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Change Drivers and Impacts in Arctic Wetland Landscapes—Literature Review and Gap Analysis

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Abstract: Wetlands are essential parts of Arctic landscapes, playing important roles for the sustainable development of the region, and linking to climate change and adaptation, ecosystem services, and the livelihood of local people. The effects of human and natural change drivers on key landscape characteristics of Arctic wetlands may be critical for ecosystem resilience, with some functional aspects still poorly understood. This paper reviews the scientific literature on change drivers for Arctic wetland landscapes, seeking to identify the main studied interactions among different drivers and landscape characteristics and their changes, as well as emerging research gaps in this context. In a total of 2232 studies of various aspects of Arctic wetland landscapes found in the literature, natural drivers and climate change have been the most studied change drivers so far, particularly regarding their impacts on carbon cycling, plant communities and biodiversity. In contrast, management plans, land use changes, and nutrient-pollutant loading, have not been investigated as much as human drivers of Arctic wetland change. This lack of study highlights essential gaps in wetland related research, and between such research and management of Arctic wetlands.

Keywords: Arctic wetland landscapes; change drivers; climate change; research gaps; wetland management

1. Introduction

There is increasing scientific recognition that Arctic aquatic species, their physical and chemical environment, and processes in freshwater and terrestrial ecosystems are affected by the changing climate, ultraviolet radiation, and management measures [1–4]. Arctic peatlands, glacier forelands, rivers, lakes, wet tundra, seashores, and shallow bays in the Arctic region constitute a significant proportion of the world's surface freshwater and wetlands [5]. Wetlands can provide various ecosystem services and nature-based solutions to a range of environmental and socio-economic challenges [6]. Such ecosystem services cover flood control, groundwater replenishment, shoreline stabilization and storm protection, sediment and nutrient retention and export, water purification, reservoirs of biodiversity, wetland products, cultural values, recreation and tourism, climate change mitigation and adaptation. Not all wetlands provide all of these services at all times. Different wetlands provide a range of services according to their type, size and location. The economic worth of the ecosystem services provided to society by intact, naturally functioning wetlands is frequently much greater than the perceived benefits of converting them to 'more valuable' intensive land use [7].

Despite this potential, wetland areas have been subject to rapid and continued decline in parts of the world [8,9]. For example, hydro-climatic changes, driven by changes in human land and water use as well as by atmospheric climate change [10,11], and in the Arctic also by permafrost thaw [12], can affect the areas, functions and services of wetlands [13]. Many wetlands are also directly drained or poorly managed, causing the loss of function and value. Although Arctic wetlands may be less affected by human activities than wetlands in other, more densely populated parts of the world, development trajectories suggest large Arctic hydro-climatic changes over the coming decades [14]. As a consequence, Arctic countries should also anticipate wetland changes, and take action to adapt wetland management and build long-term resilience for securing the biodiversity and key services of Arctic wetland ecosystems.

Many effects of global change on society and ecosystems appear as water changes, such as altered precipitation, evapotranspiration and runoff patterns, and permafrost thaw in the Arctic [10,14–16]. Previous studies have addressed impacts of global warming on flora and fauna, plant productivity, shorebird migration pathways, and ecosystem regime shifts in Arctic wetland landscapes [12,17–20]. In combating such negative impacts, wetland management, protection and restoration can provide relevant nature-based solutions [21,22]. Appropriate management of wetlands on a large scale can aid in regional water management, climate change mitigation and adaptation, maintaining biodiversity, and also providing other ecosystem services for Arctic resilience and people living in the region [23]. A review of the scientific literature with regard to such management effects can help understanding of the current state and options for improvement of management strategies for Arctic wetland landscapes. It can also identify and help to bridge gaps in understanding and between science and management [24] for maintaining Arctic wetlands as important regional landscape features.

This paper undertakes such a literature review, addressing the following questions for Arctic wetland landscapes: (1) What is known about main change drivers that can affect wetland functionality in Arctic landscapes? (2) How have the drivers and their impacts be assessed in the scientific literature? (3) What management aspects have been studied with regard to Arctic wetland preservation and restoration? (4) What research gaps emerge from investigations of these questions? The results can be used for directing future studies and research towards bridging identified gaps and supporting future management strategies for preserving Arctic wetlands and their services.

2. Materials and Methods

We address questions (1)–(4) by a comprehensive review of the scientific literature on Arctic wetland landscapes, their change drivers and impacts, and efforts to manage them. The focus is on Arctic wetlands within the area of the Conservation of Arctic Flora and Fauna (CAFF; The CAFF is a working group under the Arctic Council, for the countries of Russia, Denmark, USA, Canada, Sweden, Iceland, Norway and Finland and indigenous people, focusing on monitoring, assessment, and conservation strategies for protected areas in the whole Arctic region.) (Figure 1) including also studies with unclear exact research location. The review focuses on changes of wetland landscapes and ecosystem services arising from: (a) Various types of global change; (b) local-regional land and water use developments and management plans; and (c) interactions of natural components and processes in wetland landscapes.

The Web of Science™ Core Collection (WoS) bibliographic database is used, directing the search to identify scientific Arctic wetland-related studies up to the search date (27 November 2017). This results in 2232 unique hits, applying the following search string to the field of topic, which includes title, abstract, and keywords: (arctic OR tundra OR sub?arctic OR taiga) AND (wetland OR bog OR mire OR fen OR marsh OR peatland).

The question mark in the search string is a wild card, representing exactly 0 or 1 character. This broad search string is used to capture most of the published research on Arctic wetlands, irrespective of case studies and specific issues, concerns and characteristics addressed. Among the search results, those that have been focused on Arctic wetland landscapes within the CAFF boundary (around 40% of the collected literature (893 out of 2232)) are further theme-coded to identify their research content. The coding assigns search results to categories of studied characteristics and change drivers with the aim to detect investigation patterns for Arctic wetlands in the scientific literature. The categories are defined as outlined in Table 1, and the categorization is compatible with that in other studies [25].

Figure 1. Area of the Conservation of Arctic Flora and Fauna (CAFF). Source: GRID-Arendal, topographic map (http://www.grida.no/resources/5304).

Table 1. Structuring of studied change drivers and characteristics in published research on Arctic wetland landscapes within the CAFF boundary.

Category	Name	Description: Current Status and Changes in . . .
Wetland-related landscape characteristics	Plant communities and biodiversity	Vegetation composition, regime shifts, biodiversity, plant performance (production, growth, above- and below-ground biomass, resistance, species competition).
	Animal communities	Animal population and species, animal size/productivity/ distribution in the landscape, migration pathways.
	Carbon cycling	Carbon exchanges among soil, water, atmosphere, plants, including carbon-based greenhouse gases and compounds in animal and plant tissues.
	Nutrient cycling	Nutrient exchanges among soil, water, atmosphere, plants, including nitrogen- and phosphorus-based greenhouse gases and compounds in animal and plant tissues.
	Water cycling	Hydrology aspects, water and hydrogen and oxygen isotope exchanges among land and atmosphere (precipitation, evapotranspiration), runoff fluxes and storage changes.
	Water quality	Contaminant/pollutant concentrations, water quality effects on ecosystems and organisms.
	Energy (heat) balance	Heat balance and exchanges among land and atmosphere.
	Soil and sediment properties	Moisture/temperature/microorganisms/organic matter in the soil, permafrost and frozen layers, sediment/fossil assessments of historic changes.
	Wetland extent/distribution in the landscape	Area of water bodies, mapping and modeling of wetland landscapes, formation of peatlands.

Table 1. *Cont.*

Category	Name	Description: Current Status and Changes in . . .
Human drivers	Climate change	Climate parameters, global warming, sea level rise, future climate projections.
	Land-use change	Urban/agricultural/industrial developments in wetland landscapes.
	Nutrient-pollutant loading	Wastewater discharges to wetlands for treatment purposes, solid wastes in landfills, agricultural fertilization, heavy metal loads.
	Herbivore grazing	Grazing by native and non-native (migrant) herbivore species.
	Management plans	Protection and restoration efforts, flow regulation plans in wetland landscapes.
Natural drivers		Natural processes within soil/water/atmosphere, plant and animal communities, interactions among components and processes in wetland landscapes.

Based on the driver-characteristic classification in Table 1, a structural matrix (heat map) is created and used to visualize and analyze patterns of driver-characteristic combinations studied in the identified literature. These combinations are further divided into two groups, referred to as "assessed together" or "assessed alone", depending on whether several change drivers and/or landscape characteristics have been evaluated together in a study. That is, the body of reviewed literature is divided between the two groups, first based on the number of studied landscape characteristics, and then based on the number of studied change drivers. These two groups are used to analyze the studied interactions of landscape characteristics and change drivers in the scientific literature.

3. Results and Discussion

3.1. Research Directions

The resulting heat map of investigation patterns (Figure 2a) shows that, regarding characteristics, studies have mainly focused on plant communities and biodiversity (27.9%) and carbon cycling (23.5%). In contrast, only few studies have considered characteristics of energy (heat) balance and water quality (1.5 and 3.2%, respectively). Figure 2b illustrates the sum column in Figure 2a, which quantifies the total share of studies addressing each characteristic.

Regarding change drivers, the studies of natural drivers largely dominate the literature on Arctic wetland landscapes (61.2%). Consequently, the human change drivers are less investigated (in the remaining 38.8% of the studies). Among the human drivers, the highest number of studies (20.8%) have evaluated climate change, whereas only few studies have considered management plans and nutrient-pollutant loading (1.2 and 3.9%, respectively) as main drivers of change in Arctic wetland landscapes. Figure 2c illustrates the sum row in Figure 2a, which quantifies the total share of studies addressing each change driver.

The resulting heat map (Figure 2a) includes studies addressing more than one characteristic and/or more than one change driver. Dividing the studies into the two groups of (i) several characteristics/drivers being "assessed together" or (ii) an individual characteristic/driver being "assessed alone" (Figure 3) shows that each change driver has mostly been investigated alone (Figure 3b). Regarding characteristics, however, a considerable number of studies have investigated several characteristics together (Figure 3a). The category of plant communities and biodiversity has been mostly studied together with other characteristics (11.1%), whereas few studies have addressed energy (heat) balance even together with other characteristics (0.9%). The human drivers have to some, small, degree been studied together, with the highest number of combined studies addressing climate change together with some other change driver(s) (1.3%, Figure 3b).

The interconnectedness of studied characteristics and change drivers is illustrated in Figure 4, showing the share of studies addressing each combination of characteristics (Figure 4a) and drivers (Figure 4b). The categories of plant communities and biodiversity and soil and sediment properties have the highest number of connections (Figure 4a), i.e., they have to some degree been studied together with all other characteristics. This may indicate these characteristics as (i) essential for and/or (ii) considerably affected by other characteristics, so that studies need to consider them together with the other characteristics. Vegetation responses to disturbances may, e.g., interact with changes in other landscape characteristics, which together affect ecosystem resilience in the Arctic region [26–28]. Furthermore, historic reconstruction of the interactions of other characteristics may require/rely on investigation of soil and sediment properties [29,30]. The highest number of studies (3.2%) has addressed the plant communities and biodiversity category in combination with carbon cycling, as these are highly interacting in the landscape. Overall, the number of studies addressing several drivers together (Figure 4b, with few connections) is considerably smaller than that of studies addressing several characteristics together (Figure 4a, with several connections). The highest number of studies addressing several drivers together is for the combination of climate change and herbivore grazing (0.5%). A few studies have addressed management plans together with climate change (0.1%), and these are also the only studies addressing management plans together with any other change driver.

(a)

Wetland-related landscape characteristics	Human drivers					Natural drivers	Sum (%)
	Climate change	Land-use change	Nutrient-pollutant loading	Herbivore grazing	Management plans		
Plant communities and biodiversity	5.3	2.2	1.5	4.2	0.4	14.4	27.9
Animal communities	0.9	0.5	0.5	0.4	0.6	5.0	8.0
Carbon cycling	6.6	0.5	0.3	0.8		15.3	23.5
Nutrient cycling	1.5	0.4	0.5	0.5		5.9	8.7
Water cycling	1.3	0.5		0.1	0.1	5.1	7.0
Water quality	0.4	0.5	0.5	0.1		1.7	3.2
Energy (heat) balance	0.1					1.5	1.5
Soil and sediment properties	3.5	1.0	0.5	0.6		7.3	13.0
Wetland extent/distribution in the landscape	1.3	0.5		0.2	0.1	5.1	7.1
Sum (%)	20.8	5.9	3.9	6.9	1.2	61.2	100.0

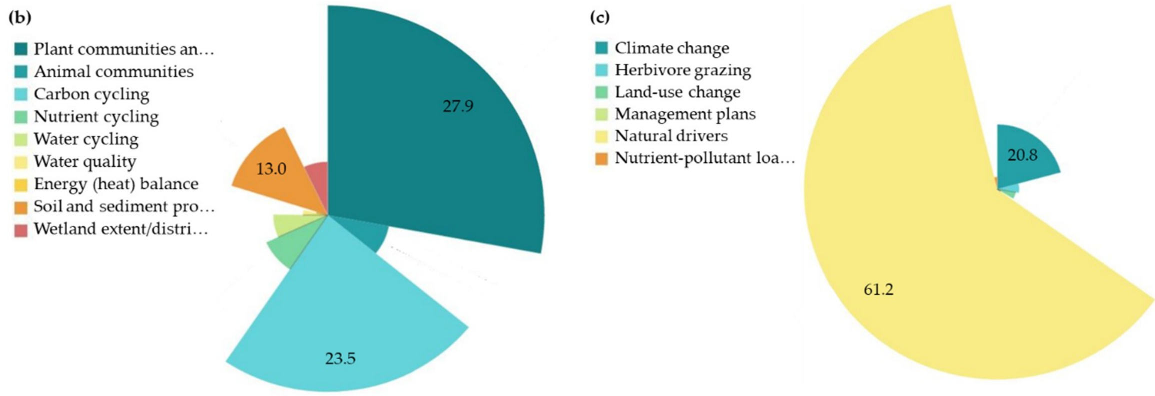

Figure 2. (**a**) Result matrix (heat map) showing the share of published studies addressing each combination of change driver (columns) and landscape characteristic (rows); (**b**) total share of studies addressing each characteristic; (**c**) total share of studies addressing each change driver. All values are in percent (%) of total 893 studies. Blue bars in non-sum cells illustrate the share (%) of studies of each driver-characteristic combination. Red bars in the sum column/row illustrate the total share (%) of studies of each characteristic (sum column) or each driver (sum row). In gray-shaded cells, the share value is zero. (For interpretation of the colors in this table, the reader is referred to the web version of the article.)

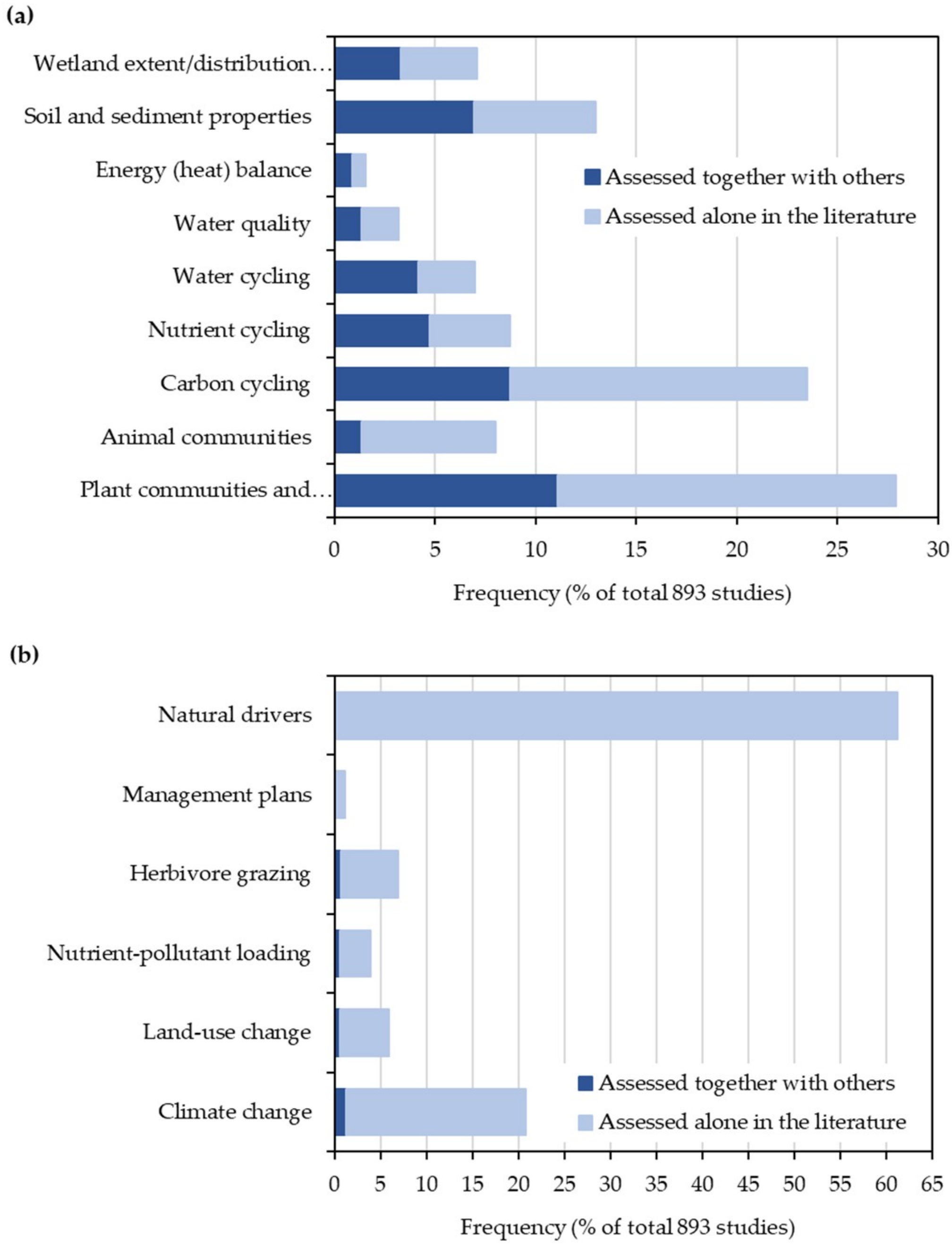

Figure 3. Share of studies addressing an individual characteristic/driver (light blue bars) or several characteristics/drivers (dark blue bars) for: (**a**) characteristics; (**b**) change drivers. (For interpretation of the colors in this figure, the reader is referred to the web version of the article.).

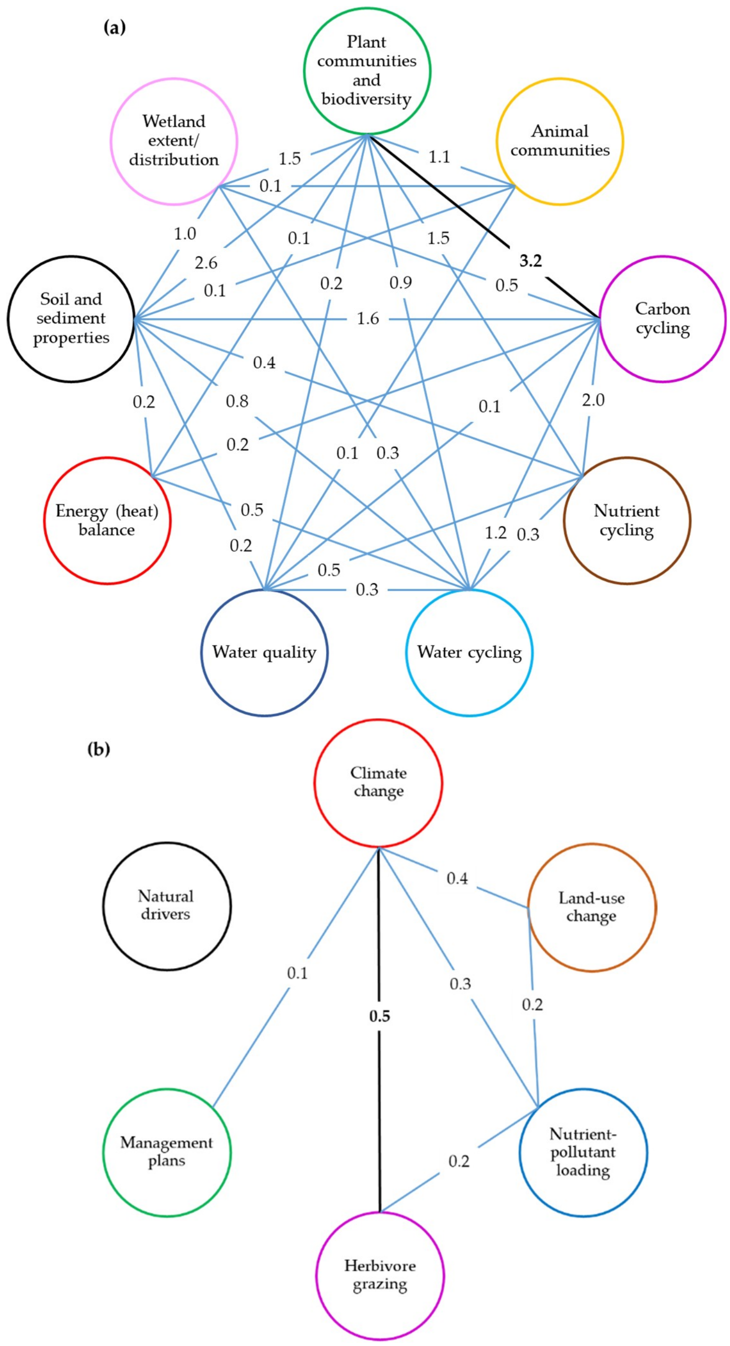

Figure 4. Combinations of investigated (**a**) wetland-related landscape characteristics, regardless of drivers; (**b**) drivers of changes in wetland landscapes, regardless of characteristics. All values are percent (% of total 893 studies). Black lines as connections between characteristics (change drivers) with bold numbers illustrate the highest frequency of investigation (corresponding % number) among all studied combinations of landscape characteristics (change drivers). (For interpretation of the colors in this figure, the reader is referred to the web version of the article.).

3.2. Research Gaps

From the heat map in Figure 2a, a total lack of studies (gray-shaded cells) emerges for driver-characteristic combinations of: land-use changes and energy (heat) balance; nutrient-pollutant loading and water cycling, energy (heat) balance, and wetland extent/distribution; herbivore grazing and energy (heat) balance; and management plans across the whole range of carbon cycling, nutrient cycling, water quality, energy (heat) balance, and soil/sediment properties. Such total lack of studies may indicate that: (i) Researchers consider a driver as not impacting on the wetland landscape characteristics (e.g., carbon/nutrient cycling may be considered as not affected by management plans; or nutrient-pollutant loading may be considered as not impacting on wetland extent/distribution); (ii) researchers have little interest in or merit from investigating the impacts of a driver on landscape characteristic (e.g., because this may require interdisciplinary efforts, or be considered as too applied, such as studying land-use changes and management/development plans and their impacts on slow, but perhaps long-lasting, changes in Arctic wetland landscapes); and/or (iii) the driver effects are prohibitively difficult and/or costly to investigate, especially in the Arctic (e.g., effects of energy (heat) balance, soil and sediment properties, herbivore grazing). At any rate, at least some of these neglected driver-characteristic combinations may be important and should be investigated in future research by possibly establishing strategically placed, integrated ecosystem studies on Arctic wetlands.

Regarding landscape characteristics, the results indicate a lack of knowledge on energy (heat) balance and water quality in Arctic wetland landscapes (Figure 2b). Figure 4a further shows that some combinations of landscape characteristics have not been studied at all, such as animal communities and nutrient/carbon/water cycling, energy (heat) balance and nutrient cycling, and wetland extent/distribution in the landscape and water quality. For example, for the latter combination, this is a remarkable lack of study, as wetlands are often considered to provide an essential service of nutrient and pollutant retention, yet with large uncertainties that need to be further investigated for this potential service [13,31].

Regarding drivers, management plans have not been studied much compared with natural or other human drivers (Figure 2c), although they may affect wetland ecosystem and their services over time. Furthermore, there has been limited research on driver combinations (Figure 4b), such as land-use change and herbivore grazing, management plans and nutrient-pollutant loading, and management plans and herbivore grazing. Combined impacts of human and natural drivers are also not investigated (no connection between natural drivers and any human driver in Figure 4b). This lack of studies indicates the limited understanding of how natural processes interact with human drivers, e.g., to affect ecosystem status and resilience.

Scientific understanding of change drivers, including management, and interacting process characteristics should play an important role for landscape development and impact assessment [32]. However, research has been limited on such interactions for Arctic wetland landscapes, e.g., between climate change and soil conditions, food webs, and ecological communities [30,33], and hydrological regimes and wetland ecosystems [12]. For example, the unknown impacts of climate-driven change in extreme winters and springs and varying duration and depth of snow cover on vegetation composition and biodiversity in high-latitude regions have limited current understanding of reproductive characteristics of plant species in the Arctic region [34,35].

Development is needed for integrated and adaptive long-term monitoring of Arctic wetland landscapes (as part of management plans and impact assessments [32]), in order to follow up change impacts and determine efficient strategies for mitigating/adapting to them at regional and national scales. Lack of recorded data on long-term changes in physical, chemical, hydrological, and biological landscape characteristics throughout the Arctic region is the main consequence of the past lack of comprehensive monitoring systems [10,12]. New research directions can also enhance knowledge on Arctic wetland landscapes and understanding of their changes due to human and natural drivers. This would provide much needed scientific underpinning to impact assessments and management plans for wetland ecosystem protection and restoration, as there is otherwise risk of low management and restoration effectiveness [13,31,32].

Reviewing and classifying published research helps identify gaps and associated new research needs, and arrive at relevant management strategy recommendations. Results from this review show that studies of natural change drivers are dominant for Arctic wetland landscapes. Such studies are essential for gaining fundamental knowledge about these landscapes. However, studies of management plans and their implementations and effects are also needed for effective ecosystem protection and restoration, but are lacking. Such investigations might be included in grey literature, i.e., reports that have not been peer reviewed and published in academic journals, with generally limited access to their outcomes. It is further unclear to what extent new research findings are applied in the development of management strategies and plans. In summary, this review highlights needs for increased science-management interactions, including new research on implementations and impacts of such strategies and plans. In addition, there is also a need to base management strategies and plans on the available scientific knowledge on Arctic wetland landscapes and ecosystems.

4. Conclusions

This review summarizes and classifies the available scientific literature on Arctic wetlands, and their landscapes and ecosystem services. It identifies key gaps and needs for new research directions to bridge them; especially highlighting key gaps on wetland management plans. Regarding landscape characteristics, many studies have addressed plant communities and biodiversity, while energy (heat) balance and water quality have been much less investigated. Regarding change drivers, studies have mostly addressed natural drivers and climate change, whereas studies of other human drivers have been much fewer and even more so for management plans as such drivers. Future research should fill these gaps to provide a deeper understanding of Arctic wetland landscapes and their ecosystems. Moreover, management strategies and plans should also increasingly account for and be based on available research findings, in order to effectively mitigate and/or adapt to key changes in Arctic wetland landscapes.

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References

1. Häder, D.-P.; Kumar, H.D.; Smith, R.C.; Worrest, R.C. Aquatic ecosystems: Effects of solar ultraviolet radiation and interactions with other climatic change factors. In: United Nations Environmental Program: Environmental Effects of Ozone Depletion and its Interactions with Climate Change: 2002 Assessment. *Photochem. Photobiol. Sci.* **2003**, *2*, 39–50. [CrossRef]
2. Michel, C.; Bluhm, B.; Gallucci, V.; Gaston, A.J.; Gordillo, F.J.L.; Gradinger, R.; Hopcroft, R.; Jensen, N.; Mustonen, T.; Niemi, A.; et al. Biodiversity of Arctic marine ecosystems and responses to climate change. *Biodiversity* **2012**, *13*, 200–214. [CrossRef]
3. Wrona, F.J.; Prowse, T.D.; Reist, J.D.; Hobbie, J.E.; Levesque, L.M.J.; Vincent, W.F. Climate impacts on Arctic freshwater ecosystems and fisheries: Background, rational and approach of the Arctic Climate Impact Assessment (ACIA). *AMBIO* **2006**, *35*, 326–329. [CrossRef]
4. Wrona, F.J.; Prowse, T.D.; Reist, J.D.; Hobbie, J.E.; Levesque, L.M.J.; Vincent, W.F. Key findings, science gaps and policy recommendations. *AMBIO* **2006**, *35*, 411–415. [CrossRef]
5. The Romsar Convention. Ramsar Focuses on Arctic Wetlands. Available online: https://www.ramsar.org/news/ramsar-focuses-on-arctic-wetlands (accessed on 20 February 2019).
6. Cohen-Shacham, E.; Walters, G.M.; Maginnis, S.; Janzen, C. *Nature-Based Solutions to Address Global Societal Challenges*; IUCN: Gland, Switzerland, 2016; pp. 1–32.
7. The Ramsar Convention. Wetland Ecosystem Services Factsheet 0—An Introduction. Available online: https://www.ramsar.org/sites/default/files/documents/library/services_00_e.pdf (accessed on 31 March 2019).
8. Davidson, N.C. How much wetland has the world lost? Long-term and recent trends in global wetland area. *Mar. Freshw. Res.* **2014**, *65*, 934–941. [CrossRef]
9. Davidson, N.C.; Fluet-Chouinard, E.; Finlayson, C.M. Global extent and distribution of wetlands: Trends and issues. *Mar. Freshw. Res.* **2018**, *69*, 620–627. [CrossRef]

10. Destouni, G.; Jaramillo, F.; Prieto, C. Hydroclimatic shifts driven by human water use for food and energy production. *Nat. Clim. Chang.* **2013**, *3*, 213–217. [CrossRef]
11. Seneviratne, S.I.; Lüthi, D.; Litschi, M.; Schär, C. Land–atmosphere coupling and climate change in Europe. *Nature* **2006**, *443*, 205–209. [CrossRef] [PubMed]
12. Karlsson, J.M.; Bring, A.; Peterson, G.D.; Gordon, L.J.; Destouni, G. Opportunities and limitations to detect climate-related regime shifts in inland Arctic ecosystems through eco-hydrological monitoring. *Environ. Res. Lett.* **2011**, *6*, 014015. [CrossRef]
13. Thorslund, J.; Jarsjö, J.; Jaramillo, F.; Jawitz, J.W.; Manzoni, S.; Basu, N.B.; Chalov, S.R.; Cohen, M.J.; Creed, I.F.; Goldenberg, R.; et al. Wetlands as large-scale nature-based solutions: Status and challenges for research, engineering and management. *Ecol. Eng.* **2017**, *108*, 489–497. [CrossRef]
14. Bring, A.; Destouni, G. Hydro-climatic changes and their monitoring in the Arctic: Observation-model comparisons and prioritization options for monitoring development. *J. Hydrol.* **2013**, *492*, 273–280. [CrossRef]
15. Karlsson, J.M.; Lyon, S.W.; Destouni, G. Thermokarst lake, hydrological flow and water balance indicators of permafrost change in Western Siberia. *J. Hydrol.* **2012**, *464–465*, 459–466. [CrossRef]
16. Streletskiy, D.A.; Tananaev, N.I.; Opel, T.; Shiklomanov, N.I.; Nyland, K.E.; Streletskaya, I.D.; Tokarev, I.; Shiklomanov, A.I. Permafrost hydrology in changing climatic conditions: Seasonal variability of stable isotope composition in rivers in discontinuous permafrost. *Environ. Res. Lett.* **2015**, *10*, 095003. [CrossRef]
17. Lindwall, F.; Svendsen, S.S.; Nielsen, C.S.; Michelsen, A.; Rinnan, R. Warming increases isoprene emissions from an arctic fen. *Sci. Total Environ.* **2016**, *553*, 297–304. [CrossRef] [PubMed]
18. Morison, M.Q.; Macrae, M.L.; Petrone, R.M.; Fishback, L. Seasonal dynamics in shallow freshwater pond-peatland hydrochemical interactions in a subarctic permafrost environment. *Hydrol. Process.* **2017**, *31*, 462–475. [CrossRef]
19. Pavon-Jordan, D.; Santangeli, A.; Lehikoinen, A. Effects of flyway-wide weather conditions and breeding habitat on the breeding abundance of migratory boreal waterbirds. *J. Avian Biol.* **2017**, *48*, 988–996. [CrossRef]
20. van der Kolk, H.J.; Heijmans, M.M.P.D.; van Huissteden, J.; Pullens, J.W.M.; Berendse, F. Potential Arctic tundra vegetation shifts in response to changing temperature, precipitation and permafrost thaw. *Biogeosciences* **2016**, *13*, 6229–6245. [CrossRef]
21. Kalantari, Z. Wetlands as large-scale nature-based solutions: Protecting Kristianstad city from flooding and reduce nutrients before rivers reach the Baltic Sea. In Proceedings of the TERRAenVISION, Barcelona, Spain, 29 January–2 February 2018.
22. Keesstra, S.; Nunes, J.; Novara, A.; Finger, D.; Avelar, D.; Kalantari, Z.; Cerda, A. The superior effect of nature based solutions in land management for enhancing ecosystem services. *Sci. Total Environ.* **2018**, *610*, 997–1009. [CrossRef] [PubMed]
23. Erwin, K.L. Wetlands and global climate change: The role of wetland restoration in a changing world. *Wetlands Ecol. Manag.* **2009**, *17*, 71–84. [CrossRef]
24. Roux, D.J.; Rogers, K.H.; Biggs, H.C.; Ashton, P.J.; Sergeant, A. Bridging the science-management divide: Moving from unidirectional knowledge transfer to knowledge interfacing and sharing. *Ecol. Soc.* **2006**, *11*, 4. [CrossRef]
25. Galatowitsch, S.M. Natural and anthropogenic drivers of wetland change. In *The Wetland Book*; Finlayson, C., Milton, G., Prentice, R., Davidson, N., Eds.; Springer: Dordrecht, The Netherland, 2016; pp. 1–10.
26. Calmels, F.; Froese, D.G.; Clavano, W.R.; Burn, C.R. Cryostratigraphic record of permafrost degradation and recovery following historic (1898–1992) surface disturbances in the Klondike region, central Yukon Territory. *Can. J. Earth Sci.* **2012**, *49*, 938–952. [CrossRef]
27. Cameron, E.A.; Lantz, T.C. Persistent changes to ecosystems following winter road construction and abandonment in an area of discontinuous permafrost, Nahanni National Park Reserve, Northwest Territories, Canada. *Arct. Antarct. Alp. Res.* **2017**, *49*, 259–276. [CrossRef]
28. Raynolds, M.K.; Walker, D.A. Effects of deglaciation on circumpolar distribution of arctic vegetation. *Can. J. Remote Sens.* **2009**, *35*, 118–129. [CrossRef]
29. Pendea, I.F.; Ponomareva, V.; Bourgeois, J.; Zubrow, E.B.W.; Portnyagin, M.; Ponkratova, I.; Harmsen, H.; Korosec, G. Late Glacial to Holocene paleoenvironmental change on the northwestern Pacific seaboard, Kamchatka Peninsula (Russia). *Quat. Sci. Rev.* **2017**, *157*, 14–28. [CrossRef]

30. Weedon, J.T.; Kowalchuk, G.A.; Aerts, R.; Freriks, S.; Röling, W.F.M.; van Bodegom, P.M. Compositional stability of the bacterial community in a climate-sensitive Sub-Arctic peatland. *Front. Microbiol.* **2017**, *8*, 317. [CrossRef]
31. Quin, A.; Jaramillo, F.; Destouni, G. Dissecting the ecosystem service of large-scale pollutant retention: The role of wetlands and other landscape features. *AMBIO* **2015**, *44* (Suppl. 1), 127–137. [CrossRef]
32. Azcárate, J.; Balfors, B.; Bring, A.; Destouni, G. Strategic environmental assessment and monitoring: Arctic key gaps and bridging pathways. *Environ. Res. Lett.* **2013**, *8*, 044033. [CrossRef]
33. Howison, R.A.; Olff, H.; van de Koppel, J.; Smit, C. Biotically driven vegetation mosaics in grazing ecosystems: The battle between bioturbation and biocompaction. *Ecol. Monogr.* **2017**, *87*, 363–378. [CrossRef]
34. Bartlein, P.J.; Edwards, M.E.; Hostetler, S.W.; Shafer, S.L.; Anderson, P.M.; Brubaker, L.B.; Lozhkin, A.V. Early-Holocene warming in Beringia and its mediation by sea-level and vegetation changes. *Clim. Past* **2015**, *11*, 1197–1222. [CrossRef]
35. Bombonato, L.; Gerdol, R. Manipulating snow cover in an alpine bog: Effects on ecosystem respiration and nutrient content in soil and microbes. *Clim. Chang.* **2012**, *114*, 261–272. [CrossRef]