustainability, and undermining their credibility, knowledge, and point of view. Hence, it is important to account for all the pressures, both internal (overgrazing) and external (land-use changes, increased number of predators, etc.).

Another significant element was the interaction between slow variables, such as identity; the social capital produced

and maintained through communal work with herds in the forest; renewal of livelihood by new generations; and changes in the environmental, economic, and political context. This, in turn, leads to the consideration of a complexity of Responses that should not be intended as "magic bullets" (Saarki, 2016:11), but as elements integrated in complex interactions and feed backs that should be evaluated directly by affected actors as positive or negative based on the effects on their own livelihoods.

For example, the introduction of snowmobiles in the 1970s could be considered the cause of a significant loss of traditional knowledge. However, the new technology was freely chosen by herders who consider it to be an enhancement. Another example is the introduction of small-scale meat processing facilities. On one hand, these facilities guarantee a better price for meat and help residents to cope with increased costs and losses of livestock from predation. On the other hand, the time that used to be dedicated to common herding activities decreased, causing a loss of social capital and generating distinctions between herders who work more in the forest and the ones who work more in the processing facilities, ultimately threatening the maintenance of traditional activities.

A similar dynamic can be seen in relation to compensative measures for predator-related losses. Herders are able to request refunds from the State if their animals are killed in traffic accidents or by predators, but this is perceived as a shift of the source of income from herding to predator-feeding, modifying the herders' sense of identity. Furthermore, to avoid predation, herders may decide to keep animals in pens, but this leads to increased costs (for fodder) and more time dedicated to farming and working only with their own animals, reduced engagement in shared activities, and therefore reduction of social capital and a sense of belonging within the community.

DPSIR Framework in the Arctic: General Recommendations

Based on the reviewed articles, we recommend a DPSIR framework that contains relevant aspects to be considered when applying the framework in the Arctic. This model provides a benchmark that will need to be defined case by case by, for example, using indicators and methods that have been applied in the non-Arctic case studies described in the Appendix. However, this common basis could build a shared approach that will allow for a more consistent method in research, community engagement, and policy design, and that will offer a regional perspective even when addressing specific local problems.

Drivers: We found two different categories of Drivers that could be addressed through Responses:

1. Anthropogenic Drivers: These Drivers are related to human policies and activities and, therefore, can be addressed even if the decision level at which this can be done may be much higher than the local level being considered in a specific research or participative project. It may be the case that the Drivers cannot be practically addressed, but they are still theoretically under human control. They may include the following:
   a. Economic/Industry-Related Drivers, such as global market trends in demand for a certain product (for example, fish or minerals).
   b. Environmental Drivers, such as increased emissions that cause climate change and ecosystem degradation through land-use changes (for example, decreased traditional grazing practices).
   c. Cultural, Societal, and Demographic Drivers, such as population growth and changes in tourists' environmental awareness.
2. Natural Environmental Drivers: These Drivers consist of natural phenomena that can't be controlled in any way by humans, for example, volcanic activity or North Atlantic Oscillation.

Note that both challenges and opportunities may come from these Drivers. For example, tourists' stronger environmental sensitivity could lead to an increase in the environmental commitment of companies and, therefore, to a reduction of harmful environmental impacts of the industry. It appears to be better to keep the positive and negative dynamics separate at the beginning of the research or participatory process by, for example, designing two separate DPSIR diagrams that can be integrated later on; this avoids confusion when interpreting indicators.

Applying the second category of Drivers in the DPSIR framework appears useful for scientific research, because it allows for a more complete description of all the factors involved in a certain dynamic. It may be irrelevant and even confusing if the aim is to engage the local community in a participatory policy-design process, because in this case the focus should be kept on identifying causes and what can actually be improved through human decisions and actions.

Pressures: Here we can identify the specific challenges and opportunities that Drivers are determining at the local level. The same categories that we used for Drivers can be applied, focusing on the anthropogenic ones:

a. Economic/Industry-Related Drivers could lead to an increased exploitation of a certain resource, for example higher volume of fish catch, the opening of new mines, or the increase in traffic.
b. Environmental Drivers could lead to decreased or increased precipitation, but also to increased competition between herders as a consequence of pastureland depletion.
c. Cultural, Societal, and Demographic Drivers could lead to increased demand for sustainable tourism products but also to increased demand for wilderness tourism that may exceed the sustainability threshold.

State: Here the economic, social, and environmental system variables that are being affected by the Pressures

are described, as well as the changes in context that will later produce specific impacts on the local community. Indicators measuring biodiversity levels, abundance and health of wild species, air quality, housing, goods and services quality and price, and availability of local or traditional jobs and their profitability and stability should be used to cover all the relevant environmental, economic, and social aspects.

Impacts: Here we can find the core of the problem that the DPSIR framework was used to address in the first place; the (generally) negative effects of some global Driver that affects the local community through the causal chain just described. We will, therefore, consider mostly socio-economic and cultural indicators, since we generally consider the environmental variables to be part of the State (and, therefore, more as causes rather than problems per se—as we have seen, DPSIR is a fairly anthropocentric model). We will therefore use indicators such as decrease in population, youth outmigration, abandonment of traditional jobs, loss of cultural heritage, and decreased community bonding practices.

Responses: This last category is crucial, because it represents the outcome of the research or of the participatory process. Two aspects should be considered when deciding what to include:

1. Effectiveness in addressing (at least) Pressures: Local communities and stakeholders may not be able to take action on the Drivers on a higher scale, so although it is valuable to ideally address the root of the issue, it is also important to identify solutions that have a chance to improve a problematic situation.
2. Consistency and completeness of the Responses: Especially in participatory processes involving different stakeholders with different views, goals, and needs, there is a risk of including contradictory or unbalanced solutions that will actually leave the issue unsolved or worsen it in the long run. For example, if decreased profitability of reindeer herding is addressed by increasing the number of animals, the business may improve in the short run but the depletion of pastures due to overgrazing will eventually backfire. Local youth education and training to work in the tourist sector could be a Response to unemployment due to loss of traditional jobs, but in the absence of a proper housing policy, increased accommodation and goods and services prices resulting from tourism may still prevent young people from being able to afford a living in the area.

Generally speaking, Responses should therefore include at least three integrated aspects. First, technical innovations, such as agro-ecological systems, implementation of environmental hazard reduction technologies and procedures, and environmental monitoring. Second, adaptations for local community empowerment and the reappropriation of local economies, such as education and training, locally owned business development, conservation of local languages, traditions and culture, and awareness-raising. Third, regulations and participatory policy design, such as just taxation and distribution to promote equity, strict limits on resource exploitation (tourist accommodation, fish catches, etc.), creating protected areas, sustainability certification for companies, and compensation schemes (for example, for herders whose herds face increased predation).

DISCUSSION AND CONCLUSIONS

In this article we review relevant examples of the DPSIR framework in the Arctic area to facilitate and improve future such applications. Based on our review of selected literature, we demonstrate that the DPSIR framework is being used and applied in many ways. Appendix Table S1 summarizes the indicators and approaches used in the five Arctic industries studied, in which variation is already noticeable. Not every study gives the same attention to all the DPSIR categories; we rarely find the same indicator in more than one study, in fact; even when similarities seem to occur, the definition or the operationalization can be different. Drivers are sometimes exclusively anthropogenic, sometimes both environmental and anthropogenic, or even unified with Pressures; Impacts are generally negative but positive ones are sometimes also included, giving a radically different meaning to the whole framework; methods for selecting indicators and gathering data are specific to each study. Furthermore, if we consider that not just one version of the DPSIR framework exists but that researchers opt for different variants (or even modify the framework according to the specific needs of their research), we get a fairly uneven scientific landscape that is challenging to summarize.

Nevertheless, even if not all the studies manage to include and properly account for the plurality of knowledge and interpretations of resource values (according to different stakeholders) or to include power and equity issues, we can notice that there is at least one feature shared among most of the research: the acknowledgment of the importance of local stakeholders' perspectives, needs, interests, and desires. As underlined earlier, this is a crucial issue, since the DPSIR framework is considered to be a valid tool. In this regard, we can consider the ductility of the DPSIR framework as an advantage, even if it comes at the expense of scientific generalization of results and ability to compare case studies. We could therefore consider it more than an analytical framework, but rather as a useful PSM aimed at providing an understanding of environmental issues affecting a specific system that can be easily grasped and shared by all affected stakeholders along all relevant governance levels in order to pursue the urgent and complex objective of sustainable development in all its three pillars.

As examples from a study conducted by Cole et al. (2014) and Cole et al. (2016), the Arctic is a complex

region where local, regional, and global actors compete for different resources or for different use of the same resource. Traditional and new economic activities interplay with the ecosystem services upon which they rely, and users prioritize different ecosystem services according to their own interests, needs, and values.

Multiple sectors and levels of governance intervene in defining policies and strategies, often with conflicting objectives. The Arctic Council has often been referred to as an important institution in such scenarios; it can provide access to relevant information, support in negotiation processes, and provide coordination for policy design and implementation. Interestingly, it has also been defined as part of the DPSIR Response category (Lovecraft and Meek, 2019). At the same time, Arctic governance needs to include local actors, to preserve traditional land use, to safeguard the right of local communities and Indigenous Peoples, and to support balanced, holistic, and sustainable development in remote and sparsely populated areas. Considering the review of selected literature and the relevant examples presented herein, the authors suggest that the DPSIR framework can be a useful tool to study conflicting land-use cases in the Arctic. It can organize complex knowledge in a clear way, include social, economic, and environmental interactions, and, if applied through participative processes, help structure discussion and negotiation between different actors, incorporating different needs, goals, and values, toward the identification of the best management of the precious and fragile Arctic resources.

ACKNOWLEDGEMENTS

This study was carried out as a part of the Horizon 2020 project ArcticHubs funded by the EU (Grant Agreement No. 869580) and the REBOUND project funded by the Strategic Research Council within the Research Council of Finland (decision Nos. 358482 and 358497).

REFERENCES

Alexander, K.A., Kershaw, P., Cooper, P., Gilbert, A.J., Hall-Spencer, J.M., Heymans, J.J., Kannen, A., et al. 2015. Challenges of achieving good environmental status in the northeast Atlantic. Ecology and Society 20(1): 49. https://www.ecologyandsociety.org/vol20/iss1/art49/

Anastasopoulou, S., Chobotova, V., Dawson, T., Kluvankova-Oravska, T., and Rounsevell, M. 2007. Identifying and assessing socio-economic and environmental drivers that affect ecosystems and their services. The RUBICODE Project. Rationalising Biodiversity Conservation in Dynamic Ecosystems.

Arctic Council. 2013. Arctic biodiversity synthesis. https://oaarchive.arctic-council.org/items/dda7d777-b852-4496-8972-3551dfd6d628

Barton, D.N., Andersen, T., Bergland, O., Engebretsen, A., Moe, S.J., Orderud, G.I., Tominaga, K., Romstad, E., Vogt, R.D. 2016. EUTROPIA. Integrated valuation of lake eutrophication abatement decisions using a bayesian belief betwork. In: Neal, Z.P., ed. Handbook of applied system science. New York: Routledge. https://brage.nina.no/nina-xmlui/handle/11250/2759930

Bell, S. 2012. DPSIR=A problem structuring method? An exploration from the "imagine" approach. European Journal of Operational Research 222(2):350–360. https://doi.org/10.1016/j.ejor.2012.04.029

Benjaminsen, T.A., and Svarstad, H. 2008. Understanding traditionalist opposition to modernization: Narrative production in a Norwegian mountain conflict. Geografiska Annaler: Series B, Human Geography 90(1):49–62. https://doi.org/10.1111/j.1468-0467.2008.00275.x

Binder, C.R., Hinkel, J., Bots, P.W.G., and Pahl-Wostl, C. 2013. Comparison of frameworks for analyzing social-ecological systems. Ecology and Society 18(4): 26. https://pure.tudelft.nl/ws/portalfiles/portal/155874174/ES_2013_5551.pdf

Bölter, M., and Müller, F. 2016. Resilience in polar ecosystems: From drivers to impacts and changes. Polar Science 10(1):52–59. https://doi.org/10.1016/j.polar.2015.09.002

Carr, E.R., Wingard, P.M., Yorty, S.C., Thompson, M.C., Jensen, N.K., and Roberson, J. 2007. Applying DPSIR to sustainable development. International Journal of Sustainable Development & World Ecology 14(6):543–555. https://doi.org/10.1080/13504500709469753

Chen, J., Jiskani, I.M., Jinliang, C., and Yan, H. 2020. Evaluation and future framework of green mine construction in China based on the DPSIR model. Sustainable Environment Research 30(1): 13. https://doi.org/10.1186/s42834-020-00054-8

Cole, S., Izmalkov, S., and Sjöberg, E. 2014. Games in the Arctic: Applying game theory insights to Arctic challenges. Polar Research 33: 23357. https://doi.org/10.3402/polar.v33.23357

Cole, S.G., Kinell, G., Söderqvist, T., Håkansson, C., Hasselström, L., Izmalkov, S., Mikkelsen, E., et al. 2016. Arctic games: An analytical framework for identifying options for sustainable natural resource governance. The Polar Journal 6(1):30–50. https://doi.org/10.1080/2154896X.2016.1171001

Dietz, T. 2017. Drivers of human stress on the environment in the twenty-first century. Annual Review of Environment and Resources 42(1):189–213. https://doi.org/10.1146/annurev-environ-110615-085440

Dempsey, D.P., Koen-Alonso, M., Gentleman W.C., and Pepin, P. 2017. Compilation and discussion of driver, pressure, and state indicators for the Grand Bank ecosystem, Northwest Atlantic. Ecological Indicators 75:331–339. https://doi.org/10.1016/j.ecolind.2016.12.011

Dittmer, J., Moisio, S., Ingram, A., and Dodds, K. 2011. Have you heard the one about the disappearing ice? Recasting Arctic geopolitics. Political Geography 30(4):202–214. https://doi.org/10.1016/j.polgeo.2011.04.002

EEA (European Environmental Agency). 1999. Environmental Indicators: Typology and overview. Technical report no.25. EEA, Copenhagen. https://www.eea.europa.eu/en/analysis/publications/tec25

Ehara, M., Hyakumura, K., Sato, R., Kurosawa, K., Araya, K., Sokh, H., and Kohsaka, R. 2018. Addressing maladaptive coping strategies of local communities to changes in ecosystem service provisions using the DPSIR framework. Ecological Economics 149:226–238. https://doi.org/10.1016/j.ecolecon.2018.03.008

Elliott, M., Burdon, D., Atkins, J.P., Borja, A., Cormier, R., de Jonge, V.N., Turner, R.K. 2017. "And the DPSIR begat DAPSI(W)R(M)!"—A unifying framework for marine environmental management. Marine Pollution Bulletin 118(1-2):27–40. https://doi.org/10.1016/j.marpolbul.2017.03.049

Gari, S.R., Newton, A., and Icely, J.D. 2015. A review of the application and evolution of the DPSIR framework with an emphasis on coastal social-ecological systems. Ocean & Coastal Management 103:63–77. https://doi.org/10.1016/j.ocecoaman.2014.11.013

Glomsrød, S., Duhaime, G., Aslaksen, I., eds. 2017. The economy of the North 2015. Oslo-Kongsvinger: Statistics Norway. https://www.zbw.eu/econis-archiv/handle/11159/2919

Gomes Júnior, A.d.A., and Schramm, V.B. 2022. Problem structuring methods: A review of advances over the last decade. Systemic Practice and Action Research 35:55–88. https://ideas.repec.org/a/spr/syspar/v35y2022i1d10.1007_s11213-021-09560-1.html

Gupta, J., Scholtens, J., Perch, L., Dankelman, I., Seager, J., Sánder, F., Stanley-Jones, M., and Kempf, I. 2020. Re-imagining the driver-pressure-state-impact-response framework from an equity and inclusive development perspective. Sustainability Science 15:503–520. https://doi.org/10.1007/s11625-019-00708-6

Horejsova, T., and Paris, C.M. 2013. Tourism and the challenge of Arctic governance. International Journal of Tourism Policy 5(1/2). https://doi.org/10.1504/IJTP.2013.054050

Jerneck, A., Olsson, L., Ness, B., Anderberg, S., Baier, M., Clark, E., Hickler, T., et al. 2011. Structuring sustainability science. Sustainability Science 6:69–82. https://doi.org/10.1007/s11625-010-0117-x

Kruse, F. 2016. Is Svalbard a pristine ecosystem? Reconstructing 420 years of human presence in an Arctic Archipelago. Polar Record 52(5):518–534. https://doi.org/10.1017/S0032247416000309

Kyriazopoulos, A., Skre, O., Sarkki, S., Wielgolaski, F.E., Abraham, E.M., and Ficko, A. 2017. Human-environment dynamics in European treeline ecosystems: A synthesis based on the DPSIR framework. Climate Research 73:17–29. https://doi.org/10.3354/cr01454

Lewison, R.L., Rudd, M.A., Al-Hayek, W., Baldwin, C., Beger, M., Lieske, S.N., Jones, C., Satumanatpan, S., Junchompoo, C., and Hines, E. 2015. How the DPSIR framework can be used for structuring problems and facilitating empirical research in coastal systems. Environmental Science & Policy 56:110–119. https://doi.org/10.1016/j.envsci.2015.11.001

Lovecraft, A.L., and Meek, C.L. 2019. Arctic coastal systems: Evaluating the DAPSI(W)R(M) framework. Coasts and Estuaries: The Future. 671–686. https://doi.org/10.1016/B978–0-12–814003–1.00039–3

Mandić, A. 2020. Structuring challenges of sustainable tourism development in protected natural areas with driving force-pressure-state-impact-response (DPSIR) framework. Environment Systems and Decisions 40(4):560–576. https://ideas.repec.org/a/spr/envsyd/v40y2020i4d10.1007_s10669-020-09759-y.html

Marín, S.L., Borja, Á., Soto, D., and Farias, D.R. 2021. Salmon farming: Is it possible to relate its impact to the waste remediation ecosystem service? In: Peri, P.L., Martínez Pastur, G., and Nahuelhual, L., eds. Ecosystem services in Patagonia: A multi-criteria approach for an integrated assessment. New York: Springer. 249–269. https://doi.org/10.1007/978–3-030–69166–0_12

Martins, J.H., Camanho, A.S., and Gaspar, M.B. 2012. A review of the application of driving forces—pressure—state—impact—response framework to fisheries management. Ocean & Coastal Management 69:273–281. https://doi.org/10.1016/j.ocecoaman.2012.07.029

Maxim, L., Spangenberg, J.H., and O'Connor, M. 2009. An analysis of risks for biodiversity under the DPSIR framework. Ecological Economics 69(1):12–23. https://doi.org/10.1016/j.ecolecon.2009.03.017

Millenium Ecosystem Assessment. 2003. Ecosystems and human well-being. A framework for assessment. Washington DC: Island Press. http://pdf.wri.org/ecosystems_human_wellbeing.pdf

Mozumder, M.M.H., Pyhälä, A., Wahab, M.A., Sarkki, S., Schneider, P., and Islam, M.M. 2019. Understanding social-ecological challenges of a small-scale Hilsa (Tenualosa ilisha) fishery in Bangladesh. International Journal of Environmental Research and Public Health 16(23): 4814. https://doi.org/10.3390/ijerph16234814

Mustika, P.L.K., Welters, R., Ryan, G.E., D'Lima, C., Sorongon-Yap, P., Jutapruet, S., and Peter, C. 2017. A rapid assessment of wildlife tourism risk posed to cetaceans in Asia. Journal of Sustainable Tourism 25(8):1138 – 1158. https://doi.org/10.1080/09669582.2016.1257012

Niemeijer, D., and de Groot, R.S. 2006. Framing environmental indicators: Moving from causal chains to causal networks. Environment, Development and Sustainability 10(1):89–106. https://doi.org/10.1007/s10668–006–9040–9

Nurmi, P. 2017. Green mining—A holistic concept for sustainable and acceptable mineral production. Annals of Geophysics. 60. https://doi.org/10.4401/ag-7420

Ólafsdóttir, R. 2021. The role of public participation for determining sustainability indicators for Arctic tourism. Sustainability 13(1):295. https://doi.org/10.3390/su13010295

Paillet, Y., Campagnaro, T., Burrascano, S., Gosselin, M., Ballweg, J., Chianucci, F., Dorioz, J., et al. 2021. With great power comes great responsibility: An analysis of sustainable forest management quantitative indicators in the DPSIR framework. Preprint. https://doi.org/10.1101/2021.02.11.430737

Potschin, M. 2009. Land use and the state of the natural environment. Land Use Policy 26:S170–S177. https://doi.org/10.1016/j.landusepol.2009.08.008

Reckermann, M., Omstedt, A., Soomere, T., Aigars, J., Akhtar, N., Bełdowska, M., Bełdowski, J., et al. 2022. Human impacts and their interactions in the Baltic Sea region. Earth System Dynamics 13(1):1–80. https://esd.copernicus.org/articles/13/1/2022/

Reid, W.V., Mooney, H.A., Cropper, A., Capistrano, D., Carpenter, S.R., Chopra, K., Dasgupta, P., et al. 2005. Millennium ecosystem assessment: Ecosytems and human well-being—Synthesis. https://www.millenniumassessment.org/documents/document.356.aspx.pdf

Rempel, J.M. 2012. Exploring the causal nexus of tourism impacts on quality-of-life. In Uysal. M., Perdue, R.R., and Sirgy, M.L., eds. Handbook of tourism and quality-of-life research. New York: Springer Science+Business Media. 583–606. https://nibmehub.com/opac-service/pdf/read/Handbook%20of%20Tourism%20and%20Quality%20of%20Life%20Research.pdf

Rounsevell, M.D.A., Dawson, T.P., and Harrison, P.A. 2010. A conceptual framework to assess the effects of environmental change on ecosystem services. Biodiversity and Conservation 19:2823–2842. https://doi.org/10.1007/s10531-010-9838-5

Ruan, W., Li, Y., Zhang, S., and Liu, C.-H. 2019. Evaluation and drive mechanism of tourism ecological security based on the DPSIR-DEA model. Tourism Management 75:609–625. https://doi.org/10.1016/j.tourman.2019.06.021

Saarinen, J., and Varnajot, A. 2019. The Arctic in tourism: Complementing and contesting perspectives on tourism in the Arctic. Polar Geography 42(2):109–124. https://doi.org/10.1080/1088937X.2019.1578287

Sanon, V.-P., Toé, P., Caballer Revenga, J., El Bilali, H., Hundscheid, L.J., Kulakowska, M., Magnuszewski, P., et al. 2020. Multiple-line identification of socio-ecological stressors affecting aquatic ecosystems in semi-arid countries: Implications for sustainable management of fisheries in sub-Saharan Africa. Water 12(6): 1518. https://doi.org/10.3390/w12061518

Sarkki, S., Komu, T., Heikkinen, H.I., Acosta García, N., Lépy, É., and Herva, V.-P. 2016. Applying a synthetic approach to the resilience of Finnish reindeer herding as a changing livelihood. Ecology and Society 21(4): 14. https://www.jstor.org/stable/26270038

Spitz, K., and Trudinger, T. 2008. Mining and the environment. From ore to metal. London: Taylor & Francis.

Svarstad, H., Petersen, L.K., Rothman, D., Siepel, H., and Wätzold, F. 2007. Discursive biases of the environmental research framework DPSIR. Land Use Policy 25(1):116–125. https://doi.org/10.1016/j.landusepol.2007.03.005

Tscherning, K., Helming, K., Krippner, B., Sieber, S., and Paloma, S.G.Y. 2011. Does research applying the DPSIR framework support decision making? Land Use Policy 29(1):102–110. https://doi.org/10.1016/j.landusepol.2011.05.009

Vacik, H., Wolfslehner, B., Seidl, R., and Lexer, M.J. 2007. Integrating the DPSIR approach and the analytic network process for the assessment of forest management strategies. In: Reynolds, K.M., Thomson, A.J., Kohl, M., Shannon, M.A., Ray, D., and Rennols, K., eds. Sustainable forestry: From monitoring and modelling to knowledge management and policy science. CAB International. https://doi.org/10.1079/9781845931742.0393

Wolfslehner, B., and Vacik, H. 2008. Evaluating sustainable forest management strategies with the analytic network process in a pressure-state-response framework. Journal of Environmental Management 88(1):1–10. https://doi.org/10.1016/j.jenvman.2007.01.027

———. 2011. Mapping indicator models: From intuitive problem structuring to quantified decision-making in sustainable forest management. Ecological Indicators 11(2):274–283. https://doi.org/10.1016/j.ecolind.2010.05.004