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

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APPENDIX

DPSIR Framework in Selected Industries Outside the Arctic

This appendix presents examples of the DPSIR framework that have been applied in selected industries outside the Arctic. Case studies were available for all the sectors except for Indigenous livelihoods.

Aquaculture and Fisheries: Martins et al. (2012) conducted a comprehensive review of indicators selected to apply the DPSIR framework to this sector. Indicators were organized according to two criteria: the DPSIR categories and the four sustainable development pillars (environment, society, economics, governance). The ecological dimension included natural environment features (species, chemical, and physical variables); the social dimension represented the characteristics of the fishing community (employment/unemployment, culture, tradition, level of education, number of fishers); the economic dimension included vessels and devices, profits, demand, and consumption; and the governance dimension was related to measures adopted to improve the other dimensions.

In a specific case study, Mozumder et al. (2019) provide a good example of how it is possible to integrate equity and justice into DPSIR analysis through participative identifications of indicators. The authors conducted interviews and focus groups with local fishers and other stakeholders in localities in Bangladesh. They considered important social factors underlying the exploitation of fisheries and created suggestions for better and more effective policies arising from local fishers' knowledge.

A mixed approach (review of scientific literature and participative methods-based research) in the definition of categories and in the selection of indicators was chosen by Sanon et al. (2020) for the analysis of their case study in countries in southern Africa.

Marín et al. (2021) used a modified version of the DPSIR framework, DAPSI(W)R(M), to assess impacts of salmon farming in Chile in relation to organic waste accumulation in marine water. AMBI (a software developed by AZTI's Marine Biotic Index) indicators were proposed for Impact assessment. The authors discuss the use of different environmental indicators and stress the importance of monitoring to set sustainable goals and policy strategies to achieve them, balancing rights and responsibilities in the use of marine resources and ecosystem services.

Forests: Paillet et al. (2021) focused on important but still limited policy-monitoring processes. They organized DPSIR categories according to indicators from the Forest Europe 2020 report that are relevant for the European Arctic. They note that most are State and Impact indicators, and that there is a lack of Drivers and Pressures indicators, making it difficult to have a complete view of the processes that affect forest ecosystems. For example, no indicator about climate change is included.

Vacik et al. (2007) improved the systems analysis view of the DPSIR framework by combining a set of criteria and indicators, multi-criteria decision-making techniques, and a modelling approach. To account for the interconnectedness of indicators, they used the analytic network process to evaluate four forest management plans according to the

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DPSIR framework by modelling the priorities of indicators and strategies as a result of their relationships within the network. The study shows that the limited analytical perspective of the original DPSIR framework can be enhanced to involve and inform stakeholders. The authors also provided a complete set of indicators.

Tourism: Mandić (2020) considered the specific challenges of tourism in natural protected areas, adopting an inductive approach for the development of a general DPSIR framework. This paper did not focus on specific case studies but used inductive and ground theory to recreate the causal chain from Drivers to Responses. The DPSIR framework was used to identify the causal relation of challenges affecting ecosystems and communities in areas where nature-based tourism is practised and to define potential responses to support sustainable development. On one hand, tourism can have positive impacts both on the environment and local communities. The growth of nature-based tourism makes protected areas particularly attractive and can therefore provide new income opportunities and economic development in remote regions. Also, if well managed, it can enhance environmental protection, raise money, and prevent land-use changes. On the other hand, over-tourism is a major threat to fragile environments and local communities whose economic and cultural needs must be considered when planning the management of the protected area to avoid negative social and environmental impacts. The author also stressed the importance of local people's participation in planning, not just to guarantee their right to fair access to natural resources and economic opportunities but to decide in an effective and democratic manner what should be included in the tourist product and what should be kept outside. Local ownership of protected areas is also essential to guarantee the persistence of environmental protection. Since establishing protected areas occurs from political will, it is always possible that protected areas can lose political support or even lose their protected status. The general framework defined by the author is highly relevant in the Arctic context, since the vast majority of tourism in the area is nature-based, and the effective and balanced management of protected areas there can have a major role in the industry's success.

Mustika et al. (2017) applied the DPSIR framework with a different approach; the authors focused more on specific environmental Impacts that could arise in the absence of strong strategies of sustainable management. The specific characteristic of this DPSIR application was the substitution of human-dimension data for ecological indicators and data, to overcome the difficulties, high costs, and long time periods needed to gather reliable data about wildlife behaviour and to produce policy recommendations. The case study considered in the paper is dolphin-watching tourism in Asia. Despite the different geographical area, the study could be consistent with last-chance tourism in the Arctic—the type of tourism that attracts visitors to see endangered species and ecosystems before they are gone, which in turn makes their extinction faster as they add further Pressures on already fragile environments. Furthermore, the paper provides important insights into the social and economic reasons underlying excessive exploitation of natural resources, bringing to light the need to consider the economic requirements of local communities in order to plan holistic and balanced development.

The last example from the tourism sector application of the DPSIR framework is the quantitative approach adopted by Ruan et al. (2019) that assesses tourism ecological security. Tourism ecological security is defined as a balanced state in which the environment can carry out its natural functions while allowing for the tourism industry's sustainable development. The authors provide a complete list of indicators and units of measurement suitable for quantitative analysis.

Mining: Even outside the Arctic context, the application of the DPSIR framework in the mining sector is limited. For a general overview, Spitz et al (2008) provide a diagram with the main variables that affect mining as a sector and list the main Pressures, Impacts, and Responses.

A study conducted by Chen et al. (2020) has more potential for application in an Arctic context. The authors apply the DPSIR framework using quantitative indicators to assess the implementation of green mining in a Chinese case study. This paper provides a complete set of indicators that could be used as a starting point for other applications of the DPSIR framework in the mining sector. Furthermore, being specifically designed to assess sustainability, it fits particularly well in Arctic mining localities, since the need to limit the negative social and ecological impacts of the industry is a growing issue in many northern countries. For example, the green mining concept has been developed in Finland (Nurmi, 2017).

DPSIR in Arctic Non-Industrial Case Studies

We can now consider six applications of the framework in the Arctic context (including some that are outside the industries we selected to discuss). The first, by Alexander et al. (2015), analyzed the different Drivers that put pressure on the northeast Atlantic, causing such adverse environmental effects as contaminant emissions, changes in biological communities due to overfishing, introduction of non-indigenous species, and the presence of microplastic. The authors recognized that Drivers and Pressures are multiple and sometimes competing, leading to high complexity and difficulty for marine environmental governance. To include all the different perspectives, values, and beliefs about priorities and possible solutions, they suggest adopting a soft system approach that can develop a comprehensive understanding of the situation and enable the drawing of different boundaries according to what the system is perceived to be. To structure the information collected in this way, they adopted a modified version of the DPSIR framework: Driver-Pressure-State-Welfare-Response (DPSWR) and present the main limits and potential biases related to it:

Variability of the Ecosystem: The environmental state can vary over time independently of anthropogenic pressures, and it is difficult to disentangle human-induced changes from natural incidents.

Cumulative Effects: Changes in human societies happen over a long time period, and despite improvement of regulation of and responses to Drivers, the pressure could increase from the legacy of previous patterns.

Ecosystem Resilience: An ecosystem can show little response to pressures until a critical threshold is reached and changes become irreversible.

Conflicting Policy Targets: Marine areas are subjected to different regulations created at several levels of governance, each of which tries to pursue different societal goals, which often conflict or call for compromise, such as economic growth and environmental conservation.

This last point is particularly relevant in the Arctic, since it stresses the importance of stakeholder participation in policy design and implementation.

Barton et al. (2016) researched the eutrophication of Vanemfjorden Lake, Norway, mostly due to nutrient loading from agriculture. The resource is affected by different uses: agriculture, recreational use for bathing and fishing, providing drinking water, and being habitat for flora and fauna. As in other studies, these authors stress that ecological value should not be measured only through biophysical indicators but also represent the resource's importance for the actors relying on it. The modified version of the DPSIR framework they proposed (DPSIR-OOBN) should therefore respond to nine criteria:

1. management relevance.
2. value plurality (ecological, social, and economic values).
3. value heterogeneity (variability along time and space).
4. interdisciplinarity.
5. knowledge systems.
6. information types (qualitative and quantitative).
7. evels of societal organization.
8. consistent scaling of plural values, and
9. consistent weighting of the relative importance of multiple types of values, explicitly addressing trade-offs.

The third Arctic paper considered was produced by Bölter et al. (2016); it describes the resilience of polar (both Arctic and Antarctic) ecosystems along the lines of the DPSIR categories. Drivers identified include anthropogenic and natural phenomena, such as human energy consumption, global political constraints, and the North Atlantic Oscillation. Indicators for Pressure, State, and Impact categories are also listed.

Kruse (2016) provides a very interesting and detailed example of a DPSIR application over an extended period. The author interprets 420 years of Svalbard history—from the first expedition to today—through the lens of human pressures on the archipelago's marine and terrestrial ecosystems. They used human presence to estimate anthropogenic pressure and subpopulations of selected species of game animals to understand environmental impacts. Protection policies have been considered as milestones in the relationship between society and environment.

Lovecraft and Meek (2019) focus on the state of Arctic coastlines through a socio-ecological perspective, applying a DAPSI(W)R(M) framework to the whole pan-Arctic coastal system and providing local, smaller scale examples. The authors emphasize the importance of considering feedback loops between society and ecosystems to understand the changes in all four types of ecosystem services (provisioning services, cultural services, regulating services, and supporting services) and the related impacts over the five components of human well-being (security, basic materials for good life, health, good social relations, and freedom of choice and action). The aim is to understand what the appropriate management goals and methods are and to ensure human well-being in relation to Arctic resources, especially considering that virtually all of them are common-pool resources. This makes systems users socio-ecologically interdependent, since both positive and negative externalities in one area of management are likely to impact another. The great variety of dimensions, structures, and compositions in Arctic communities needs also to be considered with a proper scaling of the framework and with the inclusion of different knowledges and cosmologies. The authors also provide a brief description of Arctic populations and governance, including the main Indigenous organizations and government bodies and a complete list of elements in each category of the framework.

Finally, Reckermann et al., (2022) examine human factors affecting the coastal environment of the Baltic Sea region, focusing on their mutual influence. Some of the factors are climate change, acidification, non-indigenous species, land cover and use, aquaculture, agriculture and nutrient load, dumped military material, tourism, and offshore wind farms. They used the DPSIR framework to "assign a structure to the different factors and their link to environmental changes" (Reckermann et al., 2022:6). For every factor, they identify Drivers, Pressure, State, Impact, and Responses, to give each a clear definition. For example, for "dumped military material," the Driver is the Second World War, and determines that "dumping of unexploded warfare agents in various locations" is a Pressure. State is thus "current state of corrosion of dumped warfare agents," whose change will turn into "potentially harmful impacts on marine ecosystems, potential danger of poisoning and accumulation up the food chain up to humans" Impact. The identified Response is "various national and international efforts to retrieve the dumped objects as far as possible" (Reckermann et al., 2022:5). They then proceed to focus on Impacts, whose assessment and summary is the focus of the paper.

TABLE S1. Summary of indicators used in the Arctic industries case studies.

Article	Location	Sector/topic	D – Drivers	P – Pressures	S – State	I – Impact	R – Responses
Dempsey et al., 2017	Grand Bank, Canada	Fisheries	**Human-related indicators**: social and political motivation for fishing; **large scale environmental metrics**: NAO (Winter North Atlantic Oscillation), AMO (Atlantic Multidecadal Oscillation)	**Human use indicators**: human population, landings, income, proportion of commercial species in the total catch. **Environmental indicators**: water temperature and salinity, sea ice, stratification index	**Fish community**: biomass, trophic level	decreases of human population in Newfoundland after collapse of fish biomass	Fishing moratoria
Kyriazopoulos et al., 2017	Different case studies in Europe. Arctic and sub-arctic localities: Almenningar, southern Iceland; Dovre Mt., Central Norway; Khybini Mts., Kola Peninsula (Russia); Kilpisjärvi-Käsivarsi region, northwestern Finnish Lapland; Lake Torneträsk catchment (Abisko, Sweden); Muonio, north western Finnish Lapland; northern Fennoscandia (Finland and Norway); northern Norway; northern Scandinavia (Norway/Sweden); southern Norway (Hardangervidda).	Forests (treeline ecotone dynamics)	**Both anthropogenic and environmental**: climate change; land use change; volcanic activity	**Land use changes**: abandonment of traditional pastoral activities or overgrazing; tourism; industrial development; large predator conservation policies. **Climate change**: warming climate; less precipitation; local climate fluctuations	**Combined climate change and land use change**: reduced time with snow cover; increased number of predators; soil erosion, trampling, nitrification; encroachment; droughts; disturbances; treeline shift downwards;	**Combined climate change and land use change**: wind, wildfires, avalanches, root diseases, insect outbreaks, loss of biodiversity, predation on herds, reduced aesthetic value and shorter skiing season, reduced pastures	Generally limited. Use of artificial snow, intensive herding and State compensation, land-use zoning, agri-environmental schemes, adaptive and climate-smart silviculture and rules about access to protected areas, collaborative land-use planning, hazardous fuels reduction programs and rick assessment.

TABLE S1: Summary of indicators used in the Arctic industries' case studies – *continued:*

Article	Location	Sector/topic	D – Drivers	P – Pressures	S – State	I – Impact	R – Responses
Òlafsdòttir, 2021	Snæfellsjökull National Park, Iceland	Tourism	**Society and wellbeing**: population growth, local image and culture according to residents, sustainability and environmental awareness of tourists	**Economy**: transportation and traffic; direct income from tourism. **Society and wellbeing**: travel behaviour and length of stay. **Environment**: environmentally friendly management; waste management; energy use; off-road driving	**Economy**: job opportunities and state of labour market; economic standard of living and pricing; seasonal and all-year residence; condition of roads and parking areas; indirect income from tourism; seasonal work. **Society and wellbeing**: sustainability and environmental awareness of residents; resident's public health; quality of service; contentment of living standards of tourism employees; National Park empolees' views of tourists. **Environment**: carrying capacity of vegetation and soil; biodiversity; geodiversity; air pollution; coastal erosion; freshwater resources. **Governance**: residents' experience of the national park; national park's human resources and knowledge of sustainable development	**Society and wellbeing**: residents' experience of tourism; tourists' experience and satisfaction; local equality. **Environment**: climate change	**Economy**: local production and utilization of goods and services; lavatories and other sanitary facilities for tourists; opportunities for local innovation. Society and wellbeing: residents' education and training. **Environment**: nature conservation; cultural heritage and history. **Governance**: sustainable development policy making; long term appropriation of founding for the national park; zoning and regional planning for tourism; sustainability monitoring; public participation in policy making; safety issues and information flow of tourists

TABLE S1: Summary of indicators used in the Arctic industries' case studies – continued:

Article	Location	Sector/topic	D – Drivers	P – Pressures	S – State	I – Impact	R – Responses
Rempel, J.M., 2012	North Vancouver Island, Canada	Tourism	**Negative tourism impact:** mass tourism	**Negative tourism impact**: foreign investment; peripherality; SMEs lacking coordination; lack of training and certification; tourism looking for best dollar value without considering impacts; globalization; global economic factors; lack of cultural sensitivity and understanding	**Negative tourism impact**: rate of property value change; change in price of goods and services; migration demographics; number of km^2 protected areas; ratio development: pristine lands; number of habituated/problem wildlife destroyed; air quality parameters; traffic accidents/ annum; alcohol sales; drug related arrests; noise; casino development; % employment assistance in off-season; %dependence on tourism; %First Nations speaking Kwakiutl; number of sacred and historical sites	**Negative tourism impact**: *goods and services*: less affordable housing; unfair increase in home prices and property tax; benefits to only a small % of community; unfair increases in rent; more expensive – food, clothing, and services. *Environment*: damage nature; water pollution and use too much of water; disturb wildlife; large stores put local businesses out of business; destruction of sacred and historical sites; littering. *Urban environment*: air pollution; more traffic and accidents; more drugs, alcohol and prostitution; noise pollution; more gambling; littering. *Employment*: tourism jobs replace traditional forms of employment. *Culture*: destruction of sacred and historical sites; loss of culture and traditions	**Negative tourism impact**: 1.Taxation and distribution to promote equity; subsidies for low income housing and essential goods and services; limit foreign investment 2. Limited numbers of tourists; appropriate signs; tourism operator guidelines and certification; community based ecosystem monitoring 3. Technological innovation; monitoring; legislation; education. 4. Marketing includes traditional craft in cultural tourism; tourism diversification—storm watching; employment training 5. Historic Fort Rupert Community Project; catalogue cultural capital

TABLE S1: Summary of indicators used in the Arctic industries' case studies – *continued:*

Article	Location	Sector/topic	D – Drivers	P – Pressures	S – State	I – Impact	R – Responses
Sarkki et al., 2016	Northern Finland	Reindeer herding (Indigenous livelihood)	**Positive tourism impact**: sustainable tourism -	**Positive tourism impact**: high hopes that tourism can offset declines in fishing, logging and mining; community connection to nature; protection of local environment and cultural heritage; provide benefits to local community **External pressures**: competing land use and decreasing availability of good-quality grazing lands; fragmentation and changing availability of different types of pastures due to other land uses and predators throughout the annual pasture rotation; annually shifting number of predators; weather conditions: temperature, precipitation, frost; changing status of reindeer herding as a respected livelihood **Internal Pressures**: number of reindeer may exceed the ecological carrying capacity of available grazing lands; internal competition on grazing lands among herders	**Positive tourism impact**: unemployment rate; average NVIC; income; local business; success rate; youth outmigration; number of km^2 protected areas; $ earned for protected area creation/management; % economy based on cultural and recreational ecosystem services; high school and college graduation %; municipial tax revenue; number of new roads; % public transport spatial coverage; timing of public transport; number of new restaurants, bars, hotels and B&B's per annum **Diversity and redundancy**: number and abundance of certain plant species used by reindeer as fodder in different parts of annual cycles; access of herders to alternative pastures; diversity of local knowledge regarding reindeer herding; extent of collective actions also to substitute individuals' practical tasks; diversity and amount of technological and economic resources; alternative and substituting sources of income. **Connectivity**: existence and quality of connections between grazing lands; quality of social relationships between herders; existence and quality of relationships between herders and other land users and policymakers. **Slow variables and feedbacks**: how much peaceful pastures (slow variable) are decreased due to other land use causing	**Positive tourism impact**: *socio-economic*: more money for whole community; more profits for local businesses; employment–more jobs, better pay; give youth hope for future opportunities; stronger local economy; more entertainment and recreation options; more restaurants, bars, hotels and B&B's *Environmental protection*: better quality-of-life; protect wildlife: care for environment and make area look better; less damage to environment than logging, mining and commercial fishing; create parks and protected areas *Safeguard cultural ecosystem services*: protection and preservation of traditional knowledge about nature; better understanding of different cultures and communities; education and increased environmental awareness; generate money to manage protected areas. *Infrastructures*: better public transport; better services (water, gas, electricity, internet, phone); better protection from police and fire-fighters; better roads and community facilities; more restaurants, bars, hotels and B&B's **Will the impacts cause thresholds to be exceeded: voluntary versus forced development?** changes in total number and weight of slaughtered reindeer in reindeer herding cooperatives and in subherds owned by individuals; changes in	**Positive tourism impact**: 1. Collective marketing; community fund for training scholarships; tourism management partnership/ cooperative 2. Community based ecosystem monitoring; tourism operator guidelines and certification; designated protected areas; land use planning; certification 3. Educational programs; training locals; tourism operator certification 4. Users fees from nature-based tourism **Policy and governance responses by external actors:** implementing and monitoring maximum number of reindeer within reindeer herding cooperatives; financial mechanisms to compensate for losses; implementing participatory land use planning: representative participation; quality of participation: what are the possibilities for herders to genuinely affect decision making? **Adaptation measures undertaken by reindeer herders:** supplementary feeding; building and using communal local meat processing facilities; changes in annual pasture usage cycle of herding due to environmental changes; calving inside pens to reduce losses due to predation; development of tourism-related reindeer products.

Table 3 Summary of indicators used in the Arctic industries' case studies – *continued:*

Article	Location	Sector/topic	D – Drivers	P – Pressures	S – State	I – Impact	R – Responses
Sarkki et al., 2016 *– continued:*			–		intensification of pasture use (feedback); whether new generations continue herding (slow variable) and how it is impacted by rather poor profitability of herding (feedback); whether and how collective identity of herders (slow variable) is reinforced by collective actions in herding practice (feedback)	annual communal herding practices; changes in body weights, reproduction, survival, and productivity of reindeer herds	