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Socio-economic transformation follows environmental change on Svalbard

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Abstract: The European Arctic, which includes the Svalbard archipelago, is situated in one of the areas showing most notable changes due to global warming and associated cascade events and processes. The main driving factor, temperature rise, is continuing to cause a large-scale overall decline in ice, from glacier retreating, less coastal land-fast ice to thinning and shrinking of open-sea pack ice. This, together with increased inflow of Atlantic waters, is causing profound changes in the local fauna, food web and biodiversity. In parallel, changes in landscape are also notable, mainly due to increasing coastal erosion and glacial melt. Over the past decades, both the traditional hunting-trapping lifestyle and mining have declined almost to the point of non-existence. At the same time, destination tourism and scientific research have become the major industries, both associated with an increase in the size of the main settlement of Longyearbyen, and thus also service jobs and local administration. Along with the shrinking of the glaciated Arctic landscape, the archipelago exemplifies the broadest level of nature protection in Europe. Strict environmental regulations that restrict and even prohibit human activities in large areas contribute to Svalbard being one of the best formally protected wilderness environments in the entire Arctic. Thus, as Svalbard marine ecosystems continue to change, they also are becoming more accessible to humans, and so also anthropogenic pressures are both changing and increasing in extent. We provide a compilation of both ecosystem components and human activities, together with indications of how these are, in parallel, changing. This forms the basis for future ecosystem and societal valuation assessments.

Keywords: European Arctic, climate change, human impact, societal change, biodiversity.

Introduction

The first documented visit to Svalbard archipelago was from the Dutch merchant expedition led by Willem Barents in 1596. Very soon thereafter, European whalers and seal hunters moved to this area, effectively depleting the stocks of baleen whales by the end of the XVII century (Basberg and Hacquebord 2023) and walruses by the end of the XIX century. In the XIX century until mid-XX century, the main human inhabitants of the archipelago were dispersed trappers, targeting polar bears, seals, polar foxes and beluga whales, with a gradual increase in miners exploiting coal, gypsum and asbestos (Barr 2021). The legal status of the archipelago was settled in the Svalbard Treaty of 1920, followed by the Svalbard Act of 1925, when Norway became the formal owner of the area with guaranteed free access for the countries that signed the Svalbard Treaty.

The mining industry was most active from around the 1920s until the 1980s/early1990s, primarily focused around four settlements along the west coast: Longyearbyen, Barentsburg, Pyramiden in the Isfjorden area (78°N) and Ny Ålesund, somewhat farther north. The Norwegian-run Ny Ålesund operations were closed after a tragic mine accident in the 1960s. Mining activities in Longyearbyen have been phased out during the recent decade due to international pledges to reduce fossil fuel consumption and now only produces coal to fuel the centralized energy supply for the settlement/town of Longyearbyen. There are plans in place to introduce renewable energy to the settlement within the next decade. There was an attempt to introduce a fifth mining hub in Svea, located south of Longyearbyen, in Van Mijenfjorden. Due to the aforementioned political decision to abstain from fossil fuel exploitation, all the latter activities have now ceased, and the local environment is being restored to its original state, using historical evidence as a reference.

The various mining enterprises have left a legacy of permanent infrastructure and certainly in the case of Longyearbyen, a large and now semi-urban, although still Arctic-oriented settlement. The port of Longyearbyen remains the largest on the archipelago, but several other small-scale harbors are in operation. Some of the infrastructure left by the abandoned mining industry, most notably at Ny Ålesund, have become key research hubs, offering laboratory and accommodation facilities for Arctic researchers. The Russian mining settlement of Pyramiden was disbanded in the early 1990's and, after a period of disuse, is now a destination for tourism. Barentsburg remains as a Russian industrial site, with various research activities and some international tourism.

At the same time, expedition tourism to Arctic destinations has been rapidly expanding during the past decades. These expeditions can be broadly categorized as those operating from small vessels (less than 20 persons), offering very exclusive experiences, to larger vessels (up to 750 passengers) where the emphasis is on visiting the Arctic and its biodiversity. In the recent decade, destination tourism has increasingly evolved into very large cruise ships (more than 3000 passengers each), offering a combination of polar experiences, eco-excursions, and leisure/luxury trips.

These activities have resulted in quite mixed experiences amongst the local population and the regulatory authorities. From a practical perspective, the town of Longyearbyen, which has around 2400 permanent residents, simply does not have the infrastructure to cope with an influx of people that double or even triple the population within short shore-visits.

Many countries world-wide have had a research presence on Svalbard since the mid 1900s and today researchers are the most numerous group of visitors, aside from tourists. The acquired knowledge on the nature and scale of environmental changes is stored in openly available databases, but especially in recent years, there has been a focus on societal changes in the Arctic (Schlegel and Gattuso 2023). However, there is no standardized methodology to assess environmental- societal nexus and our paper is a step towards such goal. We focus on the marine realm, as on Svalbard the terrestrial, *i.e.*, tundra biome is a minor part of the archipelago. This paper presents data on natural goods and services, as a basis for analysis of documented and predicted changes across the archipelago, with associated socio-economic consequences.

Material and Methods

Data on environmental change, expressed by temperature rise, fast ice shrinking, coastal change, follows Węsławski and Urbański (2024) that is based on the wide array of satellite imagery data summarized for the period 1980–2020. Spatial information on the protected areas was adopted from Vongraven (2014). The remainder of the information comes from published material cited in the text, supplemented by the long term *in situ* experience of the present authors.

Results and discussion

Physical environment change

Climate change in the European Arctic is believed to be occurring at a faster rate than in all other regions (ACIA 2005), modifying the local environment in a most profound way. Temperature rises in both air and water has been documented around Svalbard, averaging for both *ca.* 2°C rise over the last 20 years (Strzelewicz *et al.* 2022). Accompanying this temperature rise is de-icing, including diminishing pack-ice cover and thickness (Stocke *et al.* 2020), shorter season of fast ice presence (Urbański and Litwicka 2022), glacier retreat (Błaszczyk *et al.* 2009) and melting of the permafrost (Etzelmüller *et al.* 2011). These macroscale changes influence the regulatory services of the ecosystem (Table 1) with most profound change in albedo and temperature exchange between ocean and the atmosphere.

Associated phenomena are physical coastal changes, notably erosion and permafrost-melt (Strzelecki *et al.* 2020). Further consequences include darkening of coastal waters (Konik *et al.* 2021; Moreno and Szeligowska 2023) as well as the greening of the coastal belt both in terms of shallower expansion of the kelp forests due to less ice scouring and richer vegetation on land due to a warmer and longer growth season (Assis *et al.* 2022). The Arctic is experiencing an increase in species diversity, as a general northward expansion in distributions allows more taxa to inhabit previously unavailable areas. This has resulted in a concurrent increase in the complexity of Arctic food web, with less energy becoming available to the top predators (Węsławski *et al.* 2017). Such profound and multifaceted environmental changes cause concurrent changes in the goods and services provided by Arctic ecosystems, and as a consequence, also marked societal changes. Table 2 summarizes the habitat alteration, with clear cases of diminishing tidal glaciers and expansion of sandy and gravel beaches.

Marine biota change

The implications of these well-defined and described environmental changes on Svalbard are not fully understood for the entire marine biosphere, however, a range of ongoing changes in the marine ecosystem are evident, through long-term observations. Long term observations of the benthos, from sublittoral hard substrate assemblages, show a general trend for a decline in the longevity and body size of the organisms, favoring a greater proportion of small-bodied and more rapidly reproducing species (Beuchel *et al.* 2006; Kortsch *et al.* 2012; Al-Habahbeh

Table 1. Natural goods and services in Svalbard coastal marine ecosystem and their expected change.

Type/name of good	Size prior to 1990	Predicted change
Providing		
fish stocks	limited to shelf and demersal fish	expansion of pelagic and coastal waters fish
shrimp stocks	limited to shelf	decrease due to the fish predation
zooplankton production	high individual energy value and large herbivores range 1g/m^2/yr	lower individual energy value, small herbivores increase
primary productivity	ranging 120g/m^2/year (without sea ice production)	more nutrients, longer vegetation perion, higher share of coastal algae, drop in ice algae production
macroalgae	limited by ice scouring and siltation	increase in area and biomass
Regulatory		
erosion controll	coast protected by long freeze and fast ice presence	increased erosion due to increased exposition to waves, melt of permafrost
carbon sink	strong as most of primary production sinks ungrazed to the seabed	diminishing as most of primary production will be consumed in the water column
terrestrial carbon source	limited due to the frozen ground	increased du to the melting permafrost and exposed new coastal areas after glacial retreat
climate regulation – cooling	high albedo from ice and snow covered grounds	weaker as the snow and ice cover is being reduced
climate regulation – ocean circulation	dense water sinks in winter period	likely weaker due to smaller temperature gradients between sea and air
climate regulation – heating	sea- atmosphere heat echange	likely weaker due to smaller temperature gradients between sea and air
Socio-cultural		
wildlife watching	limited accessibility	increased logistics, more animals to watch
sense of uniqiue landscape	associated with glaciers and frozenf fjords, important to limited number of local residents	decreasing with de-icing of the archipelago, valid for the increased cruise ships tourism
sense of free space	important for limited number of local residents	decreasing with strict tourist control and administrative regulations
historical, emotional identity	important for limited number of concerned tourists	increased logistics, and concern about polar history

et al. 2020; Søreide *et al.* 2020). Kędra *et al.* (2010) produced an extensive baseline inventory of soft bottom littoral faunal species of south-Svalbard. Intertidal macroalgae (kelps and seagrasses) are shown to be in a more flourishing condition at more Atlantic-influenced sites on Svalbard, compared with those still dominated by Arctic water and more exposed to ice-scouring (Węsławski *et al.* 2010; Krause-Jensen and Duarte 2014; Wiktor *et al.* 2022).

Further, the deep-water benthos of the Hausgarten study area on the continental slope west of Svalbard is being monitored since late 1990s, providing an extremely valuable long-term reference data series (Meyer *et al.* 2013). The recent changes in the pelagic domain on Svalbard have been recorded in fish stocks, with a shift towards a greater proportion of boreal species within the communities (Misund *et al.* 2016; von Biela *et al.* 2022). This "borealisation" trend also has become clearly apparent in both zooplankton (Weydman *et al.* 2014) and microplankton (Szeligowska *et al.* 2020) communities.

Long term studies of a number of seabird species show a distinct switch in diet from Arctic to more boreal- Arctic prey items during the last decade (Vihtakari *et al.* 2018), while the plankton-eating Little auk (*Alle alle*) remains selective to Arctic copepods (Balazy *et al.* 2023). The status of seabirds and sea mammals is regularly assessed by the Norwegian Polar Institute (Descamps *et al.* 2017) and those species with an opportunistic diet show a greater success relative to those restricted to few prey items (Table 3). In terms of mammals, those which are ice-dependent are believed to be in decline (Kovacs *et al.* 2011), with some consequences that are at present difficult to predict. For example, polar bears in the absence of ice

Table 2. Coastal habitats of Svalbard their human use and expected change.

Targeted habitat type	Status on Svalbard	Type of human use	Ongoing and predicted change
Tidal glaciers	decreasing	ship and boat tourism, conservation	ice volume loss, retreat to land
Mountain glaciers and mountains	decreasing	skiing, mountainering, rescue operations	ice volume loss, retreat to high elevations
Beach sandy to gravel	increasing	coastal walks, conservation	increase following the glaciers retreat
Rocky shores and cliffs	increasing	birdwatching	increase following the glaciers retreat
Tundra with rich vegetation	stable to increasing	coastal walks, conservation	increasing following the glacial melt
Dry tundra	increasing	coastal walks, conservation	following the glacial meltwater loss
Stable fast ice on fjords	decreasing	skiing, snowscooters	likley reduced to few weeks per year in innermost fjord basins
Stable snow cover on lowland	stable to increasing	skiing, snowscooters	increased precipitation will result in larger snow fall
Rivers	stable to increasing	freshwater fishing, conservation	increase following the glaciers retreat
Lakes and lagoons	stable to increasing	freshwater fishing, conservation	increase following the glaciers retreat
Tidal flats	stable to increasing	conservation	increase following the glaciers retreat
Fjords	increasing	ship and boat tourism, conservation, rescue operations	following glacial retreat new branches of fjords are being opened

increasingly hunt on the coast on carrion, reindeer, birds and are more likely to encounter humans (Stempniewicz *et al*. 2021) and forage by increasing cabins and human encampments.

The above-mentioned biological observations, that are relatively organized and consistent since late 1990s indicate mostly changes in abundances and frequency of species already known from the area, and very few records of "invasions" or distribution shifts of species from the south (Heuvel-Greve *et al.* 2021). An excellent example is the Atlantic cod (*Gadus morhua*), which is observed in increasing numbers around Svalbard since 2005, yet the species has previously been known sporadically to visit the area in the 1930s and 1950s (Misund *et al.* 2016; Spotowitz *et al.* 2022). The appearance of the thermophilic bivalve (*Mytilus edulis*) was quite spectacular. It was present on Svalbard during the last climate optimum 9000 years ago and then became locally extinct only to re-appear first on Bear Island (Bjørnøya) in 1994 (Węsławski *et al.* 1997) and later on the main Spitsbergen island in 2005 (Berge *et al.* 2005; Leopold *et al.* 2019). Since then, the species is slowly expanding in both abundance and range on Spitsbergen during the past 20 years or so, but not more than within 300 km from the place of the first observations (Kotwicki *et al.* 2021). A similar slow expansion was demonstrated for another boreal species, the intertidal crustacean *Gammarus oceanicus* (Węsławski *et al.* 2020).

It can be summarized that biological responses to the rapid and large-scale changes in the physical conditions are relatively slow and limited on Svalbard, with the exception of some illustrative examples. Most of the species present appear to have a broad capacity to adapt to ongoing changes, and there are currently no specific records of species that have disappeared from the area as a result of environmental change. Part of this phenomenon may simply be explained by the fact that the marine fauna and fauna of Svalbard does not have any specific endemic species, representing rather a subsample of North Atlantic boreo-Arctic fauna (Brattegard and Holthe 2001; Węsławski *et al.* 2017). In terms of changing faunal assemblages, the main facilitating factor is the dissolving of the clear-cut physical borders that once kept cold-water and warm-water species separated (Blacker 1957; Deja *et al.* 2016).

Table 3. Protected and charismatic coastal and marine animals of Svalbard, their human perception and predicted change. References: 1 – Descamps *et al.* (2017), 2 – Søreide *et al.* (2020), 3 – Ottersen and Holt (2023), 4 – Hop and Gjosatter (2013).

Targeted species or group	Status on Svalbard	Ref.	Type of human use	Ongoing and predicted change
Polar bear *Ursus maritimus*	stable + 2000 animals	1	tourism, science, conservation, safety	more animals on the shore and in summer, due to the ice retreat
Walrus *Odobaenus rosmarus*	increasing + 4000 animals	1	tourism, science, conservation	more haul out grounds and population spread all over the archipelago
Reindeer *Rangifer tarandus*	stable + 20.000 animals	1	tourism, science, local hunting	likely increasing with vegetation expansion
Polar fox *Alopex lagopus*	stable + 10.000 animals	1	tourism, science, local hunting	likely increasing with bird populations
Beluga *Delphinapterus leucas*	stable	1	tourism, science, conservation	more animals close to the shore
Baleen whales *Balaenoptera*	increasing	1	tourism, science, limited whaling for minke	more species and larger populations
Dolphins and orcas *Orcinus*	increasing	1	tourism, science, conservation	more species and larger populations
Narwhale *Monodon monoceros*	stable to decreasing	1	tourism, science, conservation	decline in sightings of the species with the ice retreat
Seabird colonies *Rissa tridactyla, Urialomvia*	stable to increasing	1	tourism, science, conservation	increase of fish eaters (gulls, large auks, terns) decrease of plankton feeders (little auks and fulmars)
Tundra birds *Anser, Calidris, Branta*	stable to increasing	1	tourism, science, conservation	increase in species diversity and population size
Ringed seal *Pusa hispida*	decreasing	1	tourism, science, local hunting	decrease with fast ice retreat
Harbor seal *Phoca vitulina*	increasing	1	tourism, science, local hunting	increase with new fish populations
Bearded seal *Erignathus barbatus*	stable to decreasing	1	tourism, science, local hunting	decrease with benthic fish and benthic fauna drop
Salmonid fish *Salvelinus alpinus & Oncorhynhus gorbusha*	stable to increasing	2	tourism, science, local fishing	increase with new freshwater bodies opening
Atlantic marine fish *Gadus, Pollachius, Melanogrammus, Mallotus, Clupea, Scomber*	increasing	3	tourism, science, commercial and local fishing	increasing with biogeographic regime shift North
Arctic marine fish *Boreogadus saida*	stable to decreasing	4	science, conservation	decreasing due to increase of new predators

Societal change

Human social phenomena connected with environmental changes on Svalbard are closely linked with its increasing accessibility for tourism (Guðmundsdóttir. and Sæþórsdóttir 2009; Bonusiak 2021; Dannevig *et al.* 2023). Tour guide companies offer an increasing range of opportunities, tailored to varied levels of fitness, interests and financial budgets, lately also including "dark-season tourism" for, amongst others, northern lights experiences. In parallel, there now are almost daily commercial flights from the Norwegian mainland and an increasing demand for hotel accommodations. The University Centre on Svalbard also has increased its facilities, both in terms of office buildings and student housing complex. The increased presence of both tourists and researchers, with the associated guides and support staff, on the island has driven an increase in the size of the population in general. As a result, shops catering for tourists and winter-sports enthusiasts have blossomed, indeed. Longyearbyen boasts the worlds' northernmost shopping mall – the "Lompensenter". As a result, there has been an increasing need for municipal services, such as energy provision, waste management, drinking water, and general infrastructure. The increasing use of Svalbard as both a recreational and research arena has led to an increased need for formal environmental management by the Governor of Svalbard (Sysselmesteren), within issues including marine and terrestrial protected areas, cultural monuments and governance of rights of access to- and use of the environment (Table 4). Also, as the settlement of Longyearbyen becomes more "urbanized", the need for regular policing services also increases.

Table 4. Societal occupation on Svalbard, its environmental control and perspective.

Type of use	Facilitation	Environmental control	Administrative – managament control	Activity before 1990	Perspective activity towards 2050
local	local organisation	nature hazards, nature protection	Free	limited	increasing with population and demand
profesional	local organisation	nature hazards, nature protection	state regulation, control	diminishing	none
profesional	local organisation	nature hazards, nature protection	registration, permits, control	diminishing	close to none
local	local organisation	nature hazards, nature protection	registration, permits, control	limited, stable	limited
local	local organisation	nature hazards, nature protection	state regulation, control	limited	increasing with population and demand
profesional	market	sustainable population of cod, mackerel, shrimps	state regulation, control	limited to shrimps	increase with new fish stocks
profesional	local organisation	nature hazards, nature protection	registration, permits, control	below 500 persons/year	increase
profesional	local facilities	none	registration, permits, control	below 100 persons/year	increase with facilities provided
profesional	ship' service	ice, storms	registration, permits, control	below 10 research ships/ year	increase with tourism rise
profesional	local organisation	none	state labor law	limited to few emploees	increasing with population and demand
profesional	state and local organisation	nature hazards, nature protection	policy, registration, permits, control	limited	increasing with population and demand
profesional	local organisation	nature hazards, nature protection	registration, permits, control	limited	increasing with population and demand
profesional	state and local organisation	nature hazards, nature protection		limited	increasing with population and demand
tourism	supply shops	sustainable population of salmonids	registration, permits, control	limited	increasing with population and demand
tourism	supply shops, boats	sustainable population of cod, mackerel	not regulated	limited	increasing with population and demand
tourism	local organisation	snow cover and fast ice	zonation, permits, licences, control	limited	decrease with snow and ice limitation
tourism	supply shops	coastal geomorphology	zonation, permits, licences, control	limited	increase with tourism rise
tourism	local rental ser-	weather conditions	zonation, permits,	limited	increase with tourism

Table 4. *continued*

Type of use	Facilitation	Environmental control	Administrative – managament control	Activity before 1990	Perspective activity towards 2050
	vice		licences, control		rise
tourism	harbor facilities	focused on pack ice, tidal glaciers	state regulation, control	limited	increase with tourism rise
tourism	local organisation	common and coastal whales occurrence	zonation, permits, licences, control	limited	increase with tourism rise
tourism	local organisation	presence of large sebird colonies, rare species	zonation, permits, licences, control	limited	increase with tourism rise
tourism	local organisation	polar bear occurrence	zonation, permits, licences, control	limited to cruise ships & snow scooter travels	increase due to coastal bears occurrence
tourism	supply shops	snow cover and fast ice	zonation, permits, licences, control	limited	decrease with snow and ice limitation
tourism	supply shops	stability of rocks and slopes	zonation, permits, licences, control	limited	increase with tourism rise
tourism	local organisation	water transparency	zonation, permits, licences, control	not existing	increasing for nature and historic sites
tourism	supply shops	dry season duration	zonation, permits, licences, control	limited	limited

The changes we now are seeing in the natural environment on and around Svalbard will inevitably cause a change in the human use of the area (Stocke *et al.* 2020), which likely will continue in the foreseeable future (Dannevig *et al.* 2023). On the one hand, opportunities are being opened, such as more harvestable fish, and perhaps also in future large shellfish, in local waters that are highly desirable to local restaurants. Earlier ice-retreat in fjords is both positive, as it allows tourist boats to access areas that previously were ice-bound for much of the year, but on the other hand, many long-established snowmobile transport routes are no longer readily accessible. Much of the marketing of expedition cruises focuses on viewing the charismatic representatives of Arctic marine wildlife, *i.e.*, polar bears, walrus, seals, Arctic reindeer and foxes, puffins, *etc.*, and the merchandise sold for local revenue in shops strongly reflect this. Indeed, the demand for non-mass-produced Svalbard souvenirs also supports a local community of artists and crafts persons, creating bespoke Svalbard-themed items for sale throughout the town.

In connection with the increased population and visiting tourism, especially cruise-ships and expedition vessels, there is a need for increased safety infrastructure, such as improved harbor facilities and regulations as well as provision of emergency preparedness measures, *e.g.*, for shipwreck scenarios including oil-spill containment to evacuation of large numbers of people. As expedition tourism increases, the need for search- and rescue facilities is also increasingly important.

The historical establishment of both mining and research presences on Svalbard undoubtably have political background to maintain a presence on the archipelago as well as to harvest the inherent resources. Although one settlement on Svalbard, Barentsburg, remains a Russian community, the Svalbard Treaty prevents the establishment of military bases on Svalbard, despite the ongoing war in Europe (Svalbard Treaty 1920; Svalbard Act 1925). One perhaps less tangible factor in Svalbard tourism, and indeed people wishing to settle there, is the sense of experiencing one of the last (yet accessible) parts of the "real" Arctic wilderness, which is in rapid decline. Unlike most of Europe, Svalbard does not have roads beyond the few settlements, and the rest of the vast wilderness is only accessible via boat, foot and/or snowmobile (Simoniello *et al.* 2019; Barnes *et al.* 2021; Mamzer *et al.* 2021).

Environmental management

The Svalbard area has been divided into ten management areas, with varying levels of access permits and conservation levels (Gudmundsdóttir and Segmondsdóttir 2009). They are listed in Table 5 with indicated environmental changes in each area. A summary of the environmental changes (cumulative index) is presented in Fig. 1, where the areas with a high level of change (marked red) are also the most visited and commercially used regions of Svalbard. The least changed areas (marked green) are on the eastern coast of Svalbard, where conservation measures are the strictest. The only major human activity in this area is some demersal fishery of cod, shrimps and halibut (Misund *et al.* 2016).

The chain of events that comprises the interlinked phenomena of the warming up of the Svalbard ecosystem are

Table 5. Cumulative index of environmental change in marine and coastal Svalbard management areas shown on Fig. 1. Setup of management areas after https://www.sysselmesteren.no/siteassets/kart/temakart/ferdselsrestriksjoner/ferdsel2022_en.pdf visited 20th October 2024. Index marked as 1– low, 2 – moderate, 3 – high level of change. Colors for the cumulative index value from green (low impact) to red, indicating high level of change.

Manage-ment area no.	Location	Total area (km^2)	Marine area (km^2)	Key uses in the area	SST change 1–3	Fast-ice loss 1–3	Pack-ice loss 1–3	Coastal change 1–3	Cumu-lative change index
1	Nordaust-Svalbard Nature Reserve	55,354.3	36.7	conservation, fishery	1	3	1	2	7
2	Søraust-Svalbard Nature Reserve	21,825.9	25.4	conservation	1	3	1	1	6
3	Sør-Spitsbergen National Park	13,177.3	8.2	research, tourism	2	2	2	3	9
4	Forlandet National Park	4,626.8	4.0	research, tourism	3	3	3	3	12
5	Nordvest-Spitsbergen National Park	9,870.5	6.2	research, tourism, fishery	3	3	3	2	11
6	Nordre Isfjorden National Park	2,952.1	904	research tourism	2	2	3	2	9
7	Indre Wijdefjorden National Park	1,127.1	382	research tourism	1	3	3	1	8
8	Nordenskiöld Land National Park	1,362.3	1.2	research tourism	1	2	3	2	8
9	Bjørnøya Nature Reserve	2,981.3	2.8	conservation, fishery	2	1	2	1	6
9	Hopen Nature Reserve	3,185.6	3.1	conservation, fishery	2	1	2	1	6
10	Sassen-Bünsow Land National Park	1,230.5	73	research tourism	2	2	3	2	9
10	open access Isfjorden area			shipping, fishery, tourism, research	3	3	3	2	11

in summary two key drivers, namely, the increased influx of Atlantic waters into the Arctic system and, in part independent, the concurrent increase in air temperature. Together, the temperature rise driven by these two factors reduces coastal sea-ice and causes glaciers to recede and shrink (Węsławski and Urbański 2024).

The above-mentioned general shift in poikilothermic communities to comprise species with faster growth/fecundity, smaller body size and shorter life cycles, combined with the influx of Atlantic species from the south has repercussions farther within the food web. This shift benefits pelagic fish and fish-eating birds at the expense of plankton-feeding birds and sea mammals (Stempniewicz *et al.* 2007). Primary production may locally rise in open waters, due to the decline in pack-ice cover and thus enhanced light conditions, while melting glaciers will likely lead to increased turbidity and darker surface waters, with a resulting local decline in primary production. The possible change of nutrients discharge is likely to be limited to the narrow areas next to the seabird colonies.

These profound ongoing changes call for increased conservation efforts to save the diminishing uniqueness of the European Arctic. The projected climate change by the end of the 21st century will impact most the of the north-eastern part of the Svalbard protected areas, in a similar manner to the western parts, which already are markedly changed (Vongraven 2014). Stricter regulations are currently being implemented across Svalbard, especially lim-

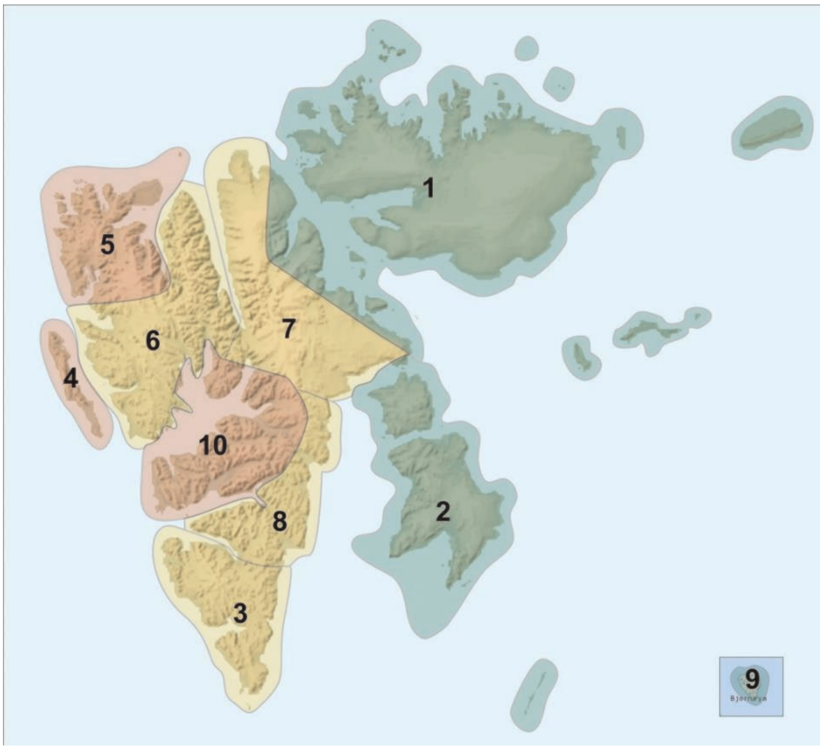

Fig. 1. Cumulative index of environmental change in marine and coastal Svalbard management areas, based on environmental change maps by Węsławski and Urbański (2024). Areas in red (4, 5, 10) are the most impacted, in yellow (3, 6, 7, 8) are moderately changed and in green (1 and 2) are the least impacted; see Table 5.

iting access to large areas in the north-east of Svalbard, which are considered still to be in a pristine condition and least impacted by warming. Other recent management measures aiming to protect wildlife dependent on increasingly scarce fast-ice, such as breeding ringed seals (*Pusa hispida*) in fjords close to human settlements, *e.g.*, by restricting snowmobile traffic (Svalbard Environmental Protection Act 2002). Such measures inevitably also have a negative impact on local residents, researchers and tour operators alike, as areas previously used for recreational, transport, business or study purposes become increasingly inaccessible. Herein lies some of the main challenges in sustainable management of human activities in vulnerable and rapidly changing Arctic environments.

It looks like the ongoing environmental change on Svalbard is regarded by authorities and conservationists as a threat, and considerable effort is directed to halt it or to diminish its effects. On the other hand, number of stakeholders, including fisherman, tour operators and industry, see the change as a benefit, and are ready to use it (Hovelsrud *et al*. 2023). Such situation might be regarded as "wicked environmental problem" (Balint *et al.* 2011) where there is no problem with establishing facts, but conclusion drawn are different for different stakeholders.

At present, there are no internationally accepted standard methodologies for assessing and valuing ecosystems, in terms of both monetary and non-monetary (nature-related) assets as well as the social implications of each of these. Various large-scale and interdisciplinary projects, such as the MARBEFES project (see Acknowledgements), specifically are developing such methodologies. The present work contributes an extensive compilation of ecosystem components and assets, together with the ways in which these currently are changing. This provides the foundation for future more formal ecosystem valuation analyses, standardised to be applicable not just for the Arctic, but also comparable at a pan-European scale.

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References

ACIA. 2005. *Arctic Climate Impact Assessment*. Scientific Report. Cambridge University Press, Cambridge.

Al-Habahbeh A.K., Kortsch S., Bluhm B.A., Beuchel F., Gulliksen B., Ballantine C., Cristini D. and Primicerio R. 2020. Arctic coastal benthos long-term responses to perturbations under climate warming. *Philosophical transactions. Series A, Mathematical, physical, and engineering sciences* 378: 20190355–20190355, doi: 10.1098/rsta.2019.0355.

Assis J., Serrão E.A., Duarte C M., Fragkopoulou E. and Krause-Jensen D. 2022. Major Expansion of Marine Forests in a warmer Arctic. *Frontiers in Marine Science* 9: 850368.

Balazy K, Trudnowska E., Wojczulanis-Jakubas K., Jakubas D., Præbel K., Choquet M., Brandner M., Schultz M., Bitz-Thorsen J., Boehnke R., Szeligowska M., Descamps S., Strøm H. and Błachowiak-Samolyk K. 2023. Molecular tools prove little auks from Svalbard are extremely selective for *Calanus glacialis* even when exposed to Atlantification. *Scientific Reports* 13: 13647, doi: 10.1038/s41598-023-40131-7.

Balint P.J., Stewart R.E., Desai A. and Walters L.C. 2011.Wicked environmental problems. Island Press: 256 pp.

Barnes D.K.A., Sands C.J, Paulsen M.L., Moreno B., Moreau C., Held C., Downey R., Bax N., Stark J.S. and Zwerschke N. 2021. Societal importance of Antarctic negative feedbacks on climate change: blue carbon gains from sea ice, ice shelf and glacier losses. *The Science of Nature* 108: 43, doi: 10.1007/s00114-021-01748-8.

Barr S. 2021. The Nineteenth Century Exploration of Svalbard. *In:* Capelotti P.J. (ed.) *The Coldest Coast*. Historical Geography and Geosciences. Springer, Cham, doi: 10.1007/978-3-030-67880-7_1.

Basberg B. and Hacquebord L. 2023. Industrial whaling in Arctic and Antarctic. *In:* Howkins A. and Roberts P. (eds.) *The Cambridge History of Polar Regions*. Cambridge University Press, Cambridge. .

Berge J., Johnsen G., Nilsen F., Gulliksen B. and Slagstad D. 2005. Ocean temperature oscillations enable reappearance of blue mussels *Mytilus edulis* in Svalbard after a 1000 year absence. *Marine Ecology Progress Series* 303: 167–175, doi: 10.3354/meps303167.

Beuchel F., Gulliksen B. and Carroll M.L. 2006. Long-term patterns of rocky bottom macrobenthic community structure in an Arctic fjord (Kongsfjorden, Svalbard) in relation to climate variability (1980–2003). *Journal of Marine Systems* 63: 35–48, doi: 10.1016/j.jmarsys.2006.05.002.

Blacker R.W. 1957. Benthic animals as indicators of hydrological conditions and climatic changes in Svalbard waters*. Fishery Investigations* 2: 1–49.

Błaszczyk M., Jania J.A. and Hagen J.O. 2009. Tidewater glaciers of Svalbard: recent changes and estimates of calving fluxes*. Polish Polar Research* 30: 85–142.

Bonusiak G. 2021. Development of ecotourism in Svalbard as part of Norway's Arctic Policy. *Sustainability* 13: 962, doi: 10.3390/su13020962.

Brattegard T. and Holthe T. 2001. Distribution of marine, benthic macroorganisms in Norway. A tabulated catalogue. Preliminary edition. *Directorate for nature management. Research Report* 3, Trondheim.

Dannevig H., Søreide J.E., Sveinsdóttir A.G., Olsen J., Hovelsrud G.K, Rusdal T. and Dale RF. 2023. Coping with rapid and cascading changes in Svalbard: the case of nature-based tourism in Svalbard. *Frontiers in Human Dynamics* 5: 1178264, doi: 10.3389/fhumd.2023.1178264.

Deja K., Węsławski J.M., Borszcz T., Włodarska- Kowalczuk M., Kukliński P., Bałazy P. and Kwiatkowska P. 2016. Recent distribution of Echinodermata species in Spitsbergen coastal waters. *Polish Polar Research* 37: 511–526.

Descamps S., Aars J., Fuglei E., Kovacs K., Lydersen Ch., Pavlova O., Pedersen A., Ravolainen V. and Strom H. 2017. Climate change impacts on wildlife in a High Arctic archipelago – Svalbard, Norway. *Global Change Biology* 23: 490–502, doi: 10.1111/gcb.13381.

Etzelmüller B., Schuler T.V., Isaksen K., Christiansen H.H., Farbrot H. and Benestad R. 2011. Modeling the temperature evolution of Svalbard permafrost during the 20th and 21st century. *The Cryosphere* 5: 67–79, doi: 10.5194/tc-5-67-2011.

Guðmundsdóttir A.M. and Sæþórsdóttir A.D. 2009. Tourism Management in Wilderness Háskólaútgáfan), *Tourism Management areas* - Svalbard, í I. Hannibalsson (ritstj.) Rannsóknir í félagsvísindum X, bls: 41–53. Reykjavík.

Heuvel-Greve M van den, van den Brink A.M., Sander T. Glorius, G., de Groot A., Laros I., Renaud P.E., Pettersen R., Węsławski J.M., Kukliński P. and Murk A.J. 2021. Early detection of marine non indigenous species on Svalbard by DNA metabarcoding of sediment. *Polar Biology* 44: 653–665, doi: 10.1007/s00300-021-02822-7.

Hop H. and Gjøsæter H. 2013. Polar cod (*Boreogadus saida*) and capelin (*Mallotus villosus*) as key species in marine food webs of the Arctic and the Barents Sea. *Marine Biology Research* 9: 878–894, doi: 10.1080/17451000.2013.775458.

Hovelsrud G.K, Olsen J., Nilsson A.E., Kaltenborn B. and Lebel J. 2023. Managing Svalbard Tourism: Inconsistencies and Conflicts of Interest. *Arctic Review on Law and Politics* 14: 86–106.

Kędra M., Gromisz S., Jaskuła R., Legeżyńska J., Maciejewska B., Malec E., Opanowski A., Ostrowska K., Włodarska-Kowalczuk M. and Węsławski J.M. 2010. Soft bottom fauna of an All Taxa Biodiversity Site – Hornsund (77oN, Svalbard). *Polish Polar Research* 31: 309–326.

Konik M., Darecki M., Pavlov A., Sagan S. and Kowalczuk P. 2021. Darkening of Svalbard fjords waters observed with satellite ocean color imagery in 1997–2019. *Frontiers of Marine Science* 8: 699318, doi: 10.3389/fmars.2021.699318.

Kortsch S., Primicerio R., Beuchel F., Renaud P.E., Rodrigues J., Lonne O.J. and Gulliksen B. 2012. Climate-driven regime shifts in Arctic marine benthos. *Proceedings of the National Academy of Sciences of the United States of America* 109: 14052–14057.

Kotwicki L., Węsławski J.M., Włodarska-Kowalczuk M., Mazurkiewicz M., Wenne R., Zbawicka M., Minchin D. and Olenin S. 2021. The re-appearance of the *Mytilus* spp. complex in Svalbard, Arctic, during the Holocene: The case for an arrival by anthropogenic flotsam. G*lobal and planetary change* 202: 103502, doi: 10.1016/j.gloplacha.2021.103502.

Kovacs K.M., Lydersen C., Overland J.E. and Moore S.E. 2011. Impacts of changing sea-ice conditions on Arctic marine mammals. *Marine Biodiversity* 41: 181–194, doi: 10.1007/s12526-010-0061-0.

Krause-Jensen D. and Duarte C. 2014. Expansion of vegetated coastal ecosystems in the future Arctic. *Frontiers in Marine Science* 1, doi: 10.3389/fmars.2014.00077.

Leopold P., Renaud P., Ambrose W.G. Jr. and Berge J. 2019. High Arctic *Mytilus spp:* occurrence, distribution and history of dispersal*. Polar Biology* 42: 237–255.

Mamzer H., Skedsmo P.V. and Węsławski J.M. 2021. Attitudes towards the polar regions as a reflection of the sense of responsibility for the environment. Theoretical background for further study. *Frontiers in Environmental Science* 9: 610926, doi: 10.3389/fenvs.2021.610926.

Meyer K.S., Bergmann M. and Soltwedel T. 2013. Interannual variation in the epibenthic megafauna at the shallowest station of the HAUSGARTEN observatory (79° N, 6° E). *Biogeosciences* 10: 3479–3492, doi: 10.5194/bg-10-3479-2013.

Misund O.A., Heggland K., Skogseth R., Falck E., Gjøsæter H., Sundet J., Watne J. and Lønne O.J. 2016. Norwegian fisheries in the Svalbard zone since 1980. Regulations, profitability and warming waters affect landings. *Polar Science* 10: 312–322.

Moreno B. and Szeligowska M. 2023. Browning and blueing – what is the fate of polar coasts? *Frontiers in Ecology and Environment* 21: 156-156, doi: 10.1002/fee.2617.

Ottersen G. and Holt R.E. 2023. Long-term variability in spawning stock age structure influences climate–recruitment link for Barents Sea cod. *Fisheries Oceanography* 32: 91–105.

Schlegel R.W. and Gattuso J.P. 2023. A Dataset for Investigating Socio-ecological Changes in Arctic Fjords. *Earth System Science Data* ESSD, 15, 3733–3746, doi: 10.5194/essd-2022-455.

Simoniello C., Jencks J., Lauro F.M., Loftis J.D., Węsławski J.M., Deja K., Forrest D.R., Gossett S., Jeffries T.C., Jensen R.M., Kobara S. Nolan L., Ostrowski M., Pounds D., Roseman G., Basco O., Gosselin S., Reed A., Wills P. and Wyatt D. 2019. Citizen-science for the future: Advisory case studies from around the globe. 2019. *Frontiers in Marine Sciences* 6: 255, doi: 10.3389/fmars.2019.00225.

Søreide J.E., Pitusi V., Vader A., Damsgård B., Nilsen F., Skogseth R., Poste A., Bailey B., Kovacs K.M., Lydersen Ch., Gerland S., Descamps S., Strøm H., Renaud P.E., Christensen G., Arvnes MP., Graczyk P., Moiseev D., Singh RK., Bélanger S., Elster J., Urbański J., Moskalik M, Wiktor J. and Węsławski J.M. 2020. Environmental status of Svalbard coastal waters: coastscapes and focal ecosystem components (SvalCoast). *In: The State of Environmental Science in Svalbard. an annual report.* Svalbard Integrated Arctic Earth Observing System (SIOS), doi: 10.5281/zenodo.4293849.

Spotowitz L., Johansen T., Hansen A., Berg E., Stransky C. and Fischer. P. 2022. New evidence for the establishment of coastal cod *Gadus morhua* in Svalbard fjords. *Marine Ecology Progress Series* 696: 119–133.

Stempniewicz L., Błachowiak-Samołyk K. and Węsławski J.M. 2007. Impact of climate change on zooplankton communities, seabird populations and Arctic terrestrial ecosystem –a scenario. *Deep-Sea Research Part II* 54: 2934–2433.

Stempniewicz L., Kulaszewicz I. and Aars J. 2021. Yes, they can: polar bears *Ursus maritimus* successfully hunt Svalbard reindeer *Rangifer tarandus platyrhynchus*. *Polar Biology* 44: 2199–2206.

Stocke A.N., Renner A.H.H. and Knol-Kauffman M. 2020. Sea ice variability and maritime activity around Svalbard in the period 2012–2019. *Scientific Reports* 10: 17043, doi: 10.1038/s41598-020-74064-2.

Strzelecki M., Szczuciński W., Dominiczak A., Zagórski P., Dudek J., and Knight J. 2020. New fjords, new coasts, new landscapes: The geomorphology of paraglacial coasts formed after recent glacier retreat in Brepollen (Hornsund, southern Svalbard). *Earth Surface Processes and Landforms* 45: 1325–1334.

Strzelewicz A., Przyborska A. and Walczowski W. 2022. Increased presence of Atlantic Water on the shelf south-west of Spitsbergen with implications for the Arctic fjord Hornsund. *Progress in Oceanography* 200: 102714, doi: 10.1016/j.pocean.2021.102714.

Svalbard Environmental Protection Act. 2002. http://www.sysselmannen.no/hovedEnkel.aspx?m=45303.

Svalbard Treaty. 1920. http://www.sysselmannen.no/The_Svalbard_Treaty_9ssFy.pdf.file.

Svalbard Act. 1925. http://www.sysselmannen.no/hovedEnkel.aspx?m=45302.

Szeligowska M., Trudnowska E., Boehnke R., Dąbrowska A., Wiktor J., Sagan S. and Błachowiak-Samołyk K. 2020. Spatial patterns of particles and plankton in the warming Arctic fjord (Isfjorden, West Spitsbergen) in seven consecutive midsummers (2013–2019). *Frontiers in Marine Science* 7, doi: 10.3389/fmars.2020.00584.

Urbański J. and Litwicka D. 2022. The decline of Svalbard landfast sea ice extent as a result of climate change. *Oceanologia* 64: 535–545, doi.org/10.1016/j.oceano.2022.03.008.

Vihtakari M., Welcker J., Moe B., Chastel O., Tartu S., Hop H., Bech C., Descamps S. and Gabrielsen G.W. 2018. Black-legged kittiwakes as messengers of Atlantification in the Arctic. *Scientific Reports* 8: 1178, doi: 10.1038/s41598-017-19118-8.

von Biela V.R., Laske S.M., Stanek A.E., Brown R.J. and Dunton K.H. 2022. Borealization of nearshore fishes on an interior Arctic shelf over multiple decades. *Global Change Biology* 29: 1822–1838.

Vongraven D. (ed.) 2014. *Basic data for the large national parks and bird reserves on West Spitsbergen. Kort Rapport* 028. Norsk Polarinstitutt, Tromso (in Norvegian).

Węsławski J.M. and Urbański J. 2024. Forty years of warming. Review of the environmental change in marine coastal habitats on Svalbard between 1981 and 2022. *Polish Polar Research* 45: 181–196, doi: 10.24425/ppr.2024.149207.

Węsławski J.M., Zajączkowski M., Wiktor J. and Szymelfenig M. 1997. Intertidal zone of Svalbard. 3 Littoral of a subarctic, oceanic island: Bjornoya. *Polar Biology* 18: 45–52.

Węsławski J.M., Wiktor J.Jr. and Kotwicki L. 2010. Increase in biodiversity in the Arctic rocky littoral, Sorkappland, Svalbard after 20years of climate warming. *Marine Biodiversity* 40: 123–130.

Węsławski J.M., Buchholz F., Głuchowska M. and Weydmann A. 2017. Ecosystem maturation follows the warming of the Arctic fjords. *Oceanologia* 59: 592–602, doi: 10.1016/j.oceano.2017.02.002.

Węsławski J.M., Legeżyńska J. and Włodarska-Kowalczuk M. 2020. Will shrinking body size and increasing species diversity of crustaceans follow the warming of the Arctic littoral? *Ecology and Evol*ution 10: 10305–10313, doi: 10.1002/ece3.6780.

Weydmann A., Carstensen J., Goszczko I., Dmoch K., Olszewska A. and Kwasniewski S. 2014. Shift towards the dominance of boreal species in the Arctic: inter-annual and spatial zooplankton variability in the West Spitsbergen Current. *Marine Ecology Progress Series* 501: 41–52, doi: 10.3354/meps10694.

Wiktor J.M. Jr, Tatarek A., Kruss A., Singh R.K., Wiktor J.M. and Søreide J.E. 2022. Comparison of macroalgae meadows in warm Atlantic versus cold Arctic regimes in the high-Arctic Svalbard. *Frontiers in Marine Science* 9: 1021675, doi: 10.3389/fmars.2022.1021675.