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The large marine ecosystem approach to assessment and management of polar bears during climate change

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ABSTRACT

As an apex predator dependent on sea ice as habitat for catching prey, polar bears (*Ursus maritimus*) are threatened in terms of survival rates due to the loss of sea ice in relation to climate change. Current management plans have made modest progress in providing adequate assessment and management of the 19 polar bear subpopulations in the five nations containing the subpopulations: Canada, Russia, Greenland, Norway, and the USA. Polar bears are distributed across Large Marine Ecosystems (LMEs) where changes in ice cover are affecting their survival. This paper describes the utility of a transboundary ecosystem-based adaptive management approach to sustain polar bear subpopulations during climate change. The LME framework provides a means to measure change in five modules (productivity, fish and fisheries and marine mammals, pollution and ecosystem health, socio-economics, and governance) and assess changes in environmental conditions to initiate conservation and recovery. In particular, this paper demonstrates that the LME approach can provide a means of diagnostic analyses and strategic planning for transboundary polar bear conservation in Arctic LMEs during climate change.

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1. Introduction

As an animal in a position to reflect the changing health and conditions of marine ecosystems, the polar bear (*Ursus maritimus*) is now in need of a global plan of action for addressing the gaps between a global vision for sustaining a species and regional wildlife management plans (Wilder, 2013). Given the circumpolar habitat of polar bears as they are found in areas of annual ice cover over the continental shelves and inter-island channels of the archipelagos of Canada, Russian Federation, Greenland, Norway, and USA (Amstrup and Gardner, 1994; Prestrud and Sterling, 1994), a successful approach to their survival would need to consider transboundary cooperative assessment and management practices. Management plans for polar bears have mostly focused on harvesting limits, which have been successful over the last 40 years in so far as a reduction in yield in many areas has occurred (Freeman and Wenzel, 2006; Peacock et al., 2011). However, management plans for the protection of polar bear habitat have been limited to some terrestrial zones (e.g., Wapusk National Park in Manitoba, Ontario Polar Bear Provincial Park in Ontario, Kong Karl's Land in Svalbard) (Bankes, 2009; ECO, 2013; Peacock et al., 2011) with little attention to marine areas. Crucial topics such as climate change, habitat protection, and human-wildlife interactions (e.g., maritime activities, human-wildlife conflicts) are discussed in international advisory management meetings. However, little to no progress has been made in responding to the difficult challenge of addressing the most important threat to polar bears, climate change. Climate change is likely to result in large-scale habitat alterations in the Arctic through declines in sea ice thickness as a result of warming trends (Sahanatien and Derocher, 2012). Declines in sea ice thickness are likely to negatively affect sea ice connectivity, which results in highly fragmented landscapes that are energetically costly for polar bears to rely upon for foraging and mating (Derocher et al., 2004; Laidre et al., 2008, Molnár et al., 2010; Sahanatien and Derocher, 2012).

Over the last 40 years, the multinational *Agreement on the Conservation of Polar Bears* (MMCC, 1973) (referred to as the "*Agreement*") has made an attempt at applying ecosystem-based principles to polar bear issues. However, the *Agreement* has fallen short of providing a framework through which challenges to the survival of polar bears can be effectively addressed. The *Agreement* specifies that ecosystems require protection through action on behalf of each of the signatory nations, yet national management has focused on polar bears as a single-sector through emphasis on harvest policies (Peacock et al., 2011; Sahanatien and Derocher, 2012; Thiemann et al., 2008b). The *Agreement* does not provide the means through which ecosystems can be assessed and managed for polar bear conservation, which is crucial to understanding and addressing the loss of sea ice under the main threat of climate change.

The Large Marine Ecosystem (LME) methodology for assessment and sustainable development of marine resources can serve as a strategic approach for sustaining polar bear subpopulations, similar to the ecosystem-based approaches previously called upon for polar bear subpopulations in other studies (Amstrup et al., 2008; Thiemann et al., 2008b). LMEs are coastal and oceanic regions defined by four ecological and oceanographic parameters: bathymetry, hydrography, productivity, and trophically dependent populations (Sherman, 2005; Sherman and Alexander, 1986). LMEs are generally in the order of 200,000 km^2 or more, and can encompass coastal zones, continental shelves, and coastal currents (Duda and Sherman, 2002). Currently, 66 LMEs are delineated and recognized in international circles as a means to achieve ecosystem-based, multi-country management of marine natural resources, particularly biotic resources (IOC-UNESCO, 2013). LMEs around the world face similar problems such as coastal development, pollution, resource extraction, and invasive species. Given that LMEs necessarily traverse national and political boundaries as they extend across or beyond territorial waters and Exclusive Economic Zones, their sound management is dependent on multinational collaboration.

The LME methodology provides a framework for evaluating, monitoring, and managing ecosystems while integrating human dimensions through five modules: productivity, fish and fisheries, pollution and ecosystem health, socioeconomics, and governance (Sherman and Duda, 1999). Through an analysis of the modules, diagnostics and strategic programs are developed as a means to assess the trends of LMEs and implement an adaptive approach to addressing their changing conditions

(Sherman, 2014). Over the past 15 years, the Global Environment Facility (GEF) has provided financial support to eligible countries working together on LME projects to reduce coastal pollution, restore habitats, recover fisheries, protect biodiversity, and mitigate and adapt to the effects of climate change (Hume and Duda, 2012). In this manner, several comprehensive multinational programs (e.g., Benguela Current Commission) have been established to sustainably manage marine resources and have met varying degrees of success for reversing environmental degradation (Cochrane et al., 2009). Although only one of the countries with polar bear subpopulations is eligible for GEF funds (i.e., Russian Federation), the present and future condition of polar bear subpopulations lies with all five countries. The GEF process can help operationalize an ecosystem-based approach for polar bear assessment and management through collaboration by GEF-eligible and GEF ineligible countries. The four GEF-donor countries (Canada, Greenland, Norway, and the USA) and one GEF-eligible country (Russian Federation) can apply LME principles and support a global plan for an ecosystem-based approach for sustaining polar bear species during climate change.

2. The LME approach of ecosystem-based management to polar bears

The foundation of the LME approach is ecosystem-based management (EBM) (Sherman, 2005; Sherman and Duda, 1999). EBM considers ecosystem components on a long-term and comprehensive basis in contrast to a sector-by-sector approach currently found in many natural resource management practices (e.g., forestry, fisheries) (Duda and Sherman, 2002; McLeod et al., 2005; Sherman, 1999). The application of EBM recognizes that healthy ecosystems are only possible with an understanding and integration of ecosystem components and their interactions (Christensen et al., 1996; McLeod and Leslie, 2009; Slocombe, 1998). The application of EBM accepts that the function and structure of ecosystems are compound and operate over a wide range of spatial and temporal scales. Thus, EBM requires relevant and appropriate scales (i.e., multiple, long-term, sustainable) for management. Further, EBM practice acknowledges that uncertainties are inherent, which requires a prescription for adaptive management driven by the best-available science and the precautionary principle (Christensen et al., 1996; Holling, 1973; Lee, 1993; Walters, 1986).

With the financial assistance of the GEF and the World Bank, EBM for recovering and sustaining marine goods and services is being implemented in 110 countries in Africa, Asia, Latin America, and eastern Europe (Duda and Sherman, 2002; Pernetta and Bewers, 2012; Sherman et al., 2010). The projects involve multiple sectoral interests (e.g., fisheries, energy, recreation) where EBM practice is applied to recover fish stocks, sustain fish populations, restore and enhance habitats (e.g., corals, mangroves), reduce pollution, control effluents and nutrient over-enrichment, address acidification, and mitigate and adapt to climate change (Sherman, 2014). Collaborative transboundary governance arrangements involving countries sharing the resources of a LME are forged to overcome sectoral barriers (e.g., disputes over borders, oil and gas, fisheries, maritime transport) and mutually tackle urgent issues affecting marine resources across boundaries (e.g., Benguela Current Commission, Caribbean LME Project, the Yellow Sea LME Project). The GEF process provides a means for countries to collaborate, build trust and confidence, and work towards a common goal of sustainable management (Carlisle, 2013). To prioritize issues, a scientific analysis in the form of a Transboundary Diagnostic Analysis (TDA) is prepared which allows countries to formally identify and document primary concerns related to their shared marine resources and sectors (e.g., fisheries, oil and gas, transportation, recreation, tourism) (Carlisle, 2013; Pernetta and Bewers, 2012; Sherman, 2014). Subsequent to a TDA, a political document in the form of a Strategic Action Program (SAP) is prepared to allow countries to focus on resolutions related to those primary areas of focus identified in the TDA. A SAP is critical to the advancement of sustainable development of marine resources in LMEs (Alexander, 1993; Carlisle, 2013; Duda and Sherman, 2002; Sherman, 2014).

A critical element to implementing EBM in LMEs is the notion that there is no “one-size-fits-all” approach and solution. Each LME and its associated watershed is unique in its characteristics, and EBM is successful in so far as countries adapt an EBM strategy under the umbrella of 5 LME modules (productivity; fish and fisheries, and marine mammals; pollution and ecosystem health; socio-economics; governance) to suit their respective needs (Carlisle, 2013). While the LME modules are the foundation common to all TDAs and SAPs, the LME approach is flexible enough to accommodate novel and alternative country-driven programs (Carlisle, 2013; Sherman, 2014). Consequently, success of EBM is measured in varying degrees and parameters. A crucial component of LMEs is the examination

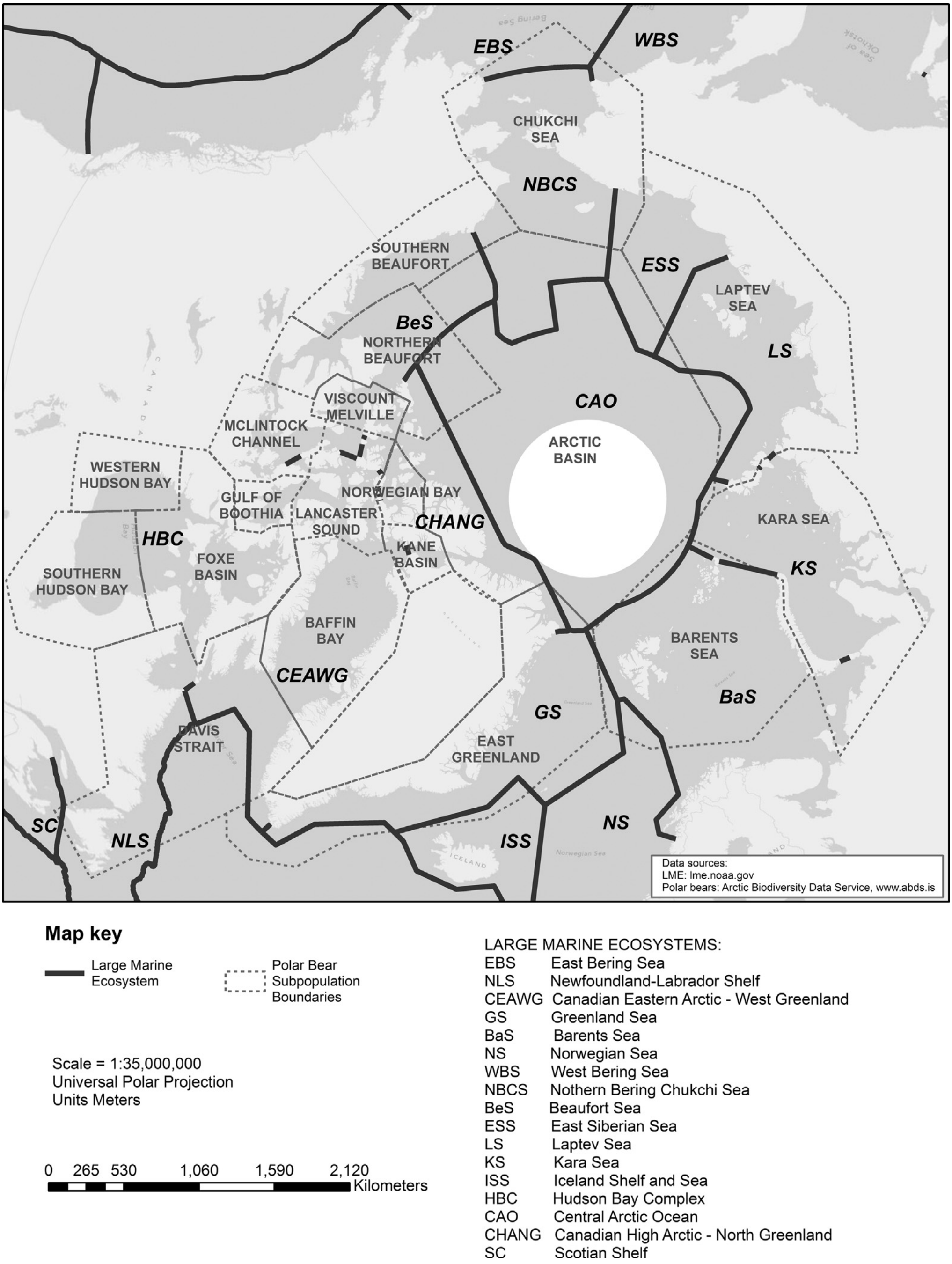

Fig. 1. Large Marine Ecosystems (LMEs) of the Arctic and Polar Bear Subpopulations. Heavy black line represents the borders of LMEs and dashed line represents polar bear subpopulations.

of linkages among coastal and marine zones to identify high priority areas of degradation and the root causes of problems (e.g., www.benguelacc.org and www.yslme.org) (Oh et al., 2005; Tang, 1993, 2003; UNDP/GEF, 2009).

Fourteen arctic LMEs contain whole or parts of polar bear subpopulations and 3 LMEs contain marginal subpopulations and require confirmation of presence (see Fig. 1). Table 1 provides an

Table 1
Polar bear subpopulations in Arctic Large Marine Ecosystems. Data sources: Large Marine Ecosystem Program (lme.noaa.gov), Arctic Biodiversity Data Service (www.abds.is).

Large marine ecosystem	Polar bear subpopulation (s) in LME	Governing nation (s) of LME and polar bear subpopulation
Hudson Bay Complex	Southern Hudson Bay	Canada
	Western Hudson Bay	Greenland
	Foxe Basin	
	Davis Strait	
Newfoundland-Labrador Shelf	Davis Strait	Canada
Canadian High Arctic–North Greenland	Kane Basin	Canada
	Northern Beaufort Sea	Greenland
	Norwegian Bay	
	Arctic Basin	
Central Arctic Ocean	Arctic Basin	Greenland
	East Greenland	Canada
	Northern Beaufort Sea	USA
	Laptev Sea	Russian Federation
	Kara Sea	Norway
	Barents Sea	
Beaufort Sea	Southern Beaufort Sea	Canada
	Northern Beaufort Sea	USA
	Viscount Melville Bay	
	McClintock Channel	
	Arctic Basin	
	Lancaster Sound	
Northern Bering–Chukchi Seas	Chukchi Sea	Russian Federation
	Arctic Basin	USA
	Southern Beaufort Sea	
East Siberian Sea	Laptev Sea	Russian Federation
	Arctic Basin	USA
	Chukchi Sea	
Laptev Sea	Laptev Sea	Russia Federation
	Arctic Basin	
Kara Sea	Kara Sea	Russia Federation
	Arctic Basin	Norway
	Laptev Sea	
	Barents Sea	
Barents Sea	Barents Sea	Norway
	Kara Sea	Russia Federation
Greenland Sea	East Greenland	Greenland
	Barents Sea	Norway
Canadian Eastern Arctic–West Greenland Sea	Baffin Bay	Canada
	Kane Basin	Greenland
	East Greenland	
	Davis Strait	
	Lancaster Sound	
	Gulf of Boothia	
East Bering Sea	Chukchi Sea	Russian Federation, USA
West Bering Sea	Chukchi Sea	Russian Federation, USA
[a]Norwegian Sea	[a]Barents Sea	Norway, Russian Federation
[a]Iceland Shelf and Sea	[a]East Greenland	Iceland, Greenland
[a]Scotian Shelf	[a]Davis Strait	Canada

[a] Polar bear subpopulations are marginal in these LMEs and require assessment and confirmation.

overview of polar bear subpopulations in LMEs. Within the LMEs there are 20–25,000 polar bears in the combined jurisdictions of 5 Arctic nations: Canada, Russian Federation, Greenland, Norway, and USA (PBSG, 2010). The distribution of polar bears is not uniform across these nations and has been divided into 19 subpopulations (Aars et al., 2006). Polar bears demonstrate habitat selection of specific ice, with preferences for sea ice over continental shelves (Arthur et al., 1996; Durner et al., 2009; Stirling et al., 1993). These preferences for stable land-fast ice are attributable to the availability of their primary prey, ringed seals (*Pusa hispida*), and shelter from adverse conditions (Mauritzen et al., 2003). Of the 19 polar bear subpopulations, one is increasing, three are stable, eight are declining, and seven are data deficient (PBSG, 2010), with some polar bear subpopulations dependent on both marine and terrestrial areas (e.g., denning habitats) for their life histories.

3. Modular strategy for polar bear sustainability

The LME approach introduces EBM practice through application of modular indicators of changing LME conditions. Three of the modules (productivity; fish and fisheries, and marine mammals; pollution and ecosystem health) are centered on biophysical dimensions, while the last two (socioeconomics; governance) involve human components. The extensive examination of these modules is critical for incorporating science into adaptive management. The following section provides a brief and preliminary review of how issues relevant to polar bears are assessed according to the LME modules. A more comprehensive analysis is needed through the TDA process. As demonstrated below, the five modules of the LME approach provide a means to assess the ecological conditions of LMEs, which is crucial for adapting and establishing mitigative actions to climate change for polar bears (Sherman, 2005).

3.1. Productivity

Trends in Arctic ice cover have been declining (Polyakov et al., 2010, Stroeve et al., 2007), and primary productivity has increased 27.5 Tg C per year since 2003 (Arrigo et al., 2008). Between 2006 and 2007, the Arctic region experienced an additional growth by 35 Tg C per year in primary productivity (Arrigo et al., 2008). Other models suggest that while a greater availability of sunlight due to a lack of sea ice will result in an increase in open-water phytoplankton, nutrient availability may limit this growth potential (Doney et al., 2012; Grebmeier et al., 2010; Steinacher et al., 2010).

Changes in primary productivity are particularly important to Arctic ecosystems due to the sensitivity to sea-ice decline. In general, warmer temperatures and reduced sea ice favor phytoplankton growth, which result in changes to overall ecosystem structure and trophic interactions (Arrigo et al., 2008; Wassmann et al., 2011). For example, an increase in pelagic productivity due to increases in phytoplankton and zooplankton was observed in the Beaufort Sea during years when early ice retreat occurred (Sallon et al., 2011). In turn, the increase in pelagic productivity may have positively affected the ringed seal populations of the region due to an increase in available prey (e.g., Arctic cod *Boreogadus saida*) that depend on planktonic communities (Forest et al., 2011; Grebmeier et al., 2010). However, this trend is not observed in all regions of the Arctic (e.g., Hudson Bay, southern Beaufort Sea) where seal productivity has not increased due to reduced ice habitat (Harwood et al., 2012b).

In contrast to other regions (e.g., southern Beaufort Sea), the Chukchi Sea and northern Bering Seas polar bear subpopulations have responded differently to the effects of declining sea ice (Harwood et al., 2012a; Rode et al., 2014). Although the Chukchi Sea and northern Bering Seas have experienced sea ice loss and warmer waters due to the effects of climate change, the polar bear subpopulations have increased (Rode et al., 2014). The increase in polar bears corresponds to the evidence for higher primary and marine productivity (e.g., prey species across trophic levels) found in the area (Rode et al., 2014; Sakshaug, 2004, Walsh et al., 1989). Thus, an increase in sea ice loss may be moderated by an increase in productivity in the Chukchi Sea and southern extents of polar bear habitat, however the future long term trends of polar bear subpopulations in response to climate change in these regions is unknown (Rode et al., 2014).

3.2. Fish and fisheries, and marine mammals

Arctic fish and marine mammal populations are in a state of flux, with varying predictions of adaptability to climate change (Burek et al. 2008; Kaschner et al., 2011; Kovacs et al., 2011; Laidre et al., 2008). While some wildlife subpopulations are increasing in specific geographic areas (e.g., Bering–Chukchi–Beaufort Sea bowhead whales *Balaena mysticetus*, Bristol Bay beluga whales *Delphinapterus leucas*, Lake Saimaa ringed seals *P. hispida*), they have yet to return to pre-exploitation historical numbers (Simpkins et al., 2007). Causes of decline for many species in the Arctic are primarily changes in climate conditions and sea ice extent, pollution, overharvest, and food distribution and availability (Kutz et al., 2004; Post and Brodie, 2012; Regehr et al., 2010). The reducing factor for polar bears is access to forage opportunities for ringed seals, which is directly linked to availability of sea ice (Thiemann et al., 2008a). Without sea ice as a platform, polar bears are unable to successfully hunt seals (Derocher et al., 2004; Durner et al., 2009).

Although abundance of polar bear subpopulations and ringed seals are associated, availability of ringed seals to polar bears is variable in any given year due to the number and survival of seal pups (Stirling and Øritsland, 1995; Thiemann et al., 2011). Ringed seals are a circumpolar arctic species dependent on annual sea ice and land-fast ice for overwintering, mating, and moulting (Freitas et al., 2008a). A crucial component of ringed seal habitat includes lair sites for parturition, nursing, and hauling out and resting sites (Pilfold et al., 2014; Smith, 1987). As snow amasses on the lee side of a pressure ridge in stable annual ice, seals depend on ice and overlying snow for their subnivean lairs (Kelly et al., 2010). As such, seals can be found in preferential sites of near-shore fast ice and interisland channels of archipelagos (Pilfold et al., 2014). Although little is known with respect to the feeding ecology of ringed seals (Kelly et al., 2010; Young and Ferguson, 2013), seasonal variation in movements are linked to life cycle stages. During the energetically costly activities of breeding and moulting during the spring months, ringed seals are not spending much time foraging and thus lose blubber that must be rebuilt through concentrated foraging activities (Freitas et al., 2008a). For foraging during the summer months, seals move towards productive ice-edges such as glacier fronts and offshore marginal ice areas in search of high concentrations of food with minimal to no feeding along the way (Freitas et al., 2008a, 2008b). Important prey species for ringed seals include Arctic cod, capelin (*Mallotus villosus*), sandlance (*Ammodytes* sp.) and Arctic sculpin (*Myoxocephalus scorpioides*) (Kelly et al., 2010; Young and Ferguson, 2013). Availability of benthic prey for ringed seals is considered relatively stable and thus contributes to ringed seal site fidelity (Kelly et al., 2010).

Ringed seals also prey on invertebrates on the underside of ice such as gammarid amphipods (Kelly et al., 2010). The diversity and abundance of invertebrates and associated fish on the underside of the ice may be correlated with the topography of the ice surface (Bradstreet, 1982; Kelly et al., 2010). Ice topography is variable from year to year, and it is unknown how climate change will affect the future trends in distribution and site fidelity of interconnected food web species.

Importantly, access to enough seals is crucial for female polar bears, who may be more susceptible to climate change effects in sea ice and related changes in ringed seal populations (Thiemann et al., 2011). Female polar bears follow delayed implantation and gaining weight following successful mating events in spring is crucial (Molnár, 2009; Molnár et al., 2010). Unique to the polar bear species of ursids, only pregnant females enter den sites to overwinter (Atkinson and Ramsay, 1995; Ramsay and Stirling, 1988). Without adequate caloric intake through forage on ringed seals during the spring and summer months, a female's physiological response is to reabsorb the blastocyst in autumn (Ramsay and Stirling, 1988). When a pregnant female polar bear is underweight, the female will fail to successfully reproduce, not enter a denning site, and will continue her life cycle in winter on sea ice similar to male polar bears (Stirling and Derocher, 1993; Stirling and Parkinson, 2006). Thus, it remains vital that female polar bears have access to stable ice from which to hunt ringed seals during the spring and summer months. Recent records indicate that sea ice break-up has been occurring 7–8 days earlier per decade (Molnár et al., 2011; Stirling and Parkinson, 2006). Actual numbers of unsuccessful female polar bears that are unable to carry a fertilized embryo to term are not available, however 40–100% of pregnant females are estimated to fail to reproduce if spring ice break-up occurs 1–2 months earlier than during the 1990s (Molnár et al., 2011).

Although polar bears do not generally rely on walrus populations for prey, older male bears can consume walruses when opportune (Thiemann et al., 2008a). Bears are better suited expending their energy reserves for growth, reproduction, and maintenance in lieu of lengthy and challenging foraging activities in search of distant walrus (Derocher, 2008; Derocher et al., 2004; Wiig et al., 2008). In the Russian Federation and Alaska, thousands of walrus were displaced due to a decline in sea ice habitat and shifts in productivity in the Chukchi Sea (Fischbach et al., 2009) requiring native hunters to travel further in dangerous (e.g., less predictable) open water for subsistence hunting which decreases overall socioeconomic conditions at the community level (Kapsch et al., 2010). Alternatively, walrus populations may also be more susceptible to polar bear predation in areas where walruses migrate to lands where they may face an increased exposure to polar bears (Calvert and Stirling, 1990; Kelly, 2001). Thus, understanding the role of productivity and correlations with invertebrates, fish, and marine mammals in the Arctic is an integral component to understanding the health and changing states of LMEs that polar bear subpopulations depend upon for their survival.

3.3. *Pollution and ecosystem health*

As a large carnivore and apex predator, polar bears may be indicators of ecosystem health in three main areas. First, the Arctic region is experiencing a loss of summer sea ice extent at an estimated rate of 10–12% per decade due to climate change in response to changes in greenhouse gas concentrations and natural variability (Comiso et al., 2008; Serreze et al., 2007; Stroeve et al., 2007, 2012). Loss of sea ice extent results in larger spans of open water, which contributes to thinner, first-year ice (i.e., ice from previous fall and winter) the following spring months (Key et al., 2013; Stroeve et al., 2012). Thinner ice is more susceptible to melting during summer months, and thus sea ice becomes further limited as continuous habitat (Stroeve et al., 2012). For example, the largest decline of sea ice extent in the Arctic observed thus far was in 2008 at a record of 10.67 million km^2 (Stroeve et al., 2012) Discontinuous habitat for polar bears results in a decrease in body mass condition due to the constraints in ability to access food sources since habitat selection is associated with seal availability (Mauritzen et al., 2003; Molnár et al. 2010, Stirling and Derocher, 2012; Stirling et al., 1993). Larger areas of open water necessitate an increase in energy by polar bears for travel across fragmented habitat (Mauritzen et al., 2003; Molnár et al., 2010; Sahanatien and Derocher, 2012). A decline in body mass condition results in lower reproduction rates, which can ultimately lead to adverse changes to polar bear population demographics (Molnár et al., 2010; Wiig et al., 2008). For example, a lack of food availability or fat accumulation in nursing females is attributed as the main cause of death in cubs in the subpopulations residing within the Hudson Bay LME (Derocher and Stirling, 1996, 1998; Derocher, 2012). Further, polar bears are likely to experience longer fasting periods and reduced on-ice feeding times in areas where spring sea ice break-up takes place increasingly early (Molnár et al., 2010; Stirling and Parkinson, 2006; Stirling and Derocher, 2012). Second, bioaccumulation occurs in polar bears due to their position as apex predator in the Arctic food web (Norstrom et al., 1998). The ringed seal demonstrates under-ice habitat site-fidelity and accumulates persistent chlorinated hydrocarbons in their diet since under-ice ocean currents tend to play a role as sinks for many pesticides and industrial chemicals (Norstrom et al., 1998). Due to their dependency on ringed seals, polar bears have been found with high (i.e., toxic) concentrations of persistent organic pollutants (POPs) (e.g., dioxins, furans, dichlorodiphenyltrichloroethane, polychlorinated biphenyls, dieldrin, lindane) (Bowes and Jonkel, 1975, Henriksen et al., 2001; Muir et al., 1988; Norstrom et al., 1998; Norstrom, 1999). The exposure and accumulation of contaminants may lead to low levels of thyroid hormones, antibodies, and vitamin A, which interferes with a bear's ability to grow, reproduce, and fight disease and infection (Jenssen, 2006; Norstrom, 1999, Sonne, 2010). Contaminants may also adversely affect bone density and brain function in polar bears (Sonne, 2010). Further, population level effects of POPs can be manifested through increased reproductive female and cub mortality rates. For example, lactating females with high concentrations of POPs can transfer these toxins to cubs through their milk (Bytingsvik et al., 2012; Derocher et al., 2003; Polischuk et al., 1995). Third, polar bears are vulnerable to the effects of oil and gas exploration and operation activities that are likely to occur with more frequency as the Arctic region becomes more accessible. Polar bears rely on their fur for insulation and direct contact with oil (e.g., oil on prey) can negatively affect a bear's ability to thermoregulate (Derocher and Stirling, 1991; Hurst and Øritsland, 1982; Vongraven and Peacock, 2011). Also, ingested oil may lead to long-term health effects in polar bears through liver and kidney damage (Hurst and Øritsland, 1982). Denning habitats are also affected by direct oil contact; the harmful effects of oil spills can permanently and irreversibly alter habitat (Amstrup and Gardner, 1994; Stirling, 1990).

3.4. Socioeconomics

Coastal areas of the Arctic LMEs are inhabited by small settlements, often of indigenous people, military camps, or larger communities dependent on an operational port, factory, or resource extraction (e.g., oil and gas). The total human population in the Arctic is estimated at 4 million, unevenly distributed across the vast northern landscape (Young and Einarsson, 2004). Arctic societies and cultures are historically resilient as they have faced and overcome many challenges to living in the North. For example, many Arctic peoples have incorporated technology (e.g., snowmobiles, internet) into their lives, albeit with juxtaposed and mixed acceptance by community members and elders (Ford et al., 2006). Hunting and fishing remain important activities particularly for subsistence living in Arctic communities, of which ice plays a significant role in the pursuit of livelihoods (Ford et al., 2006; George et al., 2004). Despite the adaptability of Arctic peoples, forthcoming challenges due to climate change include biophysical and socioeconomic stressors that may forever change their ways of life (e.g., discontinuous melting of permafrost affects infrastructure) (Young and Einarsson, 2004). Further, many Arctic communities are dependent on one or a few economies such as hydrocarbons, fisheries, or marine mammal products and thus are adversely affected when resources are limited, in a state of decline, or boycotted by far away markets (Young and Einarsson, 2004).

Over the last 30 years, tourism related to polar bears has become a lucrative industry in some areas (e.g., Churchill, Manitoba, and Svalbard, Norway) for a variety of reasons from photography of wild charismatic megafauna to 'last-chance' tourism of viewing endangered species (Aars et al., 2005; Lemelin et al., 2010; Newton et al., 2002). Each year, thousands of people embark on voyages to observe polar bears in the wild by tundra vehicle on land in Churchill and by vessel in oceanic waters in Svalbard. For example, the value of polar bear viewing in Churchill is calculated to be CAD$7.2 million per year (Olar et al., 2011). In terms of the preservation value of individual polar bears, studies have shown that Canadian households place this amount at CAD$508, which totals CAD$6 billion per year (Olar et al., 2011).

Currently, four of the five nations with polar bear subpopulations allow subsistence hunting. Norway is the only country that prohibits all forms of hunting of polar bears. Canada is the only country that uses a system of tags that local hunters are permitted to sell to sport or other non-resident, non-citizen hunters. In such cases, the resident hunter must accompany the hunt and the non-resident is allowed to kill the polar bear. The sale of a tag is estimated at around USD $20,000, which is substantially greater than the sale of a pelt through the fur trade that is estimated around USD $1000 (Dowsley, 2010). Subsistence hunting is considered to be in part supported by the sport hunt since it provides a source of income and encourages development of necessary hunting skills among younger resident hunters (Dowsley, 2010). Many northern communities in Canada impart socio-cultural importance to both the sport and subsistence hunts and some communities support the argument for an increase in allowable harvest levels (Dowsley, 2009; Dowsley and Wenzel, 2008). Since the mid-1980s, maximum yields have not been exceeded in Canada and the harvest levels have been less than the total allowable harvest quotas (CITES, 2010).

Remarkably, one non-resident hunt (at a cost of USD$45,450) in 2006 led to the verification of a wild polar-grizzly bear hybrid (NBC, 2006). This type of ursid hybrid does not occur regularly in nature due to the distinct ecological niches that grizzly bears (*Ursus arctos* ssp.) and polar bears occupy. This type of interbreeding between ursid species might be an indicator of climate change that can be highlighted on a global platform. Another hunt in 2010 revealed a second generation hybrid that was born from a polar-grizzly hybrid female and a grizzly male (CBC, 2010). Moreover, between 1996 and 2009, wildlife researchers confirmed sightings of 12 grizzlies in Wapusk National Park near Churchill in northern Manitoba (Rockwell et al., 2008). Wapusk National Park is a protected area for female polar bear denning habitat and is not a known area for grizzly bear populations (yet).

3.5. Governance

Governance of polar bears is inherently challenging due to the transnational perspective required for purposive action. Global governance is thus needed as the definition "governing without sovereign authority, relationships that transcend national frontiers" (Finkelstein, 1995) fits to the flexibility required to cover the scope of issues affecting polar bears and their habitats. Over the last 40 years, several global governance agreements have been attempted that have placed the polar bear at the forefront of international wildlife management and Arctic importance (Koivurova, 2010). The *Agreement on the Conservation of Polar Bear* was finalized in 1973 after years of discussions among the five nations with polar bear subpopulations (Larsen and Stirling, 2009; MMCC, 1973). Essentially, the *Agreement* was created to foster cooperation and sustainable management of polar bears at the political and national level, with the Polar Bear Specialist Group (PBSG) under the International Union for the Conservation of Nature (IUCN) Survival Service Commission as the Secretariat (Larsen and Stirling, 2009). The *Agreement* was ratified by all five nations by 1977, though Indigenous peoples and aboriginal groups of the Arctic were not recognized as partners until 1981. Also in 1981, Norway had proposed to expand the *Agreement* to address other environmental issues of concern but was rejected by the other nations (Larsen and Stirling, 2009). Other governance agreements were also created such as the 1988 Inuvialuit-Inupiat Polar Bear Management Agreement for the Southern Beaufort Sea subpopulation and the 2000 US-Russian Federation Polar Bear Agreement (Larsen and Stirling, 2009).

Implications of the loss of sea ice were recognized to be substantial by the IUCN and the US Federal Government at the governance level. Polar bears were listed as "vulnerable" under the IUCN Red List in 2008 and in the same year, the US Government listed the polar bear species as 'threatened' under the US Endangered Species Act (Hunter et al., 2010; Stirling and Derocher, 2012). The listing was largely due to the role that the polar bear plays in projections of climate scenarios (Clark et al., 2008). With respect to the other arctic nations, Greenland and Norway list the polar bear species as "vulnerable" while Canada maintains the status as "special concern". The Russian Federation lists the polar bear as uncertain/rare/rehabilitating although hunting of polar bears has been banned since 1967 (Obbard et al., 2010).

Another significant governing action was the bilateral "Memorandum of Understanding" between Canada and Greenland in 2009 to oversee conservation and protection of the Kane Basin and Baffin Bay subpopulations (Clark et al., 2008; Hunter et al., 2010; Vongraven et al., 2012). At the biennial meeting of the *Agreement* in December 2013, all five nations renewed the commitment to polar bear conservation as they recognized that future decline in local subpopulations is probable. Climate change, overharvest, and poaching were highlighted as key issues, although measures to address these issues were not specified (NRDC, 2013). While all nations agreed that loss of sea ice is attributable to climate change, the *Agreement*'s scope is outside of compliance and enforcement for greenhouse gas and pollution reduction.

In addition, Canada maintains the position of allowing non-resident and resident harvest activities to continue despite the concerns of overharvest levels from the Center of Biological Diversity (NRDC, 2013). Although poorly documented but often referred to, an illegal hunt in Russia is presumed to occur which may be a setback for individual polar bears (Wiig et al., 2008). Some studies report high levels of poaching of several hundred bears per year in the Chukchi/Bering Sea region (Angliss and Lodge, 2004; Angliss and Outlaw, 2008). However, a general consensus based on credible evidence is difficult to gather with respect to the occurrence of poaching in Russia, and recent discussions allude that poaching is not a major concern (Tyrrell and Clark, 2014). The trade markets for polar bear parts are primarily in China where a hide and skin can sell for USD $22,000 to $80,000 (NRDC, 2013). Thus, the impetus for legal and illegal trade in polar bear parts may be possible, which is a consideration for governance mechanisms that seek protection and conservation for polar bears.

Overall, the *Agreement* has fallen short of providing a framework through which ecosystem-based adaptive management can be realized. The *Agreement* lacks the legislative and regulatory setting for ensuring funds and administrative support are available to fulfill the requirements for adaptive management (e.g., addressing scientific uncertainty, applying strategic plans, assess restoration and conservation options on a rolling-basis). The *Agreement* does not provide the institutional basis to allow the polar bear nations to implement national conservation plans for polar bears in accordance with collaborative and integrated agreed-upon principles and practices for ecosystem sustainability (Peacock et al., 2011). While the *Agreement* calls for best-available science (Peacock et al., 2011; Thiemann et al., 2008b), it does not provide the means through which nations can identify, analyze, address and manage issues that are of a transboundary nature, which is crucial for long-term sustainability of polar bear subpopulations.

4. An LME transboundary diagnostic analysis and strategic action program for polar bears

Thus far, the *Agreement* has not been able to fully address the impacts and scalar issues that affect the 19 polar bear subpopulations (Peacock et al., 2011; Thiemann et al., 2008b). Interventions to address the root problems for long term polar bear survival have not yet materialized; only one-third of the total population of 20–25,000 polar bears is estimated to remain by 2050 (Amstrup et al., 2008; Derocher et al., 2013). This remaining one-third is expected to only reside in areas north of the Canadian archipelago and Greenland (Derocher 2012; Durner et al., 2009). It has been widely recognized that a plan of action for sustaining this circumpolar and transboundary species is needed (Derocher et al., 2013; ECO, 2013).

The TDA and SAP are parts of the GEF project cycle where GEF-eligible countries (e.g., Russian Federation) are able to secure financial assistance for LME projects, the TDA and SAP are also processes towards ecosystem-based management allowing for non-GEF eligible countries to participate in the TDA and SAP. Non-GEF eligible countries can apply the TDA and SAP as a methodology towards achieving a global plan for polar bears.

Transboundary issues are jointly identified and prioritized through the TDA, which allows countries to examine and isolate the causes affecting sustainability issues in polar bear regions (Carlisle, 2013; Wang, 2004). A TDA is based on scientific and technical information, which necessarily includes Aboriginal Knowledge for polar bears (Peacock et al., 2011), and is developed by a country-appointed Technical Task Team. The TDA is considered to be a fact-finding analysis used to scale the relative importance of transboundary problems and challenges across all five polar bear nations (Carlisle, 2013). Subsequent to a TDA, a SAP is a negotiated joint program of action that identifies political, legal, and institutional reforms needed to address the priority problems identified in the TDA. The SAP also outlines thematic strategies and investments needed to tackle the challenges brought forth in the TDA. SAP development is linked to specific National Action Plans (NAP) regardless of receiving GEF-funds, which provide direct and feasible strategies to implement. In this manner, the five polar bear nations are accountable for their NAPs and SAPs.

To achieve polar bear conservation and protection, the TDA and SAP can allow for the development and implementation of a plan for assessment and management of polar bears in Arctic LMEs. A TDA focusing on polar bear assessment and sustainability during climate change would necessarily create a call of investments from the five nations responsible for polar bear subpopulations. Through the TDA and SAP processes, agreed-upon funding priorities may be created to relate to the key issue: declining and unknown polar bear subpopulations facing further losses (Durner et al., 2009). While the SAP would identify the thematic and target areas of intervention (e.g., climate change, pollution, overharvest), the NAPs would require specific metrics for assessing, monitoring, and adaptively managing the status of polar bears. Currently, one GEF-supported project mentions polar bear habitats and subpopulations (e.g., see GEF Project ID 4485, www.iwlearn.et) from a conservation perspective but the project does not examine the varying conditions and contexts of different Arctic LMEs needed to implement management actions for sustaining polar bears during climate warming across all LMEs. For example, a comparative analysis across the LME regions of polar bear subpopulations would assist governments, donor agencies and policy makers to promote ecosystem-based polar bear management in Arctic LMEs. Specifically, analytical objectives of a GEF-funded project (i.e., led by the Russian Federation) could include:

- The assessment, governance, and management protocols for sustaining polar bear subpopulations in their respective LMEs.
- The advancement of a polar bear management reform process as it evolves in socioeconomic contexts (e.g., poaching in Russia versus tourism and harvest in Canada). The analyses should focus on points in the process where feasibility of management methods is questionable and thus likely to be significantly changed.
- The analysis of strategies used by managers (e.g., adaptive management) pursuing sustainable polar bear management to enhance the governance of polar bears across international boundaries.

With Russia as the only GEF-eligible country, a national biodiversity plan with international funds can be focused on polar bear habitat projection and integrated coastal management. As such, the involvement of WWF through their species and habitat focused projects (WWF, 2014) and the intergovernmental forum of the 8 arctic nations known as the Arctic Council (AC, 2014) can leverage further governance actions for polar bear conservation among the GEF-ineligible polar bear countries (Canada, USA, Norway, Greenland) (Born et al., 2010). Governance actions necessitate investments and commitments in biodiversity through self-financing projects for these countries ineligible for GEF-funds.

As the IUCN/SSC PBSG has been in place as the Secretariat of the *Agreement*, the PBSG may be in a prime position to head the LME approach for polar bears, though the five nations have mostly disregarded the *Agreement* aside from changes to harvest levels (Parsons and Cornick, 2011; Tyrrell and Clark, 2014). Timely negotiation and finalization of the TDA and SAP would require a thorough understanding of polar bear issues. The PBSG is well suited for facilitation of the GEF documents as the group is primarily composed of polar bear scientists and ecologists, government biologists, and a senior WWF representative (at the time of writing) (IUCN, 2013).

Importantly, the modules of the LME approach are interdependent and interrelated (Carlisle, 2013). For example, the carrying capacity of polar bears is linked to the phytoplankton availability in the Arctic region through the food web dynamics of species dependent on sea ice for their habitats (e.g., fish and ringed seals). The growth of phytoplankton is linked to pollution and ecosystem health (e.g., contaminants). Sea ice changes can be tied directly to ecosystem resilience and the ability of organisms to withstand and adapt to climate change. Predator-prey dynamics influence socio-economic conditions in so far as subsistence hunting is dependent upon the availability of bears, seals, fish, and other hunted species. With the identification of a Technical Task Team composed of the expertise of the IUCN/SSC PBSG and other appropriate stakeholders, the TDA and SAP can be well developed to address WWF's recent call for a global plan for polar bears (Wilder, 2013).

5. Conclusion

For over 40 years, polar bears have been on international agendas as one of the most important charismatic megafauna species of the Arctic. Unfortunately, adaptive management action programs have not yet been implemented that can address the critical problem of loss of sea ice habitat for polar bears across multiple country boundaries. While addressing the root causes of loss of sea ice is multifaceted as multiple drivers of climate change remain far from the Arctic, a global plan and coordinated approach for assessing and managing polar bear subpopulations in Arctic LMEs is needed and required (ECO, 2013). Given that polar bears roam across vast lands and waters, a holistic perspective through EBM is appropriate to address the issues affecting polar bear survival.

The LME approach is a means to achieve EBM and through the GEF process, countries can address the imminent challenges to sustainability of polar bear subpopulations. The TDA and SAP provide a practical process for arctic countries to achieve strategic actions that can be applied across the 14 arctic LMEs and within the boundaries of the five nations responsible for polar bear management.

Continued application, implementation, and renewal of EBM for polar bears on a timely basis (e.g., 3 years) would ensure that critical linkages between the LME modules are regularly updated and revised as appropriate to the changing conditions of the Arctic. Consequently, the LME approach would serve as an adaptable process that encourages sustainable management of polar bear subpopulations.

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References

Aars, J., Lunn, N.J., Derocher, A.E. 2006. Polar Bears. In: Proceedings of the 14th Working Meeting of the IUCN/SSC Polar Bear Specialist Group, 20–24 June 2005, Seattle, Washington, USA. IUCN.
Aars, J., Derocher, A., Andersen, M., Vongraven, D., Ekker, M., Wiig, O. 2005. Polar bear management and research in Norway 2001–2005. In: Report to the 14th Working Meeting of the IUCN/SSC Polar Bear Specialist Group. Seattle, Washington, USA, pp 20–24.
AC. 2014. History of the Arctic Council. (March 13 2014; www.arctic-council.org).
Alexander, L.M., 1993. Large Marine Ecosystems: a new focus for marine resources management. Mar. Policy 17 (3), 186–198.
Amstrup, S.C., Gardner, C., 1994. Polar bear maternity denning in the Beaufort Sea. J. Wildl. Manage., 1–10.
Amstrup, S.C., Marcot, B.G., Douglas, D.C., 2008. A Bayesian network modeling approach to forecasting the 21st century worldwide status of polar bears. In: DeWeaver, E.T., Bitz, C.M., Tremblay, L.B. (Eds.), Arctic Sea Ice Decline: Observations, Projections, Mechanisms, and Implications. Geophysical Monograph Series. American Geophysical Union, Washington DC, pp. 213–268.
Angliss, R.P., Lodge, K.L. 2004. Alaska Marine Mammal Stock Assessments, 2003. United States Department of Commerce, NOAA Technical Memorandum, NMFS-AFSC-144.
Angliss, R.P., Outlaw, R.B. 2008. Alaska Marine Mammal Stock Assessments, 2007. United States Department of Commerce, NOAA Technical Memorandum, NMFS-AFSC-180.
Arrigo, K.R., van Dijken, G., Pabi, S., 2008. Impact of a shrinking Arctic ice cover on marine primary production. Geophys. Res. Lett. 35 (L19603), 1–6.
Arthur, S.M., Manly, B.F., McDonald, L.L., Garner, G.W., 1996. Assessing habitat selection when availability changes. Ecology 77 (1), 215–227.
Atkinson, S., Ramsay, M., 1995. The effects of prolonged fasting of the body composition and reproductive success of female polar bears (*Ursus maritimus*). Funct. Ecol., 559–567.
Bankes, N., 2009. Climate change and the regime for the conservation of polar bears. In: Koivurova, T., Keskitalo, E.C.H., Bankes, N. (Eds.), Climate Governance in the Arctic, vol. 50. Springer, Netherlands, pp. 351–382.
Born, E., Sonne, C., Dietz, R. 2010. Research on polar bears in Greenland 2005–2009. In: Obbard, M.E., Thiemann, G.W., Peacock, E., DeBruyn, T.D. (Eds.), Polar Bears: Proceedings of the 15th Working Meeting of the IUCN/SSC Polar Bear Specialist Group, Copenhagen, Denmark, 29 June–3 July 2009. IUCN Gland, Switzerland and Cambridge, UK, pp. 135–148.
Bowes, G.W., Jonkel, C.J., 1975. Presence and distribution of polychlorinated biphenyls (PCB) in arctic and subarctic marine food chains. J. Fish. Res. Board Can. 32 (11), 2111–2123.
Bradstreet, M.S., 1982. Occurrence, habitat use, and behavior of seabirds, marine mammals, and arctic cod at the Pond Inlet ice edge. Arctic 35 (1), 28–40.
Burek, K.A., Gulland, F.M.D., O'Hara, T.M., 2008. Effects of climate change on arctic marine mammal health. Ecol. Appl. 18 (sp2), S126–S134.
Bytingsvik, J., Lie, E., Aars, J., Derocher, A.E., Wiig, Ø., Jenssen, B.M., 2012. PCBs and OH-PCBs in polar bear mother–cub pairs: a comparative study based on plasma levels in 1998 and 2008. Sci. Total Environ. 417, 117–128.
Calvert, W., Stirling, I., 1990. Interactions between polar bears and overwintering walruses in the central Canadian High Arctic. Bears: their biology and management. International Association for Bear Research and Management 8, 351–356.
Carlisle, K.M., 2013. The Large Marine Ecosystem approach: application of an integrated, modular strategy in projects supported by the Global Environment Facility. Environ. Dev..
CBC. 2010. Bear Shot in N.W.T. was Grizzly-polar Hybrid. (February 1 2014; www.cbc.ca).
Christensen, N.L., Bartuska, A.M., Brown, J.H., Carpenter, S., D'Antonio, C., Francis, R., Franklin, J.F., MacMahon, J.A., Noss, R.F., Parsons, D.J., Peterson, C.H., Turner, M.G., Woodmansee, R.G., 1996. The report of the Ecological Society of America Committee on the scientific basis for ecosystem management. Ecol. Appl. 6 (3), 665–691.
CITES. 2010. Management and international trade of polar bear from Canada. In: Fifteeth Meeting of the Conference of the Parties. Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). Doha, Qatar.
Clark, D.A., Lee, D.S., Freeman, M.M., Clark, S.G., 2008. Polar bear conservation in Canada: defining the policy problems. Arctic, 347–360.
Cochrane, K., Augustyn, C., Fairweather, T., Japp, D., Kilongo, K., Iitembu, J., Moroff, N., Roux, J., Shannon, L., Van Zyl, B., 2009. Benguela Current Large Marine Ecosystem—Governance and management for an ecosystem approach to fisheries in the region. Coast. Manage. 37 (3–4), 235–254.

Comiso, J.C., Parkinson, C.L., Gersten, R., Stock, L., 2008. Accelerated decline in the Arctic sea ice cover. Geophys. Res. Lett. 35 (L01703), 1–6.
Derocher, A., Stirling, I., 1996. Aspects of survival in juvenile polar bears. Can. J. Zool. 74 (7), 1246–1252.
Derocher, A., Stirling, I., 1998. Maternal investment and factors affecting offspring size in polar bears (*Ursus maritimus*). J. Zool. 245 (3), 253–260.
Derocher, A., Wolkers, H., Colborn, T., Schlabach, M., Larsen, T., Wiig, Ø., 2003. Contaminants in Svalbard polar bear samples archived since 1967 and possible population level effects. Sci. Total Environ. 301 (1–3), 163–174.
Derocher, A.E., 2008. Polar bears in a warming arctic. In: MacCraken, M.C., Moore, F., Topping Jr, J.C. (Eds.), Sudden and Disruptive Climate Change: Exploring the Real Risks and How We Can Avoid Them. The Climate Institute, Sterling, VA, pp. 193–204.
Derocher, A.E., 2012. Polar Bears: A Complete Guide to Their Biology and Behavior. The Johns Hopkins University Press, Baltimore, Maryland.
Derocher, A.E., Stirling, I., 1991. Oil contamination of polar bears. Polar Rec. 27 (160), 56–57.
Derocher, A.E., Lunn, N.J., Stirling, I., 2004. Polar bears in a warming climate. Integr. Comp. Biol. 44 (2), 163–176.
Derocher, A.E., Aars, J., Amstrup, S.C., Cutting, A., Lunn, N.J., Molnár, P.K., Obbard, M.E., Stirling, I., Thiemann, G.W., Vongraven, D., Wiig, Ø., York, G., 2013. Rapid ecosystem change and polar bear conservation. Conserv. Lett. 6 (5), 368–375.
Doney, S.C., Ruckelshaus, M., Duffy, J.E., Barry, J.P., Chan, F., English, C.A., Galindo, H.M., Grebmeier, J.M., Hollowed, A.B., Knowlton, N., 2012. Climate change impacts on marine ecosystems. Mar. Sci. 4, 11–37.
Dowsley, M., 2009. Inuit-organised polar bear sport hunting in Nunavut territory, Canada. J. Ecotourism 8 (2), 161–175.
Dowsley, M., 2010. The value of a polar bear: evaluating the role of a multiple-use resource in the Nunavut mixed economy. Arctic Anthropol. 47 (1), 39–56.
Dowsley, M., Wenzel, G., 2008. The time of the most polar bears: a co-management conflict in Nunavut. Arctic 61 (2), 177–189.
Duda, A.M., Sherman, K., 2002. A new imperative for improving management of large marine ecosystems. Ocean Coast. Manage. 45, 797–833.
Durner, G.M., Douglas, D.C., Nielson, R.M., Amstrup, S.C., McDonald, T.L., Stirling, I., Mauritzen, M., Born, E.W., Wiig, Ø., DeWeaver, E., Serreze, M.C., Belikov, S.E., Holland, M.M., Maslanik, J., Jon, A., Bailey, D.A., Derocher, A.E., 2009. Predicting 21st-century polar bear habitat distribution from global climate models. Ecol. Monograph. 79 (1), 25–58.
ECO. 2013. Neglected Obligations: No Conservation Planning for Polar Bears, Serving the Public Annual Report 2012/2013. Environmental Commissioner of Ontario, The Queen's Printer for Ontario, Toronto, pp. 103–105.
Finkelstein, L.S., 1995. What is global governance. Global Governance 1, 367–372.
Fischbach, A.S., Monson, D.H., Jay, C.V. 2009. Enumeration of Pacific Walrus Carcasses on Beaches of the Chukchi Sea in Alaska Following a Mortality Event, September 2009. United States Geological Survey Open-File Rep. 2009-1291, Washington DC: US Geological Survey.
Ford, J.D., Smit, B., Wandel, J., 2006. Vulnerability to climate change in the Arctic: a case study from Arctic Bay, Canada. Global Environ. Change 16 (2), 145–160.
Forest, A., Tremblay, J.-É., Gratton, Y., Martin, J., Gagnon, J., Darnis, G., Sampei, M., Fortier, L., Ardyna, M., Gosselin, M., 2011. Biogenic carbon flows through the planktonic food web of the Amundsen Gulf (Arctic Ocean): a synthesis of field measurements and inverse modeling analyses. Prog. Oceanogr. 91 (4), 410–436.
Freeman, M.M., Wenzel, G.W., 2006. The nature and significance of polar bear conservation hunting in the Canadian Arctic. Arctic 59, 1.
Freitas, C., Kovacs, K.M., Ims, R.A., Lydersen, C., 2008. Predicting habitat use by ringed seals (*Phoca hispida*) in a warming Arctic. Ecol. Modell. 217 (1), 19–32.
Freitas, C., Kovacs, K.M., Ims, R.A., Fedak, M.A., Lydersen, C., 2008. Ringed seal post-moulting movement tactics and habitat selection. Oecologia 155 (1), 193–204.
George, J.C., Huntington, H.P., Brewster, K., Eicken, H., Norton, D.W., Glenn, R., 2004. Observations on shorefast ice dynamics in Arctic Alaska and the responses of the Iñupiat hunting community. Arctic 57, 4.
Grebmeier, J.M., Moore, S.E., Overland, J.E., Frey, K.E., Gradinger, R., 2010. Biological response to recent Pacific Arctic sea ice retreats. Eos, Trans. Am. Geophys. Union 91 (18), 161–162.
Harwood, L.A., Smith, T.G., Auld, J.C., 2012. Fall migration of ringed seals (*Phoca hispida*) through the Beaufort and Chukchi Seas, 2001—02. Arctic, 35–44.
Harwood, L.A., Smith, T.G., Melling, H., Alikamik, J., Kingsley, M., 2012. Ringed Seals and sea ice in Canada's western arctic: harvest-based monitoring 1992–2011. Arctic 65, 4.
Henriksen, E.O., Wiig, Ø., Skaare, J.U., Gabrielsen, G.W., Derocher, A.E., 2001. Monitoring PCBs in polar bears: lessons learned from Svalbard. J. Environ. Monit. 3 (5), 493–498.
Holling, C.S., 1973. Resilience and stability of ecological systems. Annu. Rev. Ecol. Syst. 4, 1–23.
Hume, A., Duda, A., 2012. Global Environment Facility strategy for assessing and managing large marine ecosystems during climate change. In: Sherman, K., McGovern, G. (Eds.), Frontline Observations on Climate Change and Sustainability of Large Marine Ecosystems. United Nations Development Programme, New York, pp. 1–15.
Hunter, C., Caswell, H., Runge, M., Regehr, E., Amstrup, S., Stirling, I., 2010. Climate change threatens polar bear populations: a stochastic demographic analysis. Ecology 91 (10), 2883–2897.
Hurst, R.J., Øritsland, N.A., 1982. Polar bear thermoregulation: effect of oil on the insulative properties of fur. J. Therm. Biol. 7 (4), 201–208.
IOC-UNESCO. 2013. IOC-IUCN-NOAA Consultative Committee Meeting on Large Marine Ecosystems. In: Fifteenth Annual Session. Intergovernmental Oceanographic Commission. Reports of Meetings and Experts and Equivalent Bodies, Paris.
IUCN. 2013. Present Members of the IUCN/Polar Bear Specialist Group. (March 13 2014; http://pbsg.npolar.no/en/members/).
Jenssen, B.M., 2006. Endocrine-disrupting chemicals and climate change: a worst-case combination for arctic marine mammals and seabirds. Environ. Health Perspect. 114 (S-1), 76.
Kapsch, M.-L., Eicken, H., Robards, M., 2010. Sea ice distribution and ice use by indigenous walrus hunters on St. Lawrence Island, Alaska. In: Krupnik, I., Aporta, C., Gearheard, S., Kielsen Holm, L., Laidler, G. (Eds.), SIKU—Arctic Residents Document Sea Ice and Climate Change. Springer, Berlin, pp. 115–144.

Kaschner, K., Tittensor, D., Ready, J., Gerrodette, T., Worm, B., 2011. Current and future patterns of global marine mammal biodiversity. PLoS One 6 (5), e19653.
Kelly, B.P., 2001. Climate change and ice breeding pinnipeds. In: Walther, G.R., Burga, C.A., Edwards, P.J. (Eds.), Fingerprints of Climate Change. Springer, US, pp. 43–55.
Kelly, B.P., Badajos, O.H., Kunnasranta, M., Moran, J.R., Martinez-Bakker, M., Wartzok, D., Boveng, P., 2010. Seasonal home ranges and fidelity to breeding sites among ringed seals. Polar Biol. 33 (8), 1095–1109.
Key, J.R., Mahoney, R., Liu, Y., Romanov, P., Tschudi, M., Appel, I., Maslanik, J., Baldwin, D., Wang, X., Meade, P., 2013. Snow and ice products from Suomi NPP VIIRS. J. Geophys. Res. Atmos. 118 (23), 12816–12830.
Koivurova, T., 2010. Limits and possibilities of the Arctic Council in a rapidly changing scene of Arctic governance. Polar Rec. 46 (02), 146–156.
Kovacs, K., Lydersen, C., Overland, J., Moore, S., 2011. Impacts of changing sea-ice conditions on Arctic marine mammals. Mar. Biodivers. 41 (1), 181–194.
Kutz, S., Hoberg, E., Nagy, J., Polley, L., Elkin, B., 2004. "Emerging" parasitic infections in arctic ungulates. Integr. Comp. Biol. 44 (2), 109–118.
Laidre, K., Stirling, I., Lowry, L., Wiig, Ø., Heide-Jørgensen, M., Ferguson, S., 2008. Quantifying the sensitivity of arctic marine mammals to climate-induced habitat change. Ecol. Appl. 18 (sp2), S97–S125.
Larsen, T., Stirling, I., 2009. The Agreement on the Conservation of Polar Bears—Its History and Future. Rapportserie NR 127, 1–17.
Lee, K., 1993. Compass and Gyroscope: Integrating Science and Politics for the Environment. Island Press, Washington, DC.
Lemelin, H., Dawson, J., Stewart, E., Maher, P., Lueck, M., 2010. Last-chance tourism: the boom, doom, and gloom of visiting vanishing destinations. Curr. Issues Tourism 13 (5), 477–493.
Mauritzen, M., Belikov, S., Boltunov, A., Derocher, A., Hansen, E., Ims, R., Wiig, Ø., Yoccoz, N., 2003. Functional responses in polar bear habitat selection. Oikos 100 (1), 112–124.
McLeod, K., Leslie, H. (Eds.), 2009. Ecosystem-based Management for the Oceans Island Press, Washington, DC.
McLeod, K., Lubchenco, J., Palumbi, S., Rosenberg, A. 2005. Scientific Consensus Statement on Marine Ecosystem-Based Management. Signed by 221 Academic Scientists and Policy Experts with Relevant Expertise. 〈www.compassonline.org/pdf_files/EBM_Consensus_Statement_v12.pdf〉).
MMCC, 1973. Agreement on the Conservation of Polar Bears. The Marine Mammal Commission Compendium, Oslo, Norway 1604–1606.
Molnár, P.K. 2009. Modelling Future Impacts of Climate Change and Harvest on the Reproductive Success of Female Polar Bears (*Ursus maritimus*). Ph.D. Thesis. Mathematical and Statistical Biology. University of Alberta, Edmonton, Alberta.
Molnár, P.K., Derocher, A.E., Thiemann, G.W., Lewis, M.A., 2010. Predicting survival, reproduction and abundance of polar bears under climate change. Biol. Conserv. 143 (7), 1612–1622.
Molnár, P.K., Derocher, A.E., Klanjscek, T., Lewis, M.A., 2011. Predicting climate change impacts on polar bear litter size. Nat. Commun. 2, 186.
Muir, D.C., Norstrom, R.J., Simon, M., 1988. Organochlorine contaminants in Arctic marine food chains: accumulation of specific polychlorinated biphenyls and chlordane-related compounds. Environ. Sci. Technol. 22 (9), 1071–1079.
NBC. 2006. Wild Find: Half Grizzly, Half Polar Bear. (December 12 2013; www.nbc.com).
Newton, S.T., Fast, H., Henley, T, 2002. Sustainable development for Canada's Arctic and Subarctic communities: a backcasting approach to Churchill, Manitoba. Arctic 55 (3), 281–290.
Norstrom, R., Belikov, S., Born, E., Garner, G., Malone, B., Olpinski, S., Ramsay, M., Schliebe, S., Stirling, I., Stishov, M., 1998. Chlorinated hydrocarbon contaminants in polar bears from eastern Russia, North America, Greenland, and Svalbard: biomonitoring of Arctic pollution. Arch. Environ. Contam. Toxicol. 35 (2), 354–367.
Norstrom, R.J., 1999. Trends and effects of contaminants in polar bears. In: Kalhok, S. (Ed.), Synopsis of Research Conducted under the 1999–2000 Northern Contaminants Program. Minitry of Indian and Northern Affairs, Ottawa, Canada, pp. 173–181.
NRDC. 2013. Polar Bear Hunting on Rise Despite Species' Decline. Press Release. (December 12 2013; www.nrdc.org).
Obbard, M.E., Thiemann, G.W., Peacock, E., DeBruyn, T.D. 2010. Polar bears. In: Proceedings of the 15th Working Meeting of the IUCN/SSC Polar Bear Specialist Group, Copenhagen, Denmark, 29 June–3 July 2009. IUCN.
Oh, J.R., Choi, H., Hong, S.-H., Yim, U.H., Shim, W.-J., Kannan, N., 2005. A preliminary report of persistent organochlorine pollutants in the Yellow Sea. Mar. Pollut. Bull. 50 (2), 217–222.
Olar, M., Louvel, J., Hernandez, M., Sauvé, C., Zussy, S., Messier, J. 2011. Evidence of the Socio-economic Importance of Polar Bears for Canada. Prepared by EcoRessources Consultants. Environment Canada. Canada Wildlife Service. Her Majesty the Queen in Right of Canada.
Parsons, E., Cornick, L., 2011. Sweeping scientific data under a polar bear skin rug: the IUCN and the proposed listing of polar bears under CITES Appendix I. Mar. Policy 35 (5), 729–731.
PBSG. 2010. Summary of Polar Bear Population Status per 2010. (December 13 2013; http://pbsg.npolar.no/en/status/status-table.html).
Peacock, E., Derocher, A., Thiemann, G., Stirling, I., 2011. Conservation and management of Canada's polar bears (*Ursus maritimus*) in a changing Arctic. Can. J. Zool. 89 (5), 371–385.
Pernetta, J.C., Bewers, J.M., 2012. Transboundary diagnostic analysis in international waters interventions funded by the global environment facility. Ocean Coast. Manage. 55, 1–12.
Pilfold, N.W., Derocher, A.E., Stirling, I., Richardson, E., 2014. Polar bear predatory behaviour reveals seascape distribution of ringed seal lairs. Popul. Ecol. 56 (1), 129–138.
Polischuk, S., Letcher, R., Norstrom, R., Ramsay, M., 1995. Preliminary results of fasting on the kinetics of organochlorines in polar bears (*Ursus maritimus*). Sci. Total Environ. 160, 465–472.
Polyakov, I.V., Timokhov, L.A., Alexeev, V.A., Bacon, S., Dmitrenko, I.A., Fortier, L., Frolov, I.E., Gascard, J.-C., Hansen, E., Ivanov, V. V., Laxon, S., Mauritzen, C., Perovich, D., Shimada, K., Simmons, H.L., Sokolov, V.T., Steele, M., Toole, J., 2010. Arctic Ocean Warming Contributes to Reduced Polar Ice Cap, 40. American Meteorological Society2743–2757.

Post, E., Brodie, J., 2012. Extinction risk at high latitudes. In: Hannah, L. (Ed.), Saving a Million Species. Island Press/Center for Resource Economics, Washington, DC, pp. 121–137.
Prestrud, P., Sterling, I., 1994. The International Polar Bear Agreement and the current status of polar bear conservation. Aquatic Mammals 20. (113-113).
Ramsay, M., Stirling, I., 1988. Reproductive biology and ecology of female polar bears (*Ursus maritimus*). J. Zool. 214 (4), 601–633.
Regehr, E.V., Hunter, C.M., Caswell, H., Amstrup, S.C., Stirling, I., 2010. Survival and breeding of polar bears in the southern Beaufort Sea in relation to sea ice. J. Anim. Ecol. 79 (1), 117–127.
Rockwell, R., Gormezano, L., Hedman, D., 2008. Grizzly bears, *Ursus arctos*, in Wapusk National Park, Northeastern Manitoba. Can. Field Nat, 323–326.
Rode, K.D., Regehr, E.V., Douglas, D.C., Durner, G., Derocher, A.E., Thiemann, G.W., Budge, S.M., 2014. Variation in the response of an Arctic top predator experiencing habitat loss: feeding and reproductive ecology of two polar bear populations. Global Change Biol. 20 (1), 76–88.
Sahanatien, V., Derocher, A.E., 2012. Monitoring sea ice habitat fragmentation for polar bear conservation. Anim. Conserv. 15 (4), 397–406.
Sakshaug, E., 2004. Primary and secondary production in the Arctic Seas. In: Stein, R., MacDonald, R.W. (Eds.), The Organic Carbon Cycle in the Arctic Ocean. Springer, Berlin, pp. 57–81.
Sallon, A., Michel, C., Gosselin, M., 2011. Summertime primary production and carbon export in the southeastern Beaufort Sea during the low ice year of 2008. Polar Biol. 34 (12), 1989–2005.
Serreze, M.C., Holland, M.M., Stroeve, J., 2007. Perspectives on the Arctic's shrinking sea-ice cover. Science 315 (5818), 1533–1536.
Sherman, K., 1999. A modular approach to the monitoring and assessment of large marine ecosystems. In: Kumpf, H., Steidinger, K., Sherman, K. (Eds.), The Gulf of Mexico Large Marine Ecosystem: Assessment, Sustainability, and Management. Blackwell Science, Malden, MA, pp. 34–63.
Sherman, K., 2005. The large marine ecosystem approach for assessment and management of ocean coastal waters. In: Hennessey, J., Sutinen, J. (Eds.), Sustaining the Large Marine Ecosystem: the Human Dimension, vol. 13. Elsevier, Amsterdam, pp. 3–16.
Sherman, K., 2014. Adaptive management institutions at the regional level: the case of large marine ecosystems. Ocean Coast. Manage. 90, 38–49.
Sherman, K., Alexander, L.M. 1986. Variability and Management of Large Marine Ecosystems AAAS Symposium 99. Westview Press., Boulder, CO.
Sherman, K., Duda, A., 1999. An ecosystem approach to the assessment and management of coastal waters. Mar. Ecol. Prog. Ser. 190, 271–287.
Sherman, S., Adams, S., Aquarone, M.-C. 2010. Scope and Objectives of Global Environment Facility Supported Large Marine Ecosystems Projects [available at www.lme.noaa.gov]. USDOC, National Oceanic and Atmospheric Administration. Report no.
Simpkins, M., Kovacs, K.M., Laidre, K., Lowry, L., 2007. A Framework for Monitoring Arctic Marine Mammals - Findings of a Workshop Sponsored by the U.S. Marine Mammal Commission and U.S. Fish and Wildlife Service. Valencia, CAFF International Secretariat 1–17.
Slocombe, D.S., 1998. Defining goals and criteria for ecosystem-based management. Environ. Manage. 22 (4), 483–493.
Smith, T.G., 1987. The ringed seal, *Phoca hispida*, of the Canadian western Arctic. Can. Bull. Fish. Aquat. Sci. 216, 1–87.
Sonne, C., 2010. Health effects from long-range transported contaminants in Arctic top predators: an integrated review based on studies of polar bears and relevant model species. Environ. Int. 36 (5), 461–491.
Steinacher, M., Joos, F., Frolicher, T., Bopp, L., Cadule, P., Cocco, V., Doney, S.C., Gehlen, M., Lindsay, K., Moore, J.K., 2010. Projected 21st century decrease in marine productivity: a multi-model analysis. Biogeosciences 7 (3), 979–1005.
Stirling, I., 1990. Polar bears and oil: ecological perspectives. In: Geraci, J.R., Aubin, D.J.S. (Eds.), Sea Mammals and Oil: Confronting the Risks. Academic Press, San Diego, CA, pp. 223–234.
Stirling, I., Derocher, A.E., 1993. Possible impacts of climatic warming on polar bears. Arctic, 240–245.
Stirling, I., Øritsland, N.A., 1995. Relationships between estimates of ringed seal (*Phoca hispida*) and polar bear (*Ursus maritimus*) populations in the Canadian Arctic. Can. J. Fish. Aquat. Sci. 52 (12), 2594–2612.
Stirling, I., Parkinson, C.L., 2006. Possible effects of climate warming on selected populations of polar bears (*Ursus maritimus*) in the Canadian Arctic. Arctic 59, 261–275.
Stirling, I., Derocher, A.E., 2012. Effects of climate warming on polar bears: a review of the evidence. Global Change Biol. 18 (9), 2694–2706.
Stirling, I., Andriashek, D., Calvert, W., 1993. Habitat preferences of polar bears in the western Canadian Arctic in late winter and spring. Polar Rec. 29 (168), 13–24.
Stroeve, J., Holland, M.M., Meier, W., Scambos, T., Serreze, M., 2007. Arctic sea ice decline: faster than forecast. Geophys. Res. Lett. 34 (9), L09501.
Stroeve, J.C., Serreze, M.C., Holland, M.M., Kay, J.E., Malanik, J., Barrett, A.P., 2012. The Arctic's rapidly shrinking sea ice cover: a research synthesis. Clim. Change 110 (3–4), 1005–1027.
Tang, Q., 1993. Effects of long-term physical and biological perturbations on the contemporary biomass yields of the Yellow Sea ecosystem. In: Sherman, K., Alexander, L.M., Gold, B.D. (Eds.), Large Marine Ecosystems: Stress, Mitigation and Sustainability. AAAS Press, Washington, DC, pp. 79–93.
Tang, Q., 2003. The Yellow Sea and mitigation action. In: Hempel, G., Sherman, K. (Eds.), Large Marine Ecosystems of the World: Trends in Exploitation, Protection and Research. Elsevier Science, Amsterdam, Netherlands, pp. 121–144.
Thiemann, G.W., Iverson, S.J., Stirling, I., 2008. Polar bear diets and arctic marine food webs: insights from fatty acid analysis. Ecol. Monograph. 78 (4), 591–613.
Thiemann, G.W., Derocher, A.E., Stirling, I., 2008. Polar bear *Ursus maritimus* conservation in Canada: an ecological basis for identifying designatable units. Oryx 42 (04), 504–515.
Thiemann, G.W., Iverson, S.J., Stirling, I., Obbard, M.E., 2011. Individual patterns of prey selection and dietary specialization in an Arctic marine carnivore. Oikos 120 (10), 1469–1478.

Tyrrell, M., Clark, D.A., 2014. What happened to climate change? CITES and the reconfiguration of polar bear conservation discourse. Global Environ. Change 24, 363–372.

UNDP/GEF. 2009. Reducing Environmental Stress in the Yellow Sea Large Marine Ecosystem, Strategic Action Programme for the Yellow Sea Large Marine Ecosystem. United Nations Development Programme, IW: Science.

Vongraven, D., Peacock, E. 2011. Development of a Pan-arctic Monitoring Plan for Polar Bears. CAFF Monitoring Series Report no. 1. Circumpolar Biodiversity Monitoring Program.

Vongraven, D., Aars, J., Amstrup, S., Atkinson, S.N., Belikov, S., Born, E.W., DeBruyn, T.D., Derocher, A.E., Durner, G., Gill, M., Lunn, N., Obbard, M.E., Omelak, J., Ovsyanikov, N., Peacock, E., Richardson, E., Sahanatien, V., Stirling, I., Wiig, Ø., 2012. A circumpolar monitoring framework for polar bears. Ursus 23 (sp2), 1–66.

Walsh, J., McRoy, C., Coachman, L., Goering, J., Nihoul, J., Whitledge, T., Blackburn, T., Parker, P., Wirick, C., Shuert, P., 1989. Carbon and nitrogen cycling within the Bering/Chukchi Seas: source regions for organic matter effecting AOU demands of the Arctic Ocean. Prog. Oceanogr. 22 (4), 277–359.

Walters, C., 1986. Adaptive Management and Renewable Resources. Macmillan, New York, NY.

Wang, H., 2004. An evaluation of the modular approach to the assessment and management of large marine ecosystems. Ocean Dev. Int. Law 35, 267–286.

Wassmann, P., Duarte, C.M., Agusti, S., Sejr, M.K., 2011. Footprints of climate change in the Arctic marine ecosystem. Global Change Biol. 17 (2), 1235–1249.

Wiig, O., Aars, J., Born, E.W., 2008. Effects of climate change on polar bears. Sci. Prog. 91 (2), 151–173.

Wilder, J., 2013. Emerging conservation challenges. In: Tesar, C. (Ed.), Wanted: A Global Plan for Polar Bears. The Circle, vol. 3. WWF Global Arctic Programme, pp. 24–26.

WWF. 2014. Polar Bear. (March 10 2014; http://worldwildlife.org/species/polar-bear).

Young, B., Ferguson, S., 2013. Seasons of the ringed seal: pelagic open-water hyperphagy, benthic feeding over winter and spring fasting during molt. Wildl. Res. 40 (1), 52–60.

Young, O.R., Einarsson, N., 2004. A human development agenda for the Arctic: major findings and emerging issues. In: Einarsson, N., Larsen, J.N., Nilsson, A., Young, O.R. (Eds.), Arctic Human Development Report. Stefansson Arctic Institute, Akureyri, Iceland, pp. 229–242.