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Predictions of 27 Arctic pelagic seabird distributions using public environmental variables, assessed with colony data: a first digital IPY and GBIF open access synthesis platform

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Abstract We present a first compilation, quantification and summary of 27 seabird species presence data for north of the Arctic circle (>66 degrees latitude North) and the ice-free period (summer). For species names, we use several taxonomically valid online databases [Integrated Taxonomic Information System (ITIS), AviBase, 4 letter species codes of the American Ornithological Union (AOU), The British List 2000, taxonomic serial numbers TSNs, World Register of Marine Species (WORMS) and APHIA ID] allowing for a compatible taxonomic species cross-walk, and subsequent applications, e.g., phylogenies. Based on the data mining and machine learning RandomForest algorithm, and 26 environmental publicly available Geographic Information Systems (GIS) layers, we built 27 predictive seabird models based on public open access data archives such as the Global Biodiversity Information Facility (GBIF), North Pacific Pelagic Seabird Database (NPPSD) and PIROP database (in OBIS-Seamap). Model-prediction scenarios using pseudo-absence and expert-derived absence were run; aspatial and spatial model assessment metrics were applied. Further, we used an additional species model performance metric based on the best publicly available Arctic seabird colony location datasets compiled by the authors using digital and literature sources. The obtained models perform reasonably: from poor (only a few coastal species with low samples) to very high (many pelagic species). In compliance with data policies of the International Polar Year (IPY) and similar initiatives, data and models are documented with FGDC NBII metadata and publicly available online for further improvement, sustainability applications, synergy, and intellectual explorations in times of a global biodiversity, ocean and Arctic crisis.

Keywords Pelagic circumpolar seabird distribution · Open access online databases · GIS (Geographic Information System) · Circumpolar seabird colonies · International Polar Year (IPY) · Arctic biodiversity · Global Biodiversity Information Facility (GBIF) · Data mining synthesis

Introduction

The Arctic has experienced many changes in the last 40 years (Overpeck et al. 1997; Serreze et al. 2000). These have been well documented for the terrestrial environment

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(Martin and Tyler 1995; CAFF 2001a; Arctic Council 2004; Hinzman et al. 2005), and are inherently linked with coastal and marine ecosystems (Krasnov and Barrett 1997; Full 1999; Krupnik and Jolly 2002; NRC 2003; Frolov et al. 2009). The changes also provide a global connection and link with the atmosphere (Walter et al. 2006; Anisimov et al. 2007). The Arctic marine ecosystem is still poorly described, and consistent data are widely lacking; this region and its seabirds present one of the last frontiers and show by now an international management dilemma. This study stands in the context of the missed Biodiversity targets for 2010 (see Mace et al. 2010 for a review) and the International Polar Year (IPY; www.ipy.org).

This contribution first provides an overview regarding the overall challenges and approaches when studying Arctic pelagic seabirds. It is followed by an overview and short summary of Arctic seabirds, their habitat, the related research and conservation management and history. Then, we pursue the major research focus of this paper: an assessment of the pan-Arctic summer distribution of 27 Arctic seabirds species through the combination of field data and progressive modeling, which is followed by a general discussion of the findings in the wider Arctic and management context.

Most Arctic seabird studies focus on colonial seabirds and terrestrial inventories, special observations, and species lists with rough abundance estimates, but are often not based on a rigorously modern scientific and spatial research design (Braun 2005) and latest statistical analysis, while data are not fully accessible in public databases, including literature from Russia (Bakken 2000), Norway (and some Swedish, and Icelandic) (Anker-Nilssen et al. 2000; Bakken et al. 1996, Bakken 2000) and Denmark (including circumpolar and Greenland literature; Lyngs 2003). Contacting the original field observers, or obtaining the original reference texts, usually presents a large challenge. Here, polar libraries could still play a major role, as well as digital sources, to help better explore data for seabird projects.

All Arctic seabird species have been generally described (Schreiber and Burger 2002; Gaston 2004). For some Russian areas like the Barents Sea (Belopolsky 1957) and the Kola peninsula, large long-term datasets exist, some from 1921 onwards. Further, the *Birds of North America* (BNA http://bna.birds. cornell.edu/bna) species accounts cover the North American continent well, but less so for the circumpolar Arctic, whereas Alaska lacks a specific modern Arctic seabird reference (but see Bailey 1948; Smith and Smith 2009 for Bering Sea and general seabird reports). The adjacent Yukon and its seabirds are partly covered by Sinclair et al. (2003). Russian bird species are covered in Knystautas (1993; general overview), Krechmar et al. (1991) for the Arctic tundra, and Kondratyev et al. (2000) and Artukhin and Burkanov (1999) for the wider Sea of Okhotsk region; many technical research reports exist. Greenland is covered, in part, by Boertmann (1994). Some European Arctic species are dealt with in Cramp and Simmons (1977, 1983) and Cramp (1985). Global reviews such as del Hoyo et al. (1992, 1996) add to these details, but, similar to species monographs, e.g., Kampp et al. (1994); Grant (1997); Gaston and Jones (1998); Furness (1987) and general overviews, e.g., Harrison (1983), they are often imprecise on specific circumpolar Arctic details, e.g., distribution maps, local details and resource selection. Specific circumpolar multispecies Arctic seabird publications are virtually missing (see CAFF 2001a for general overview). Specific species and status reviews for local Arctic areas can be found in Gavrilo et al. (1998a, b) for Russia, Anker-Nilssen et al. (2000) for the Barents Sea, and Krasnov et al. (2007) for the Russian–Norwegian coast.

So far, Arctic seabirds have mostly been studied for various aspects of their nesting behavior, phenology, trends (Vaughan 1991) and their huge colonies (e.g., Birkhead 1993), but less so for quantified pelagic distributions and migrations. However, all these features are contributing to sustaining these breeding sites overall. Seabirds are considered indicators of ecosystem health (Furness and Monaghan 1987; Schreiber and Burger 2002), and the observed big changes in population size and distributions, e.g., for gulls, gannets and skuas (http://npweb.npolar.no/english/arter/storjo), suggests serious ecological problems in the wider food chain (see Wayland et al. 2010 for stressed individual gulls). The tight connection between circumpolar nesting seabirds with climate have already been shown by Irons et al. (2008). The current approaches to circumpolar seabird monitoring and conservation are so far not fully habitat- and ecosystem-based, not truly spatially explicit, and do not focus on spatial Population Viability Analysis (sPVA) and pro-active, predictive opportunities to be used in an adaptive management framework (Braun 2005; Chapin et al. 2010). The use of digital opportunities and tools is widely lacking (Cushman and Huettmann 2010), and no written or mutually accepted guidance exists on the management of pelagic seabirds (Nettleship 1991; Gaston 2004). A specific Arctic knowledge-focus is not widely presented for most seabird species and their pelagic distributions (see Schreiber and Burger 2002), nor are many Arctic peculiarities well addressed, studied and known. Although other Arctic species like polar bears are already listed as endangered, together with their habitats, the majority of all the ecosystem components might become extinct within less than 50 years (Arctic Council 2004).

An Arctic seabird species that carries, for instance, such a serious conservation status is the Ivory Gull (*Pagophila eburnea*), a strict sea-ice specialist for most of the year (Gilg et al. 2005, 2010). This situation can extend to the entire High Arctic seabird community and that is directly affiliated with the sea ice ecosystem of concern. A second noteworthy observation is that no generally agreed taxonomy exists for Arctic seabirds. In addition to the many national taxonomies, at least five international taxonomies exist for Arctic seabirds (ITIS at www.itis.gov; AviBase at http://avibase.bsc-eoc.org/avibase.jsp; AOU at http://www.aou.org/checklist/north/index.php, WORMS at http://marinespecies.org/index.php; and Brooke 2002) with no complete agreement on taxonomy, or at the subspecies level (see Anker-Nilssen et al. 2000 for a general overview; K. Winker, personal communication). See also scientific references such as *The Bird List 2000* by the British Ornithological Union (BOU 1999), del Hoyo et al. (1992, 1996) for *Handbook of the Birds of the World*, and *The Birds of the Western Palaeartic* by Cramp and Simmons (1977, 1983) and Cramp (1985).

Detailed knowledge at the subspecies level will be a requirement for management, metapopulation studies, red list classifications, and treatment of local populations, for instance, in the context of genetic diversity and already occurring or predicted Arctic environmental changes (Krasnov and Barrett 1997; Overpeck et al. 1997; Krupnik and Jolly 2002; Arctic Council 2004). The use of consistent and globally unique taxonomic serial numbers (TSNs in ITIS; APHIA# in WORMS) can help to resolve this problem, and is of high international research and management value, e.g., for linking with online databases such as Genbank and Barcoding for adding DNA for environmental decision making (Mordecai et al. 2010).

Arctic seabird studies: current status

Compared to seabirds in temperate or tropical zones, Arctic seabirds were not studied until rather late, with most studies starting in the 1960s (Vaughan 1991; Gaston 2004). So far, most research, publications and management have focused on nesting seabirds, and the nesting cliffs (called 'bazaars' in Russian; e.g., Vaughan 1991). This includes sites in coastal Greenland (Evans 1984), the Hudson Bay region (Gaston and Nettleship 1981), the wider White Sea region (Uspenski 1956), Svalbard (Anker-Nilssen et al. 2000), Aleutian islands (Gibson and Byrd 2007), Seward-Alaska (Kessel 1989) and the northern Sea of Okhotsk (overview in Huettmann 2008). A further emphasis on isolated islands is noticeable (Uspenski et al. 1963; Stishov et al. 1991; Vaughan 1991; Birkhead 1993; Nettleship et al. 1994; Wannhoff and Toermer 1997; Huettmann 2008). A second study focus during the breeding season is found for coastal tundra sites (Vaughan 1991; Sinclair et al. 2003). It is further noteworthy that many (tourist) ships cruise the Arctic, but mostly without any seabird observers on board and therefore not so far providing much pelagic and colony seabird data or making use of their full potential.

Major Arctic research programs that include seabirds were the International Northern Sea Route Program (INSROP; http://www.fni.no/insrop/; Thomassen et al. 1994; Bakken et al. 1996; Gavrilo et al. 1998a, b; supported by Russia, Norway and Japan), the North American Shipping Route (supported by U.S. and Canada), the Seward peninsula investigation in Alaska (Kessel 1989), and the Barents Sea initiatives between Norway and western Russia (Anker-Nilssen et al. 2000). In Alaska, the former Minerals Management Service (MMS; www.mms.gov) maintained for many decades a large Arctic ecosystem assessment effort that also included seabirds. The Canadian MacKenzie river delta has received similar attention (http://www.beaufortseapartnership.ca/google_earth_atlas.html). These efforts have been tightly related to economic growth activities that eventually promote Gross Domestic Products (GDP; Rosales 2008), e.g. via governmental licensing rules for offshore oil and gas production (Yergin 1991). Private birding activities have also contributed to our knowledge on Arctic seabirds (Vaughan 1991; Coastal Ocean Assessment and Seabird Survey Team (http://depts.washington.edu/coasst/), but mostly focused on terrestrial ecosystems and thus, centered on accessible islands, beaches and nesting sites. For Russia, relevant studied seabird islands and cliff sites are, for instance, Vaigach Island, Yugor and Kola Peninsula and Novaya Zemlya, Taimyr, Severnaya Zemlya, Commander and Wrangel Islands. For the North Atlantic, Herald Island, Svalbard and Jan Mayen are well studied, whereas in the North Pacific, St. Lawrence and Cooper Islands have received much attention (references provided in the previous paragraphs).

In terms of seabird distribution modeling and predictions for the Arctic, no coherent models exist. Three studies have been started: Diamond et al. (1993), Huettmann and Diamond (2001), and Fauchald et al. (2002), with decent to very good success. A first risk model was completed by Gavrilo et al. (1998b).

A compressed biological summary for selected seabird species

For a general overview, we briefly summarize, for a subset of 27 pelagic species, their taxonomy (Table 1), and general biological and environmental information (Tables 2 and 3). Our assessment focused on the entire population with birds in open waters during summer, and it includes ice edge, polynyas and similar hotspots attracting animals, as well as proximities to man-made habitats, e.g. settlements, fisheries, garbage dumps and oil platforms, in addition to colonies. This paper makes use of colonies (Gaston 2004) but rather considers their role in the wider context of seabird life history, evolution, pelagic distribution, biodiversity, the ocean ecosystem, and a sustainable adaptive management (Braun 2005).

Table 1 Taxonomic naming details of 27 Arctic seabird species selected for this study (– indicates identical name, *NA* species not on the list), and based on five widely used taxonomies (all freely available online)

ITIS common name	ITIS scientific name	ITIS taxonomic serial number (TSN)	AOU common name (50th supplement)	AOU abbreviation (4 letter alpha codes)	AviBase common name	AviBase scientific name	Avibase ID	WORMS common name	WORMS scientific name	WORMS APHIA ID number	The British List 2000 common name	The British List 2000 scientific name
Razorbill	*Alca torda*	176971	–	RAZO	–	–	64F4DD81371B269F	–	–	137128	–	–
Dovekie	*Alle alle*	176982	–	DOVE	–	–	B0932D89F1F74318	–	–	137129	Little Auk	–
Kittlitz's Murrelet	*Brachyram-phus brevirostris*	176998	–	KIMU	–	–	7AD855E2377EBA1E	–	–	254310	NA	NA
Pigeon Guillemot	*Cepphus columba*	176991	–	PIGU	–	–	2F5DF476344AEA92	–	–	343902	NA	NA
Black Guillemot	*Cepphus grylle*	176985	–	BLGU	–	–	B5AA5952E13FE5F3	–	–	137130	–	–
Atlantic Puffin	*Fratercula arctica*	177025	–	ATPU	–	–	2771624B64AD7F2C	–	–	137131	Puffin	–
Tufted Puffin	*Fratercula cirrhata*	177032	–	TUPU	–	–	F79373497BC9C8FD	–	*Lunda cirrhata*	344610	NA	NA
Horned Puffin	*Fratercula corniculata*	177029	–	HOPU	–	–	24111FA5AE00A5DB	–	–	343903	NA	NA
Northern Fulmar	*Fulmarus glacialis*	174536	–	NOFU	–	–	049D9AEA4AFBFDFA	–	–	137195	–	–
Herring Gull	*Larus argentatus*	176824	–	HEGU	–	–	F002188E226DF09C	–	–	137138	–	–
Lesser Black-backed Gull	*Larus fuscus*	176821	–	LBBG	–	–	49025D8B171EFAD7	–	–	137142	–	–
Iceland Gull	*Larus glaucoides*	176811	–	ICGU	–	–	12D5BA6CB1F71DCD	–	–	137144	–	–
Heuglin's Gull	*Larus heuglini*	176821	–	NA	Siberian Gull	–	4592C07EAC30C4CF	–	–	423477	–	–
Glaucous Gull	*Larus hyper-boreus*	176808	–	GLGU	–	–	A59FA446D6B40057	–	–	137145	–	–
Great Black-backed Gull	*Larus marinus*	176815	–	GBBG	–	–	E826E9F3FBAED223	–	–	137146	–	–
Thayer's Gull	*Larus thayeri*	176828	–	THGU	–	–	69E839448750A39A	–	–	343922	NA	NA
Ivory Gull	*Pagophila eburnea*	176851	–	IVGU	–	–	FED91A1F00C4E67C	–	–	137154	–	–
Ross's Gull	*Rhodostethia rosea*	176864	–	ROGU	–	–	4CD353D243C27F86	–	–	137155	–	–
Black-legged Kittiwake	*Rissa tridactyla*	176875	–	BLKI	–	–	FB4D08F0837D4683	–	–	137156	–	–
Long-tailed Jaeger	*Stercorarius longicaudus*	176794	–	LTJA	–	–	1D4464402EC9FD21	–	–	137171	Long-tailed Skua	–
Parasitic Jaeger	*Stercorarius parasiticus*	176793	–	PAJA	–	–	39086887E9EAFEB3	–	–	137172	Arctic Skua	–
Pomarine Jaeger	*Stercorarius pomarinus*	176792	–	POJA	–	–	7CB8F5B711DE64D0	–	–	137173	Pomarine Skua	–
Great Skua	*Stercorarius skua*	176797	–	GRSK	–	–	BB041C6E5DB73FC7	–	*Catharacta skua*	137174	Skua	–
Aleutian tern	*Sterna aleutica*	176893	*Onychoprion aleuticus*	ALTE	–	–	BEE4F34A70214978	–	–	343925	–	*Onychoprion aleuticus*
Arctic tern	*Sterna paradisaea*	176890	–	ARTE	–	–	BDC5CF80BE6CFC21	–	–	137165	–	–

Common Murre	*Uria aalge*	176974	–	COMU	–	–	39F29B55EF9A542F	–	–	137133	Guillemot	–
Thick-billed Murre	*Uria lomvia*	176978	–	TBMU	–	–	B70B5840ABCD5CFC	–	–	137134	Brünnich's Guillemot	–
Sabine's Gull	*Xema sabini*	176866	–	SAGU	–	–	8618265647 2B476B	–	–	137167	–	–

Due to a lack of convenient to use digital public information, this study did not employ seabird banding and recovery data (Barrett et al. 1997; Lyngs 2003; and Anker-Nilssen et al. 2000 for Herring Gull, Great-Black-backed Gull, Glaucous Gull, Black-legged Kittiwake, Ivory Gull, Arctic Tern, Common Murre, Thick-billed Murre, Razorbills, Black Guillemot, Dovekie and Atlantic Puffin; CAFF Conservation of Arctic Flora and Fauna 2004 for Murres). For a first compiled published summary of such Arctic data sources, see Online Resource 1. First studies exist that try to track such data, connect them internationally, and analyze movement patterns (CAFF 2004 for a list of studies that achieved this). Despite various interpretation and research design problems (e.g., no statistical review and use of latest quantitative methodology such as data mining, machine learning, autocorrelation), this source of banding data remains invaluable for hypothesis testing regarding movement patterns and changes in Arctic ecosystems. It should be thoroughly worked up, reviewed and made available digitally for predictive modeling and other projects, e.g., via EURING (http://www.euring.org/).

In general, pelagic distributions, migration and movement patterns of Arctic seabirds are still either poorly known, not up to date, or change quickly with ocean and sea ice status (Divoky 1976; Hunt et al. 1996; Mehlum et al. 1998). Major impacts are introduced through human provisioning of additional food supplies (Furness and Monaghan 1987), but these effects are poorly studied. Further, virtually none of the existing seabird distribution maps from scientific sources are in entire agreement with each other, the underlying raw data are rarely available, and the derived maps are not quantitative, nor based on consistent data and latest techniques and accuracy assessments that are usually used in the disciplines of species distribution and predictive modeling (e.g., Guisan and Zimmermann 2000; Pearce and Ferrier 2000; Hegel et al. 2010). Statistically, the literature sources rarely perform well when scrutinized, yet this is required for a sound science-based management of a precious natural resource (Cushman and Huettmann 2010). Much of the current seabird distribution information can be well summarized as a qualitative "*assumed general pelagic occurrence*" (in Gavrilo et al. 1998a).

The taxonomy of seabirds is currently in disagreement internationally (gulls or albatrosses as polar examples; Schreiber and Burger 2002; Onley and Scofield 2007). Anker-Nilssen et al. (2000) cited mismatching names for many Arctic bird species. AviBase, probably the widest used taxonomy covering over 15 languages, pursues a morphometric, field-based and spatial (but less genetic) approach to species and subspecies delineation, catering primarily for bird watchers. As an example of taxonomic problems, the gull taxon *heuglini*, is currently considered as either a sub-species of the Lesser Black-backed Gull or a

Table 2 Biological overview matrix for 27 circumpolar seabird species (information sources: authors and citations mentioned in text)

Name	Distribution	Migration details (into wintering ground)	Wintering area	Productivity (general ranking)
Alca torda	North Atlantic	Southwards	Temperate ocean	Low
Alle alle	North Atlantic, some North Alaska	Southwards	Subarctic	Low
Brachyramphus brevirostris	North Pacific	Resident	Subarctic	Low
Cepphus columba	North Pacific	Southwards	Subarctic	Low
Cepphus grylle	Circumpolar	Resident	Subarctic	Low
Fratercula arctica	North Atlantic	Southwards	Temperate ocean	Low
Fratercula cirrhata	North Pacific	Southwards	Temperate ocean	Low
Fratercula corniculata	North Pacific	Southwards	Temperate ocean	Low
Larus argentatus	Circumpolar, coastal and marine, low arctic	Southwards	Subarctic	High
Larus fuscus		Southwards	Subarctic	Medium
Larus glaucoides	Circumpolar	Southwards	Subarctic	Medium
Larus heuglini	Russian Arctic	Southwards	Subtropical	Medium
Larus hyperboreus	North Atlantic	Circumpolar	Subarctic	Medium
Larus marinus	Circumpolar	Southwards	Subarctic	Low
Larus thayeri	North Canada	Southwards	Subarctic	Medium
Pagophila eburnea	Circumpolar	Circumpolar	Circumpolar	Medium
Rissa tridactyla	Circumpolar	Southwards	Subarctic	High
Rhodostethia rosea	Circumpolar	Circumpolar	Subarctic	Medium
Stercorarius parasiticus	Circumpolar	Southwards	Temperate ocean	High
Stercorarius pomarinus	Circumpolar	Southwards	Temperate ocean	High
Stercorarius longicaudus	Circumpolar	Southwards	Temperate ocean	High
Stercorarius skua	North Atlantic	Southwards	Temperate ocean	Medium
Sterna aleutica	North Pacific	Southwards	Temperate ocean	High
Sterna paradisaea	Circumpolar	Southwards	Southern hemisphere	High
Uria aalge	North Atlantic	Southwards	Temperate ocean	Low
Uria lomvia	Circumpolar	Southwards	Subarctic	Low
Xema sabini	Circumpolar	Southwards	Southern Hemisphere	Low

subspecies of the Herring Gull (Burger and Gochfeld 1996). Less controversial, but still confusing, are Thayer's and Vega Gulls. Several subspecies have been described for Black-legged Kittiwakes (Slyus (1982), Dovekies (Day et al. 1988), and for auks (Nettleship et al. 1996; Friesen et al. 1996). The conservation status of subspecies is widely unknown for most seabirds (Strann and Vader 1992), rendering a biologically valid conservation assessment for many Arctic species almost impossible.

Seabirds are widely described as indicators of food chains, ecosystems and ecological processes. Areas like the Northeast Atlantic, and parts of the Pacific, stand out with studies on these questions. These food chains can be rather large, specific and complex, covering land and sea. This complexity is often expressed in the foraging range of seabird species (Schreiber and Burger 2002) which can reach way beyond 30 km of a colony (e.g, .over 700 km for some species: Huettmann and Diamond 2001).

Seabirds can be strong predators in ocean systems (Schreiber and Burger 2002) and specifically in the sub-Arctic (Cairns et al. 2008). They also produce guano and relevant input for nutrient cycles (Stempniewicz 1992; Schreiber and Burger 2002). This is specifically true for Arctic regions that are otherwise relatively nutrient poor, and for locations that concentrate seabirds and biomass in huge numbers (Gavrilo et al. 1998a; Irons et al. 2008). The biological role that ice edges (Hunt et al. 1996; Mehlum 1990, 1997; Gilg et al. 2010), fronts (Mehlum et al. 1998) and polynyas (Brown and Nettleship 1981; Falk and Moeller 1995) generally play for Arctic seabirds has been investigated many times, whereas the importance of abiotic seascape factors such as bathymetry and sea ice characteristics, water density and mixed-layer depths are less well described but still relevant drivers (Shuntov 2000; Huettmann 2000; Newton 2003; Cairns et al. 2008). They set the framework for the ecological niche of seabirds.

Table 3 Biological overview matrix for 27 circumpolar seabird species (information sources: authors and citations mentioned in text)

Name	Diseases	Contamination load	Stress tolerance (general ranking)	Indicator value (ocean habitat)	Data completeness (pelagic; for this study)
Alca torda	NA	NA	Little	Low	Medium
Alle alle	NA	Potential	Little	High	Medium
Brachyramphus brevirostris	NA	NA	Little	High	Poor
Cepphus columba	NA	NA	Little	High	Poor
Cepphus grylle	NA	NA	Little	Medium	Medium
Fratercula arctica	NA	Potential	Little	Low	Medium
Fratercula cirrhata	NA	NA	Little	High	Poor
Fratercula corniculata	NA	NA	Little	High	Poor
Larus argentatus	Avian influenza	High	High	Low	Medium
Larus fuscus	NA	NA	Low	Medium	Medium
Larus glaucoides	NA	Potential	Medium	Medium	Medium
Larus heuglini	NA	NA	Medium	High	Low
Larus hyperboreus	NA	Potential	Medium	High	Medium
Larus marinus	NA	Potential	Medium	Medium	Poor
Larus thayeri	NA	Potential	Medium	Medium	Poor
Pagophila eburnea	NA	NA	Low	High	Poor
Rissa tridactyla	NA	Potential	High	Low	Medium
Rhodostethia rosea	NA	NA	Medium	High	Medium
Stercorarius parasiticus	NA	Medium	High	Low	Medium
Stercorarius pomarinus	NA	Medium	High	Low	Medium
Stercorarius longicaudus	NA	Medium	High	Medium	Poor
Stercorarius skua	NA	Medium	High	Low	Medium
Sterna aleutica	NA	Low	Low	High	Poor
Sterna paradisaea	NA	High	High	High	Medium
Uria aalge	NA	Low	Little	Medium	Poor
Uria lomvia	NA	High	Little	High	Poor
Xema sabini	NA	NA	Medium	High	Medium

Because of such an inherent link that seabirds have with their environment, changes in the Arctic can often be directly detected and observed through seabirds. Such a link has already been made in the Arctic with Murre population trends and climate shifts (Irons et al. 2008), the decline of Lesser Black-Backed Gulls, and the herring crash (Anker-Nilssen et al. 2000). Specific declines of Thick-billed Murres have been linked with fisheries bycatch, as well as chronic oil spills (Nettleship and Birkhead 1985; Wiese et al. 2004). A link with contaminants (e.g., PCB, DDE and HCB; Crane & Galasso 1999) has been made for Herring Gulls (Anker-Nilssen et al. 2000) and Ivory Gulls (Braune et al. 2006); many other similar links exist (e.g., Daelemans 1994; Wayland et al. 2010) but are not yet fully described.

Arctic seabird conservation and policies

Arctic seabird data have already been used for an informed decision-making. For instance, Bakken (2000) states that "The colony database for the Barents Sea Region has been used for oil/seabirds impact assessments in the Barents Sea…, identification of vulnerable areas in relation to oil spills …and for evaluation of the protected areas in Svalbard…".

Arctic conservation is a widely discussed subject (Syroechkovkiy and Rogacheva 1994; Krasnov et al. 2005). However, modern and well-achieving policies elsewhere such as Strategic Conservation Planning, Eco-system Management and Adaptive Management (Cushman and Huettmann 2010) do not really exist and have not yet been applied (Nikolaeva et al. 2006; but see Huettmann and Hazlett 2010).

The lingering oil issues for Arctic seabirds have been known for many decades (Leighton et al. 1985; Boertmann et al. 1996; Wiese et al. 2004; Krasnov et al. 2005) and seabird data were used for an oil vulnerability assessment in the Russian Arctic (Gavrilo et al. 1998a, b).

Other Arctic environmental impact studies including seabird data come from the Fylla region in Greenland (Mosbech et al. (1996), and the Alaskan Arctic (Truett and

Johnson 2000; ABR http://www.abrinc.com/; personal communication). The shipping assessments have already been mentioned.

The impact of Arctic fisheries, especially bycatch and discard, has also been discussed for more than two decades (Nettleship and Birkhead 1985; Mendenhall and Anker-Nilssen 1996; Bakken and Falk 1998), although several federally managed fisheries are still without impact studies (Dietrich et al. 2009). The notion of 'subsidized predators' and ship-following seabirds, e.g., to feed on offal, are well known to occur (Erikstad et al. 1988; Furness 1987).

Another issue in the Arctic and sub-Arctic is the impact of human harvest on seabird resources (Merkel and Barry 2008). This scheme has also received international recognition (see Gaston and Elliot 1991; Boertmann et al. 1996; Wiese et al. 2004), and agencies are mandated by law and several international treaties to administer this issue accordingly.

To account for all of these problems, larger monitoring schemes and international conservation policies were set up (Petersen et al. 2008). Many of these initiatives are described in Boardman (2006) and Cioc (2010). Anker-Nilssen et al. (2000) describes the following policy activities:

- Arctic Environmental Protection Strategy (AEPS) of 1991
- Convention of Arctic Flora and Fauna (CAFF; http://arctic-council.org/working_group/caff)
- Arctic Monitoring and Assessment Programme (AMAP; http://www.amap.no/)
- Emergency Prevention, Prepardness and Response (EPPR) and Protection of the Arctic Marine Environment (PAME; http://www.pame.is/)

The Circumpolar Biodiversity Monitoring Plan (CBMP) is a new approach that further adds to these efforts. All these schemes aim to integrate within the Arctic Council (AC; http://arctic-council.org/). The AC promotes the explicit goal of the protection of the arctic environment and a sustainable development, but lacks any regulatory authority for the international section of the Arctic beyond the Exclusive Economic Zone (EEZ) to monitor and implement it. It is not clear what strategy, science and management vision is used by AC as to how all these goals are to be reached successfully, and with regards to seabirds, e.g., following concepts outlined in Braun (2005), Chapin et al. (2010) or Cushman and Huettmann (2010). Further, specific working groups also exist, such as the Circumpolar Seabird Working Group, initiated in 1993, and the Working Group on Sustainable Development (SDWG; http://arctic-council.org/working_group/sdwg) established by AC in 1998.

Lastly, some smaller, bi- or tri-lateral agreements exist in relation to pelagic seabirds and their study. These can be policies such as the Migratory Bird Act, North American Bird Conservation Initiative (NABCI; http://www.nabci.net/vision.htm; Boardman 2006), or less formal and directed ones such as the Russian–Norwegian Seabird Expert Group (Anker-Nilssen et al. 2000). It is worth pointing out that these agreements mostly follow traditional policy and science views (Rosales 2008), and lack relevant spatial, predictive and data considerations (Cushman and Huettmann 2010).

Study goals

The goal of this investigation is to provide for the first time a large-scale, quantitative conservation-related synthesis that is explicit in space and time for circumpolar seabird distribution in the pelagic realm and which is in agreement with the principles of the latest International Polar Year (IPY). To achieve this goal, we use virtually all publicly available information, and employ predictive modeling to overcome gaps in data and knowledge. We opted for a large-scale approach, because this has never been done before for Arctic seabirds, and to add new knowledge and insights (Huettmann and Diamond 2001, 2006; Cairns et al. 2008). Based on earlier work and best available scientific knowledge, we try here to assemble a first circumpolar digital modeling platform to be used by the public worldwide for improved globally relevant sustainability management decisions and assessments.

Materials and methods

The Arctic seabird literature was reviewed and assessed for this synthesis and for 27 selected seabird species (Table 1). We used location names that are publicly known, and which can be tracked in BioGeomancer (www.biogeomancer.org; Chapman and Wieczorek 2006).

Predictive distributions can be derived in several ways. Here, we use two traditional model-prediction approaches involving the ecological niche in the multi-dimensional environmental space (Hegel et al. 2010). We approximately followed CAFF (2001a) using the 66°N latitude as the delineation of our study area: the Arctic Circle (Fig. 1) and its subregions (full list of subregion names is given in Online Resource 2, legend). We are aware that additional and sometimes substantial numbers of arctic seabirds are found further south (e.g., in Iceland, Hudson Bay, Bering Sea and Sea of Okhotsk) but we decided to start with a 'first cut' at 66°N, as widely done elsewhere. Our model and its data lend themselves for spatial adjustment and extensions as needed by specific users. Presence data (Fig. 2) were taken from the GBIF database (www.gbif.org) for the species listed in Table 1. The GBIF data reflect the public data availability in a given region, and they are

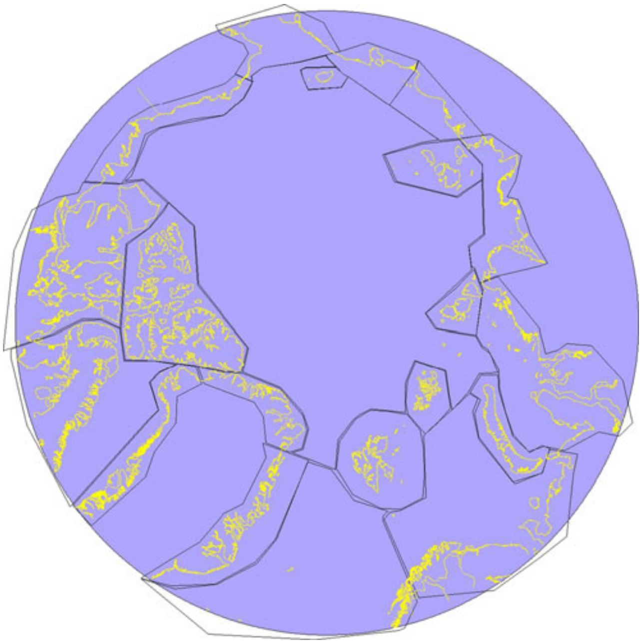

Fig. 1 Study area (Arctic Circle of 66°N latitude) and assessment regions

widely used for modeling worldwide, e.g. through OpenModeler (http://openmodeller.sourceforge.net/). The queries can either be done manually, or with a specific R code (http://www.r-project.org/; GetGBIF code kindly provided by B. Best, run by M Lindgren) and provide a downloadable CSV file for each species. For Alaska, we added data from the North Pacific Pelagic Seabird Database provided to us (USGS BRD, J. Piatt, personal communication). For Eastern Canada, additional data from the PIROP database (Brown et al. 1975; Brown 1986; Lock et al. 1997); Huettmann 2000) were provided through OBIS-Seamap (http://seamap.env.duke.edu/; Vanden Berghe et al. 2010). All raw data, summaries and data credits for each institutions and datasets can be found in the Online Resource. We employed two scenarios: modeling of presence/random (1,000 pseudo-absence points in the Arctic; created with Hawth's tools http://www.spatialecology.com/htools/ in ArcGIS 9.3), and modeling of presence/derived expert absence (VanDerWal et al. 2009; Hegel et al. 2010). Modeling of presence/expert-derived absence is based on the 1,000 pseudo-absence (random) points, and where we labeled locations specifically for what we assess as 'confirmed absence'. This process was guided by maps in Harrison (1983) and then fine-tuned with specific publications, and confirmed by all co-authors and expert publications we are aware of.

For circumpolar predictors, we used 26 available public GIS environmental layers (Table 4). These have been successfully used earlier and in similar projects (Huettmann 2000; Rutzen 2008; Oppel and Huettmann 2010; Humphries 2010). We included a new Dimethylsulfide (DMS) layer, which appears to perform very powerful for ecological and atmospheric processes, and for some seabirds (storm-petrels) and beyond (Humphries 2010). We used public data because then these layers can be assessed by everybody and in a transparent fashion. The use of 26 predictors allows us to test for multivariate statistical interactions, which make for a critical feature for good prediction and inference (Oppel et al. 2009; Oppel and Huettmann 2010). Secondly, we use more than 4–6 parsimonious predictors traditionally selected 'a priori'. This is because (1) it is entirely unclear how to select such a shortlist of predictors in a biologically meaningful fashion (Oppel et al. 2009), and (2) because it is impossible to know in advance how these variables vary for each species. Our multivariate environmental dataset serves as the best possible proxy for biotic predictors, which is still widely lacking for the Arctic and in many ocean studies. We used chemical, temperature and other predictors because they are 'continuous' in their units, and tend to make for best-possible models. The approach we used here is ideally suited for the applied specific modeling algorithm, and which we describe next.

We employed RandomForest as a modeling algorithm. It is part of decision-trees (Yen et al. 2004; Pittmann and Huettmann 2006; see Huettmann and Diamond 2001; Oppel and Huettmann 2010 for Arctic applications), widely used for data mining, machine learning and predictions (Hastie et al. 2008; Breiman 2001 for review of RandomForest algorithm), and has received very favorable applications and reviews (Elith et al. 2006; Magness et al. 2008). RandomForest does not suffer too much from the problem to have clean and meaningful predictors beforehand because it makes best possible use of the offered set. Further, it provides powerful optimizations for dealing with 'too many' predictors (Oppel et al. 2009; see Magness et al. 2008 for an example using over 60 predictors). RandomForest frequently performs at a very high level, e.g. with an accuracy above 85% (e.g., Elith et al. 2006), but it also has some weaknesess, many even unexplored (see Elith and Graham 2009). For example, RandomForest does not deal so well with autocorrelated data, but we think for point data on a large-scale this is less of an issue (see Huettmann and Diamond 2006 for mild scale effects when testing specific 10-min pelagic seabird survey data and for a fraction of the current study area). Ultimately, the subsequent accuracy assessments are the benchmarks and will be informative for such issues. We used the R and Salford implementations of RandomForest and applied the informed default settings. These have been used successfully by us and elsewhere (Breiman 2001), and are known to perform very well (e.g., Ohse et al. 2009; Booms et al. 2009 for Alaskan applications). Our model-prediction maps are not based on

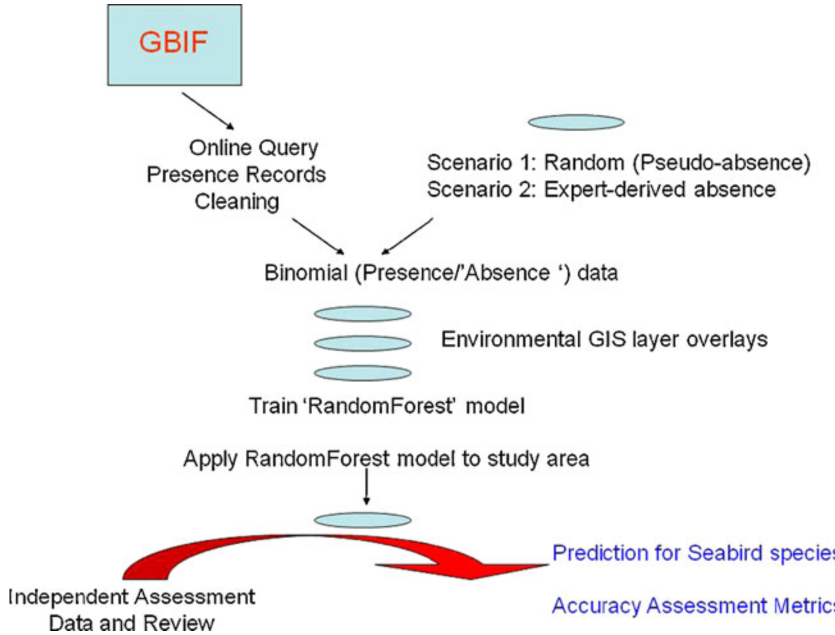

Fig. 2 Flowchart for this study of the analysis methods and on how the predictions and accuracy assessments were carried out

probabilities or maximum likelihood, and therefore provide a relative index of occurrence (ROI; Pearce and Ferrier 2000).

Our models are spatially explicit, but not very specific in time. They present a distribution pattern from public data that were pooled across time, but which is based on the majority of data coming from the summer season (~ice-free waters) when most seabird fieldwork is done in the Arctic (Gaston 2004). For this study, we initiated this process with the large-scale niche description of 27 pelagic seabird species. We believe that due to the open access approach we chose, all models and data can be made more specific and filtered down in time and space by users interested in such questions.

Model accuracy tests

Our models describe the general circumpolar niche of pelagic seabirds, as most collected seabird data are pooled: they are collected during the Arctic breeding season, summer, and when the ocean is ice free. They are usually not collected near the coast, and over sea ice. These data then inform the pelagic ecological niche we describe and assess for performance (Guisan and Zimmermann 2000; Braun 2005; see Huettmann and Diamond 2001 for an example). Sample sizes for all species, queries, model runs and assessments are shown in Tables 5 and 6 (Online Resource 3 shows raw data material before GIS processing and work-up for modeling). We chose several performance metrics to assess our predictions in parallel: aspatial Receiver Operator Characteristics (ROCs), two absence scenarios, by region, colony overlays, and comparison with expert knowledge. We agree that the regular ROC, non-spatial, can be over-optimistic when not checked spatially and with alternative data. Further, it is primarily used for classic presence/absence scenarios. But it can still be interpreted with care for most binomial distributions. The issue that a presence/random design is used, in part, is fully considered in our interpretation though, e.g. lack of emphasize in ROC on the random class, and thresholds. We further agree that a 50/50% approach for model training and assessment data would be ideal (Hegel et al. 2010). However, very few modeling projects actually use this approach, and it is usually not fully feasible for spatial assessments, for our data situation, and where many nations and agencies do not make their data available to efforts like ours for balanced and high spatial sample coverage. Lastly, we used six (!) assessment techniques for our predictions, and we are not aware of any seabird study that uses that many metrics to obtain a valid model prediction assessment to convince, and honestly assess, performance (see for instance Huettmann and Diamond 2001 and Yen et al. 2004 for two metrics).

We also used expert knowledge from the authoritive literature to see how well our predictions match the published knowledge in space and time (see tables in "Results" for literature sources; Fig. 1; and Online Resource 2 for regions). This is a common approach in predictive modeling (Drew et al. 2010). Although qualitative, we believe that this comparison is representative for the distributional knowledge of arctic seabirds and rather powerful, equaling a meta-analysis (Worm and Myers 2003).

For many seabird species, colony locations tend to summarize a large majority of the local population (breeders and most non-breeders attracted for mating and

Table 4 List of 26 public environmental data used for the circumpolar prediction of pelagic seabirds in this study

Data Set Topic	Dataset Name	Source	Scientific reference
Ocean bathymetry	Bathymetry	I. Rutzen	Rutzen (2008)
Euclidean distance to 1,000-m isobath	Distance to shelf	G. Humphries	ArcMap calculation
Euclidean distance to edge of ice	Distance to ice edge	G. Humphries	ArcMap calculation
Nitrate concentration at 0 m	Nitrates 0 m	NOAA WOA	Rutzen (2008)
Nitrate concentration at 10 m	Nitrates 10 m	NOAA WOA	Rutzen (2008)
Nitrate concentration at 20 m	Nitrates 20 m	NOAA WOA	Rutzen (2008)
Nitrate concentration at 30 m	Nitrates 30 m	NOAA WOA	Rutzen (2008)
Percent sea ice coverage	Sea ice	NSIDC	http://nsidc.org/
Phosphate concentration 0 m	Phosphates 0 m	NOAA WOA	Rutzen (2008)
Phosphate concentration 10 m	Phosphates 10 m	NOAA WOA	Rutzen (2008)
Phosphate concentration 20 m	Phosphates 20 m	NOAA WOA	Rutzen (2008)
Phosphate concentration 30 m	Phosphates 30 m	NOAA WOA	Rutzen (2008)
Salinity at surface	Salinity 0 m	NOAA WOA	Rutzen (2008)
Salinity at 20 m	Salinity 20 m	NOAA WOA	Rutzen (2008)
Salinity at 30 m	Salinity 30 m	NOAA WOA	Rutzen (2008)
Silicate concentration at 0 m	Silicates 0 m	NOAA WOA	Rutzen (2008)
Silicate concentration at 10 m	Silicates 10 m	NOAA WOA	Rutzen (2008)
Silicate concentration at 20 m	Silicates 20 m	NOAA WOA	Rutzen (2008)
Silicate concentration at 30 m	Silicates 30 m	NOAA WOA	Rutzen (2008)
Water temperature at surface	Temperature 0 m	NOAA WOA	Rutzen (2008)
Water temperature at 10 m	Temperature 10 m	NOAA WOA	Rutzen (2008)
Water temperature at 20 m	Temperature 20 m	NOAA WOA	Rutzen (2008)
Water temperature at 30 m	Temperature 30 m	NOAA WOA	Rutzen (2008)
Volume discharge from rivers	River discharge	I. Rutzen	Rutzen (2008)
Euclidean distance to human settlements	Distance to settlements	I. Rutzen	Rutzen (2008)
Concentration of dimethyl-sulfide (DMS) at surface	Dimethyl-sulfide (DMS)	G. Humphries	Humphries (2010)

food). A 30-km foraging zone was chosen as a minimum area in which seabird concentrate around colonies (Birt et al. 1987; Diamond et al. 1993; Huettmann and Diamond 2001) and which should at least match predicted presences. For colony data, we used the point sources outlined in Table 7. For the most part, we were not able to obtain the original colony point data, e.g. from CAFF (Irons et al. 2008), and thus had to manually re-digitize these locations into ArcGIS. This solution is not always spatially precise and also highly inefficient when considering that most of these data were originally created in GIS before they were turned into a hardcopy publication. However, it is also clear that neither the CAFF colony dataset nor any others yet exist that is publicly available and that has all colonies and all species mapped and up to date, and in good GIS formats, e.g. according to IPY.

We overlaid 'presence only' colony sites, buffered by 30 km, with the ROI. We did not use confirmed absences for colony sites of specific species because (1) they were widely lacking for most species, and (2) when applying these with a 30-km buffer zone, they usually overlap with nearby presence sites (Fig. 3) and then do not provide a helpful and clean assessment. Also, we did not use the actual population size at a colony as a metric because the counting protocols for seabird colonies are not always known across the Arctic, and not always compatible, and finally metadata were widely lacking for these data. For a first model presented here, we focus on a robust presence/absence type of analysis with colony (presence) overlays (similar than done successfully by Huettmann and Diamond 2001).

Finally, we would like to point out that the 'presence only' data we use, e.g. from GBIF and ORNIS (http://128.32.146.144/pres/PresentationServlet?action=home), are not all survey data but consist, in part, of museum specimens which could have been collected from convenient and accessible locations, such as seabird colonies. Therefore, they might not always be spatially independent of the assessment data. We think this is a small problem, if at all.

Results

Distribution and status of Arctic seabirds and subspecies

Based on compiled raw (Online Resource 3) and GIS 'presence only' data (Online Resource 4 and 5), we

Table 5 Receiver OperatingCharacteristic (ROC) model accuracy from RandomForest in R

Model species	Model 1			Model 2		
	ROC	No. presences	No. absences	ROC	No. presences	No. absences
Alca torda	0.865	10	961	0.996	10	746
Alle alle	0.986	4,173	961	0.999	4,194	351
Brachyramphus brevirostris	0.990	19	961	0.999	30	933
Cepphus grylle	0.989	1,263	961	0.999	1,367	39
Cepphus columba	0.479	1	961	0.467	1	943
Fratercula arctica	0.978	79	961	0.998	81	541
Fratercula cirrhata	0.996	15	961	0.999	16	943
Fratercula corniculata	0.997	94	961	0.999	99	937
Fulmarus glacialis	0.981	10,160	961	0.995	10,255	436
Larus argentatus						
Larus glaucoides	0.971	29	961	0.973	1,361	220
Larus hyperboreus	0.986	3,551	961	0.999	5,578	1,511
Larus thayeri	0.991	326	961	0.999	433	725
Pagophila eburnea	0.988	1,238	961	0.999	1,288	44
Rhodostethia rosea	0.992	185	961	0.999	252	87
Rissa tridactyla	0.982	8,379	961	0.996	8,704	842
Stercorarius pomarinus	0.992	791	961	0.999	1,361	220
Stercorarius parasiticus	0.987	579	961	0.999	1,142	177
Stercorarius longicaudus	0.986	632	961	0.999	3,127	1,511
Stercorarius skua						
Sterna aleutica	0.454	1	961	0.450	1	943
Sterna paradisea	0.994	150	961	0.999	1,734	202
Uria aalge	0.994	392	961	0.999	392	673
Uria lomvia	0.993	6,708	961	0.999	6,868	362
Xema sabini	0.994	515	961	0.999	911	253

Model 1 refers to presence/pseudo-absence. Model 2 refers to presence/expert-derived absence. *Larus argentatus* and *Stercorarius skua* lacked observations (presences)

produced 27 publicly and freely available seabird species distribution models and maps (Fig. 4; Online Resource 6) with a quantitative habitat association and regional accuracy metrics as a reliability measure. We perceive these spatial models as a first quantitative, digital and spatially explicit circumpolar distribution result for pelagic seabirds; they should form a solid basis and science platform for more study, hypothesis testing, rapid assessments and ongoing model improvements.

With regards to drivers of circumpolar seabird distribution, we found that, from the 26 tested predictors, subsurface water temperature, e.g. between 10 and 30 m, plays an overwhelming role (Table 8; full details about all predictor rankings and response curves are available from the authors on request). This finding sets the stage for climate change modeling. Other noteworthy predictors were proximity to human villages, and concentrations of phosphate, nitrate and silicate, and distance to ice edge. The nutrient-related predictors are all known to be affected by humans globally (Young and Steffen 2009) and thus point towards human impacts (Moeller et al. 2007 for Arctic tern) and which should apply even stronger in the more extreme Arctic conditions; this demands for more study. Surprisingly, dimethyl sulfide (DMS) only played a small role for the species tested (Table 8). Overall, and considering that climate change is man-made (Arctic Council 2004), the Arctic seabird community appears to be already dominated by man-made features.

In terms of seabird distribution types, six general distribution categories were found in the derived maps (Fig. 4): Atlantic species (e.g., Atlantic puffin), Pacific species (e.g., Kittlitz’s murrelet, Tufted Puffin), circumpolar species (e.g., Jaegers, Glaucous Gull), coastal shelf species (e.g., Black and Pigeon Guillemots, Aleutian Tern), island hotspots (e.g., Skuas), and warm water species (related to Gulf Current, e.g., Common Murre, Lesser-black Backed Gull).

Table 6 Performance metrics for predictive species models overlaid with best available colony data sets within foraging ranges

Model species	Mean Relative Index of Occurrence (ROI) of known colony locations with a ~30km buffer (pelagic section)	Comments
Alca torda	0.82	
Alle alle	0.62	
Brachyramphus brevirostris	NA	Birds breed inland; relatively few nests known.
Cepphus columba	NA	No circumpolar nest layer known to exist.
Cepphus grylle	0.15	Low metric due to missing data in Norway and Russia. But good ROI exist for Northern Alaska.
Fratercula arctica	0.89	
Fratercula cirrhata		No good nest layer known to exist.
Fratercula corniculata	0.63	
Fulmarus glacialis	0.53	
Larus argentatus	NA	Birds breed on land and coastal; large number of nests are missing. No good nest layer known to exist.
Larus fuscus	0.71	
Larus glaucoides	0.91	
Larus heuglini	No model run	No good data and nest layer known to exist.
Larus hyperboreus	0.71	
Larus marinus	0.74	
Larus thayeri	NA	No good nest layer known to exist.
Pagophila eburnea	0.61	Several nest sites occur on land, and are not well expressed in this metric
Rhodostethia rosea	0.89	Many colonies occur on land, and are not included
Rissa tridactyla	0.46	Low metric probably due to lack of data in Northern Russia
Stercorarius longicaudus	NA	Tundra breeder (usually inland), no good nest layer known to exist
Stercorarius parasiticus	NA	Tundra breeder (usually inland), no good nest layer known to exist
Stercorarius pomarinus	NA	Tundra breeder (usually inland), no good nest layer known to exist
Stercorarius skua	NA	No good nest layer known to exist
Sterna aleutica	0.99	
Sterna paradisaea	0.68	
Uria aalge	0.51	
Uria lomvia	0.42	Low metric due to missing pelagic data for Northern Norway and Northern Russia
Xema sabini	0.53	

This model-prediction metric mostly covers breeding birds near land; it is less accurate for pelagic species and non-breeders (which can be up to 40% in a given seabird species population)

The assessments using ROCs showed generally high values, and favored expert-derived absences (model 2 in Tables 5 and 6). However, assessment differences were usually small. Overall, models were most reliable and had highest accuracy for most pelagic bird species while lower accuracy was found for a few coastal species (which have not been well sampled and occur in regions with weaker environmental data qualities; Huettmann 2000; Humphries 2010), species with unresolved subgenus variations (Lesser Black-backed Gull, Herring Gull, Iceland Gull; Grant 1997) or potential sister taxa (for Tufted Puffin, Razorbills, Aleutian Tern). The main driver for a poor model, though, is we believe, as taken from Tables 5 and 6, the very low sample size of ‘presence records’ (which cannot get well compensated even through the many good absence records). Further, we found that results for regional model assessments, when compared with expert knowledge, performed very well for most species (Tables 9 and 10).

Table 7 Sources for public Arctic seabird colony data used and considered for this study

Location	Reference	Species covered	Metadata	Digital data available upon request	Data quality	Used in this study?
West Greenland	Boertmann et al. (1996) (ORNIS Consult Ltd. and GERI)	Arctic multipspecies	No	No	No quantitative statistical accuracy provided	Manually digitized for colony hotpots
Barents Sea region	Anker-Nilssen et al. (2000); Bakken (2000)	Arctic ultipspecies	No	No	No quantitative statistical accuracy provided	Manually digitized for colony hotpots
Kara Sea	Bakken (2000)	Arctic multipspecies	No	No	Poor spatial species resolution; no quantitative statistical accuracy provided	Not used
Circumpolar	CAFF (2004)	Common Murre and Thick-billed Murre	No	No	No quantitative statistical accuracy provided	Not Used
Circumpolar	Gilchrist et al. (2008)	Ivory Gull	No	No	No quantitative statistical accuracy provided	Manually digitized for colony hotpots
Greenland	Egevang and Boertmann (2008)	Ross's Gull	No	NA	No quantitative statistical accuracy provided	Manually digitized for colony hotpots
Eastern Greenland	Gilg et al. (2005)	North Atlantic multispecies	No	Yes	No quantitative statistical accuracy provided	Digital import of locations and attributes
Jan Mayen	Van Franeker et al. (1998)	North Atlantic multispecies	No	NA	No quantitative statistical accuracy provided	Not used
Lena Delta	Gilg et al. (2000)	Russian Arctic species	No	No	No quantitative statistical accuracy provided	Digital database import of locations and attributes
Beringia Seabird Database	Beringian Seabird Colony Catalog (2004) http://alaska.fws.gov	North Pacific species	No	Yes	No quantitative statistical accuracy provided	Digital database import of locations and attributes
Severnaya Zemlaya	De Korte and Volkov (1993)	Ivory Gull	No	NA	No quantitative statistical accuracy provided	Manually digitized for colony hotpots

When using seabird colony overlays combined with a 30-km buffer (to represent the average foraging zone), we found good agreement between model data and breeding sites in coastal and in remote islands. Seabird species that can breed more inland, e.g. Ivory Gull and Jaegers, showed weaker linkages, or even lacked good quality colony data. Species like Herring Gull have a rather dominant terrestrial ecology and require different assessment metrics than a link with main colony locations.

Overall, the use of expert knowledge (here based on compiled literature sources; Tables 9 and 10) probably gives one of the best assessment options for such model predictions, similar to a consensus approach. Results for regional model assessments, and when compared with expert knowledge, performed good to very good for most species.

Regarding their conservation status (see Tables 11 and 12 in "Discussion"), Arctic seabirds got classified by most mandated institutions as either being of 'no relevant conservation concern' or they lack real world action that achieves on the ground, pro-actively and in times of climate change, e.g. Ivory Gull (see text box1). These specific results clearly show that many (endangered) subspecies are not well known, not well studied, and no relevant budget is

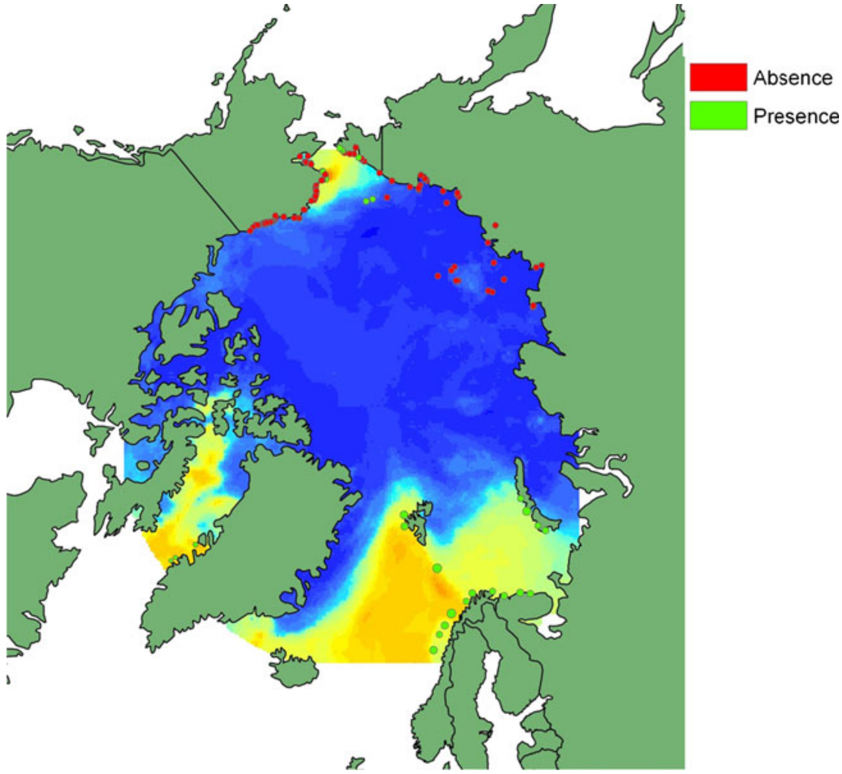

Fig. 3 Example: Predicted distributions for Common Murres (*orange pixels* in the prediction surface show presence, *yellow* intermediate and *blue* absence. *Green dots* show known colony sites where murres are present, and *red dots* predicted absences

currently assigned to improve the situation overall. As already shown in Boardman (2006) and Rosales (2008), many 'paper laws' dominate the Arctic and its global support system.

Text box 1 re. Ivory Gull protection and policies, as taken from http://arcticportal.org/ (also cited in Gilchrist et al. 2007):

"...*The Ivory Gull has been protected in West Greenland since 1977 under the Greenland Home Rule Order of 5 May 1988 concerning the protection of birds in Greenland. In Svalbard, it has been protected since 1978, under the Svalbard Environmental Protection Act. In Russia, it was listed in the Red Data Book of the USSR (1984) and now is registered as a Category 3 (Rare) species in the Red Data Book of the Russian Federation according to the Decree of State Committee of Russian Federation for Environmental Protection of 1997. Consequently, the Ivory Gull is listed in regional Red Data Books along its breeding range in Russia. In Canada, the Ivory Gull is a non-game species, and as such is protected in North America under the Migratory Birds Convention Act and related Migratory Bird Regulations. It is currently being up-listed to the status of Endangered Species. The Ivory Gulls has also been up-listed to Near Threatened (NT) in The World Conservation Union IUCN list in 2005*..."

Discussion

In the following section, we will discuss in a constructive fashion the key features of our models, the intentions, findings, results and management applications:

Distribution maps

Accuracy

The model accuracy tests followed standard procedures (Drew et al. 2010), and include several metrics in parallel, quantitative and qualitative. Here, we assess for the first time the general, large, ecological circumpolar seabird niche for 27 species.

Even for small-scale distributions, dispersal is a common feature in the Arctic, e.g. seabirds encountered when flying over the North Pole (Uspenski 1969; Vuilleumier 1996). Species like Black Guillemot, Thick-billed Murre, Dovekie, Black-legged Kittiwake, Northern Fulmar, Arctic Tern, Long-tailed Jaeger, Parasitic Jaeger, Pomarine Jaeger and Glaucous, Sabine' and Ross's gulls can be encountered virtually anywhere in the circumpolar Arctic at most times of the year. It is likely that several of these species are associated with colonies north of Severnaya Zemlya and also with Franz Josef Land.

For a few species, e.g. Razorbills, Aleutian Tern and Iceland Gull, our models perform poorly. The regional assessment using expert knowledge (Tables 9 and 10), indicates for most other species good to very good predictions. It should be kept in mind that most of these presence data are collected without a real research design, are pooled, and opportunistic in space and time (sensu Kadmon et al. 2004). Sites difficult to access are usually under-

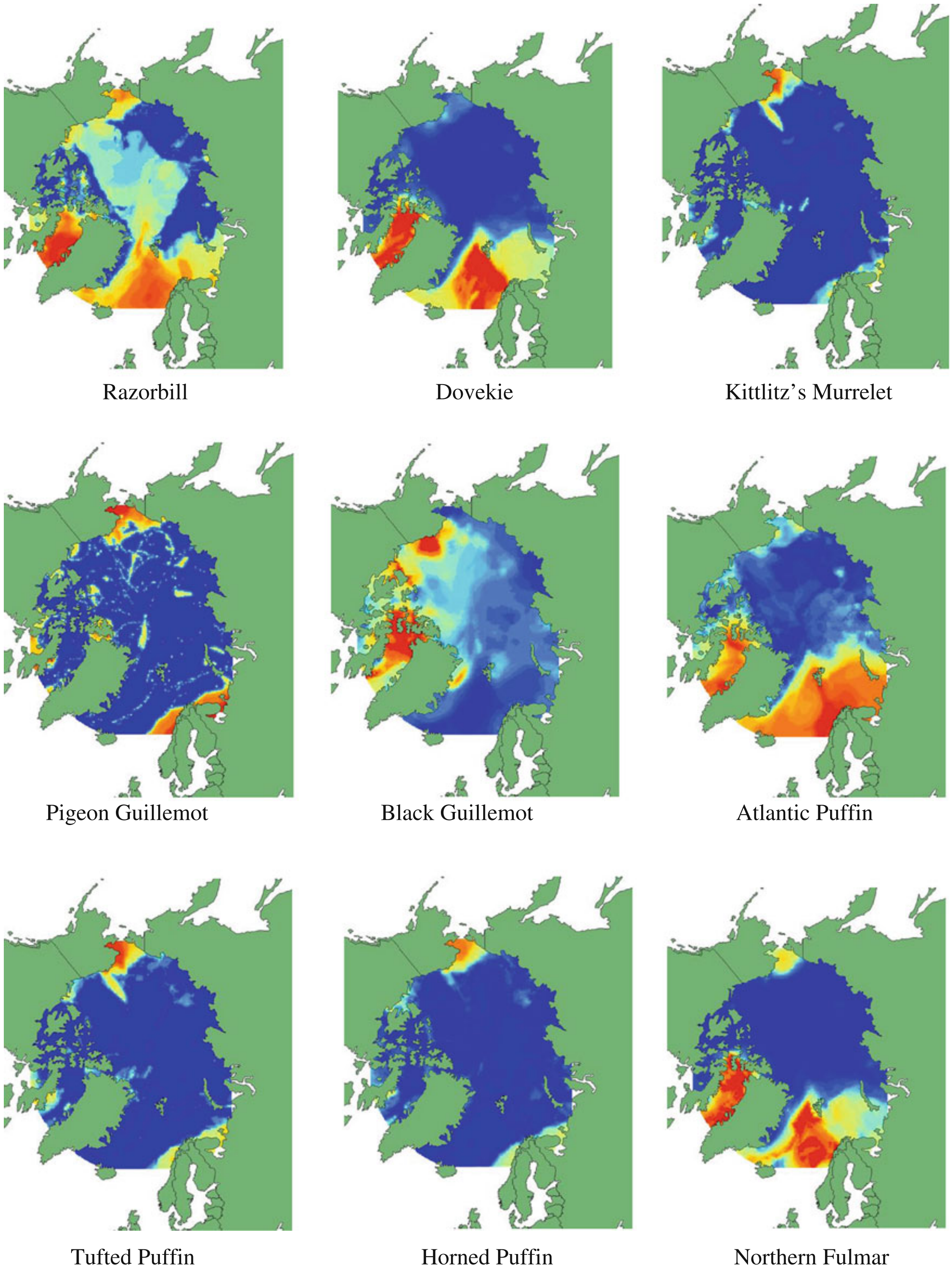

Fig. 4 Panel map of 27 seabird species predictions (all relevant raw model data and high resolution ArcGIS maps, and accuracies are found in the Online Resource and tables). *Red* presence, *blue* absence, *yellow* less present, *light blue* less absent

sampled, and generally, publication and reporting biases also occur in training and assessment information, e.g. for non-english speaking regions where only a few publications from the complete knowledgebase got transferred.

The aspatial use of the ROC metric from the model algorithm itself for model assessment is not so useful for spatial interpretations; it tends to be overly optimistic when compared spatially. Using seabird colonies for accuracy tests,

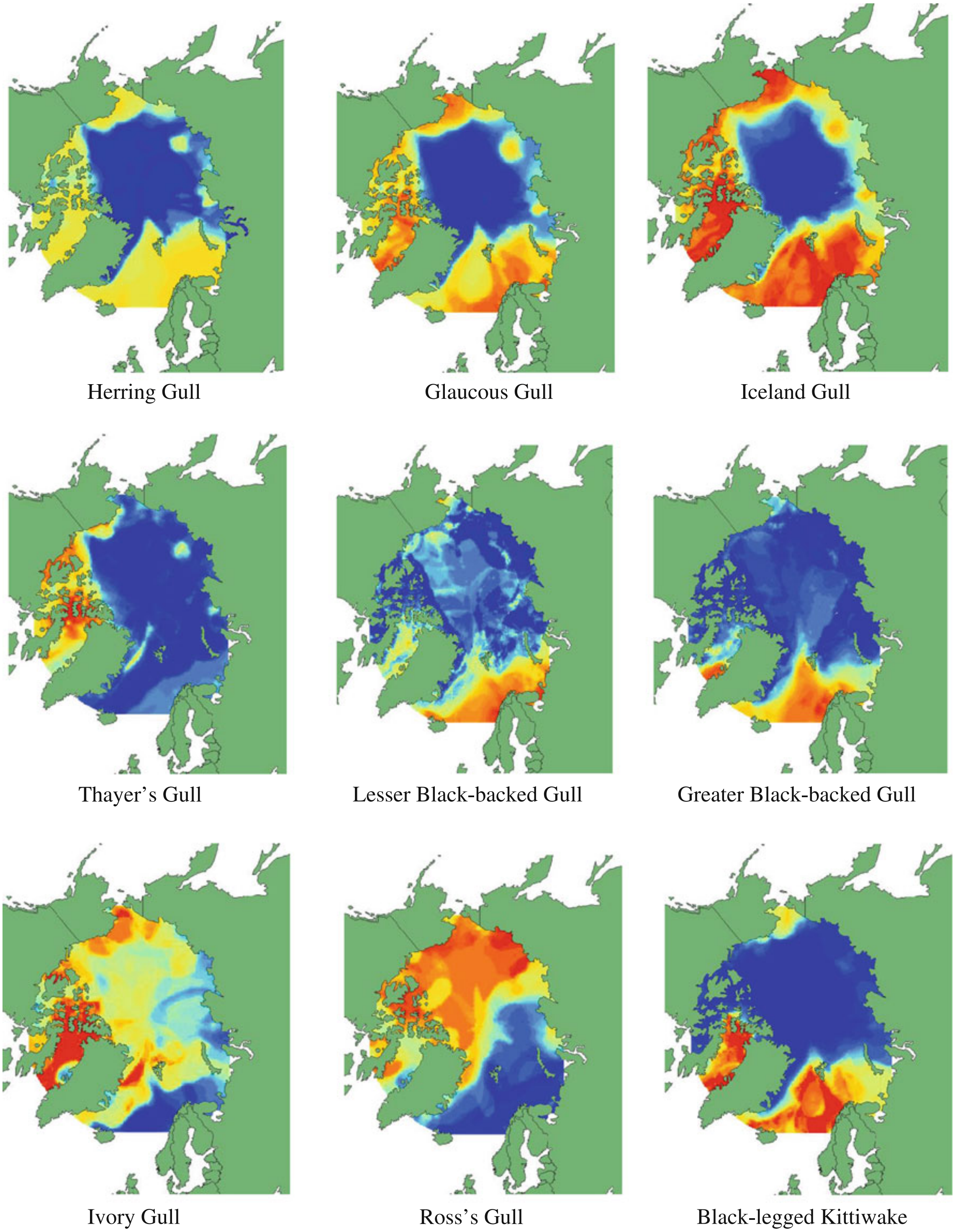

Fig. 4 (continued)

and with a 30-km foraging buffer, can potentially be flawed for species that have a high proportion of non-breeders and which forage huge distances, or for ones that nest on land. But Huettmann and Diamond (2001) and Yen et al. (2004), for instance, have already successfully used distance to colony and nesting habitat as a model performance measure. The assessment based on expert knowledge carries only qualitative information, but performed well and is further in support

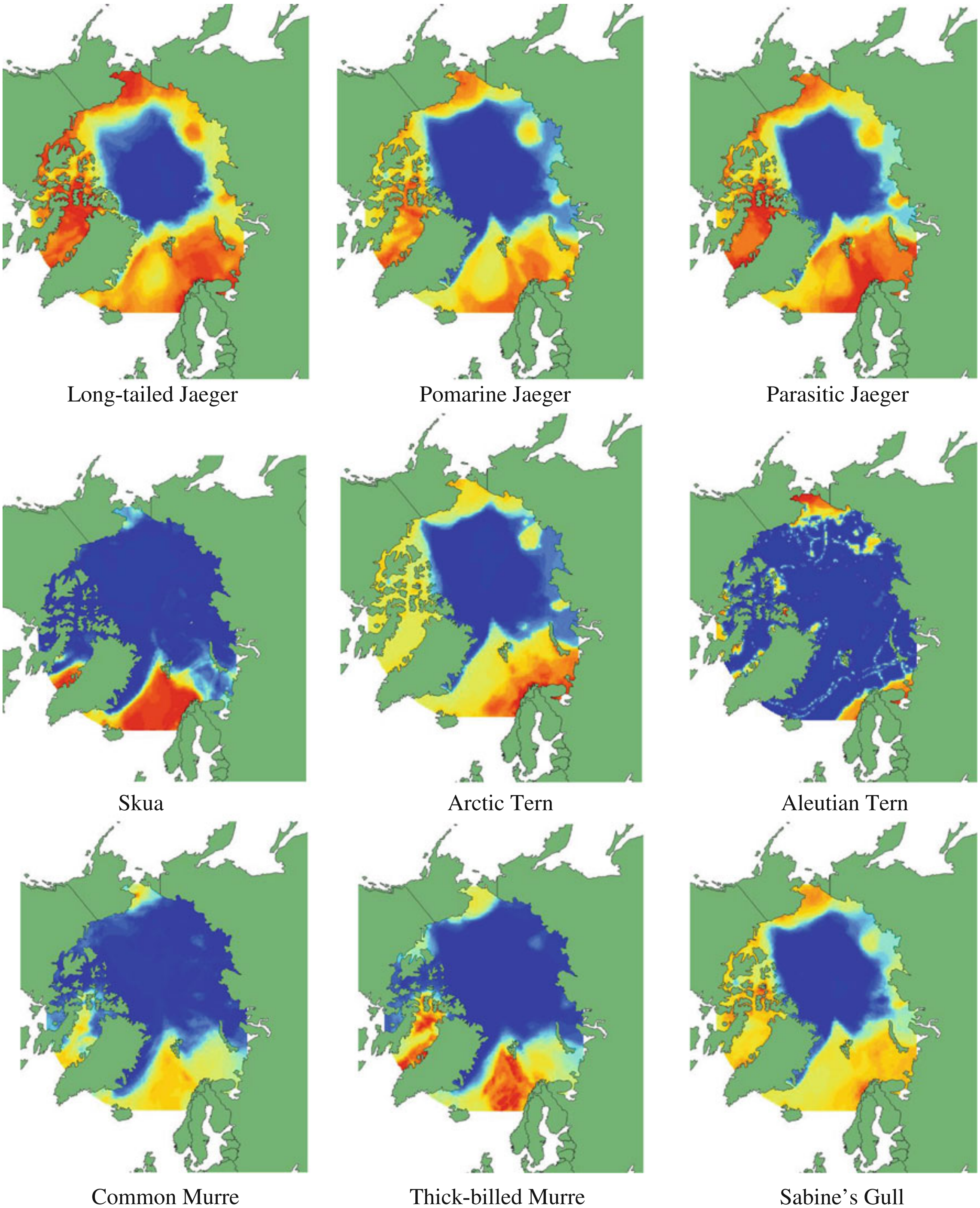

Fig. 4 (continued)

of the ROCs. Regardless, any of these measures should still receive more study and ground-truthing in the field. Topics like scale, autocorrelation and polar geographic projections have not received much attention in polar and global models (but see Huettmann and Diamond 2006) and should be considered in future work.

Overall, the obtained models ranged from poor (few species) to high and very high accuracy (most species). This is in general agreement with Huettmann and Diamond (2001) for the Northwest Atlantic, but differs from Fauchald et al. (2002) for the Northeast Atlantic. We think that the variations of the findings by the latter authors can be explained by their use of linear methods (see Yen et al. 2004; Elith et al. 2006 for a relatively poor performance of these methods). In most cases, models using expert-derived absence performed better (Table 5). Beyond

Table 8 Summary of the ‘top3’ model predictors for each species for the best performing RandomForest species predictions (model 2 based on expert-derived absence; model 1 not shown; for more details see “Materials and methods”)

Name of model species	Model 2		
	1st important predictor	2nd important predictor	3rd important predictor
Alca torda	Temp. at 20 m	Temp. at 10 m	Silicate at 30 m
Alle alle	Temp. at 20 m	Dist. to settlement	Temp. at 10 m
Brachyramphus brevirostris	Phosphate at 30 m	Silicate at 20 m	Temp. at 30 m
Cepphus grylle	Nitrate at 30 m	Temp. at 0 m	Nitrates at 20 m
Cepphus columba	NA	NA	NA
Fratercula arctica	Temp. at 20 m	Temp. at 10 m	Salinity at 20 m
Fratercula cirrhata	Temp. at 0 m	Temp. at 30 m	Phosphate 20 m
Fratercula corniculata	Dist to Ice Edge	Temp. at 20 m	Temp. at 10 m
Fulmarus glacialis	Temp. at 10 m	Dist. to settlement	Temp. at 20 m
Larus argentatus	Dist. to settlement	Temp. at 20 m	Temp. at 0 m
Larus fuscus	Temp. at 0 m	Temp. at 30 m	Temp. at 20 m
Larus glaucoides	Temp. at 10 m	Temp. at 20 m	Temp. at 30 m
Larus hyperboreus	Temp. at 10 m	Temp. at 0 m	Temp. at 30 m
Larus marinus	Temp. at 30 m	Temp. at 0 m	Temp. at 20 m
Larus thayeri	Temp. at 0 m	Temp. at 30 m	Phosphate at 0 m
Pagophila eburnea	Phosphate at 30 m	Temp. at 20 m	Phosphate at 0 m
Rhodostethia rosea	Phosphate at 30 m	Salinity at 30 m	Phosphate at 10 m
Rissa tridactyla	Salinity at 30 m	Salinity at 20 m	Temp. at 20 m
Stercorarius pomarinus	Temp. at 10 m	Temp. at 20 m	Temp. at 30 m
Stercorarius parasiticus	Temp. at 10 m	Temp. at 30 m	Temp. at 20 m
Stercorarius longicaudus	Temp. at 10 m	Temp. at 20 m	Distance to Sea Ice
Stercorarius skua	Temp. at 10 m	Temp. at 30 m	Temp. at 20 m
Sterna aleutica	Temp. at 0 m	Temp. at 20 m	Phosphate at 30 m
Sterna paradisea	Temp. at 30 m	Temp. at 0 m	Temp. at 10 m
Uria aalge	Temp. at 0 m	Temp. at 20 m	Phosphate at 30 m
Uria lomvia	Temp. at 20 m	Temp. at 10 m	Temp. at 30 m
Xema sabini	Temp. at 10 m	Temp. at 20 m	Temp. at 30 m

the model assessment method, wider large-scale distributions by some seabird species might also be of interest for affecting accuracy tests. This also deserves more research attention for the Arctic, in seabirds and beyond.

Noteworthy in our maps is the consistent but small occurrence of predictions in areas that are not occupied by some species (e.g., for Tufted Puffins, Razorbills), resulting in a lower overall accuracy assessment than the maps otherwise have for most of the range (which usually is fairly high). These smaller prediction errors can probably get widely resolved with better taxonomy, when applying specifically improved model boosting procedures and new data, and when using geo-referenced ocean regions or clustering results (Huettmann et al, in preparation).

Biological information

The Arctic suffers from the lack of reliable and accessible distribution maps and as a base for a best possible decision-making (Huettmann 2007). Here, we provide for the first time a consistent and quantitative “bird’s eye” view of species occurrences. Overall, we qualitatively identified from the distribution maps (Fig. 4) six distinct regions for pelagic seabirds in the Arctic: Atlantic, Pacific, circumpolar, shelf, islands and warm waters (Gulf Current). The consistent occurrence of small predicted presence spots for some species hints towards fragmented but now extinct populations, and even vicariant taxa separated in space. Depending on the underlying data, this could also present re-colonization and dispersal events. More study and ground-truthing would be needed. A link with Genbank/Barcoding and towards ‘seascape genetics’ might prove insightful, and for explaining relevant biogeographic patterns and changes. However, the data situation (=coverage and available geo-referenced samples) for such work is still very slim.

This modeling project focuses on predictions, but less on inference. However, our models identified subsurface water

Table 9 Regional assessment of model predictions (relative index of occurrence ROI) for 27 circumpolar seabird species

Species name (ITIS)	Literature source	Region										
		Svalbard	Barents Sea	Kara Sea	Wrangel Island	Chukchi Sea	Franz-Josef Land	New Siberian Islands	Severnaya Zemlya	Atlantic (Greenland Sea)	West Greenland	North Alaska and Canada
Alca torda	i, ii, iii, v, vii, x	No known breeding here, but model shows high RIO values	No sources show Razorbill extending this far into the Barents sea			No records for RAZO here, but model shows high RIO				No sources show RAZO spreading as far north as our model predicts		No records for RAZO here, but model shows high RIO
Alle alle	i, ii, iii, v, vii, x				x shows birds here in winter	Our model shows low RIO values, but bree-ding colo-nies exist	Our model shows low RIO values, but breeding colonies exist	Our model shows low RIO values, but breeding colonies exist	Our model shows low RIO values, but breeding colonies exist			x shows birds occur here, but not in agree-ment with i or vii
Brachyramphus brevirostris	i, v, vii, x		Some moderate RIO values here, but no records for KIMU in this area							Some moderate RIO values here, but no records for KIMU in this area		
Cepphus grylle	i, ii, iii, v, vii, x	Low RIO values in model, but all sources show breeding/presence	Low RIO values in model, but all sources show breeding/presence here	Low RIO values in model, but all sources show breed-ing/presence			Low RIO values in model, but all sources show breeding/presence	Low RIO values in model, but all sources show breeding/pre-sence	Low RIO values in model, but all sources show breeding/pres-ence	Low RIO values in model, but all sources show breeding/presence		
Cepphus columba	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Fratercula arctica	i, ii, iii, v, vii, x				Model shows moderate RIO values, though no records for Atlantic Puffin in this area	Model shows high RIO values though no breeding colonies near these islands		
Fratercula cirrhata	i, v, vii, x		Some moderate RIO values here, but no records in this area				Some moderate RIO values here, but no records for TUPU in this area	
Fratercula corniculata	i, v, vii, x		Some moderate RIO values here, but no records in this area				Some moderate RIO values here, but no records for HOPU	
Fulmarus glacialis	i, ii, iii, v, vi, xi					Sources show breeding colonies of NOFU here, but model shows low RIO		
Larus argentatus	i, ii, iii, v, iv, v	no sources agree with our model. Our model shows high RIO here, all sources say no breeding		ix says breeding here, x does not agree with ix. Our model shows moderate RIO		x, ix and ii show no breeding here, moderate RIO values occur here in our model		We have high RIO values here, but no source shows Herring Gull breeding in these areas - though personal accounts of HEGU

Table 9 (continued)

Species name (ITIS)	Literature source	Region										
		Svalbard	Barents Sea	Kara Sea	Wrangel Island	Chukchi Sea	Franz-Josef Land	New Siberian Islands	Severnaya Zemlya	Atlantic (Greenland Sea)	West Greenland	North Alaska and Canada
Larus fuscus	ii, iii, ix, x	Our model shows high RIO here, no sources show breeding around Svalbard		x shows breeding here (ix does not agree) - our model shows low RIO for this area		Our model shows high RIO here, but no records for this species						
Larus glaucoides	i, iii, v, iv, v	No source shows breeding around Svalbard - our model has high RIO there	No source showing Iceland gull here - our model has high Rio here	Moderate RIO values - no records for this area	High RIO here, no records of Iceland gull here	High RIO in model - no records of Iceland gull here	Moderate RIO values - no records of Iceland gull here	High RIO here in model - no records of Iceland gull here				High RIO in model - no records of Iceland gull here - BUT – E. Weiser has a picture of an Iceland / Thayer's gull in Barrow
Larus hyperboreus	i, ii, iii, v, ix, x								Our model shows low RIO here - all sources show breeding populations on these islands			
Larus marinus	i, ii, iii, v, ix, x					Our model shows moderate RIO values here, but no records for this area						
Larus thayeri	i, iii, v, ix, x							Model shows moderate RIO here - but no records exist				ix and x do not show this species here but we have presence points in these areas
Pagophila eburnea	i, ii, iii, iv, v, ix, x											

Rhodostethia rosea	x, ix, x	Model shows moderate RIO values - no records for this species					x shows these islands to be part of winter distribution, our model has low RIO values		
Rissa tridactyla	i, ii, iii, iv, v, x	x and iv shows breed-ing here, our model has low RIO			x and ii show breeding here, our model has very low RIO for this area.	x and iv shows breeding here, our model has low RIO	x and iv shows breeding here, our model has low RIO		
Stercorarius pomarinus	i, v, viii, x	viii claims to be breed-ing area, our model shows low RIO							
Stercorarius parasiticus	i, ii, v, viii, x	viii claims to be breed-ing ar-ea. our model is in partial agree-ment show-ing mode-rate Rio values							
Stercorarius longi-caudus	i, v, viii, x		viii claims no breeding in this area - our models show high RIO		viii claims no breeding in this area - our models show high RIO	viii claims no breeding in this area - our models show high RIO	viii claims no breeding in this area - our models show high RIO		
Stercorarius skua	ii, v, viii, v			Does not match any known record: model is high RIO, but no records for Great skua					
Sterna aleutica	i, v, x	Model showing high RIO in places, but no records for the species				Model showing high RIO in places, but no records for the species		Model showing high RIO in places, but no re-cords for the species	Model showing high RIO in places, but no records for the species

Table 9 (continued)

Species name (ITIS)	Literature source	Region										
		Svalbard	Barents Sea	Kara Sea	Wrangel Island	Chukchi Sea	Franz-Josef Land	New Siberian Islands	Severnaya Zemlya	Atlantic (Greenland Sea)	West Greenland	North Alaska and Canada
Sterna paradisea	i, ii, iii, v			x shows breeding here, model shows low RIO					x shows breeding here, model shows low RIO			
Uria aalge	i, ii, iii, v, vii, x											
Uria lomvia	i, ii, iii, iv, v, vii, x				iv and x show breeding colonies and migration through here, our model shows low RIO values			iv and x show breeding colonies and migration through here, our model shows low RIO values				
Xema sabini	i, ii, iii, v, iv, v				ix claims no breeding here, (x does claim breeding here), but our model shows moderate RIO values							

See Fig. 1 for map of regions. Empty regional fields indicate 'No Relevant Accuracy Concern'

Literature sources:

i Birds of North America online (see "Introduction")

ii Anker-Nilssen et al. (2000)

iii Boertmann et al. (1996)

iv INSROP (1998) online (see "Introduction")

v Brinkley (2007)

vi Onley and Scofield (2007)

vii Gaston and Jones (1998)

viii Furness (1987)

ix Grant (1997)

x del Hoyo et al. (1996)

xi del Hoyo et al. (1992)

Table 10 Continuation of Table 9: regional assessment of model predictions for 27 circumpolar seabird species

Common name (ITIS)	Region										Overall Assessment
	Northeast Greenland	Northeast Canada	Novaya Zemlya	Central Cana-dian Arctic	Central Arctic	Eastern Siberian Sea	Western Siberian Sea	Leptev Sea	Canaldian Archipelago	East Greenland	
Alca torda					No records for RAZO here, but model shows moderate RIO						MODERATE/POOR: Model is predicting over the ice and such - it looks like this model is influenced by bathymetry. Not many presence points here to base a good model on.
Alle alle				x show birds occur here, but not in agreement with i or vii		x show birds occur here, but not in agreement with i or vii	x show birds occur here, but not in agreement with i or vii			x show birds occur here, but not in agreement with i or vii	MODERATE: Does a good prediction for the most part, except in Northern Russia and Chukchi sea.
Brachyramphus brevirostris											VERY GOOD: Similar to Horned Puffins, very good with a few "blips" - but few data make this model.. Still requires much more data.
Cepphus grylle			Low RIO values in model, but all sources show breeding/ presence here			Low RIO values in model, but all sources show breeding/ presence here	Low RIO values in model, but all sources show breeding/ presence here	Low RIO values in model, but all sources show breeding/ presence here			MODERATE: This model works well in North America, but fails miserably for the rest of the Arctic. This looks like a data problem (lack of data.
Cepphus columba	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	Sample size too small.
Fratercula arctica											VERY GOOD: This model seems to do very well in all areas.
Fratercula cirrhata					There is a band of high RIO extending into the central Arctic,						VERY GOOD: Similar to Horned Puffins, very good with a few "blips" - but few data make this model.. Still require much more data.

Table 10 (continued)

Common name (ITIS)	Region										Overall Assessment
	Northeast Greenland	Northeast Canada	Novaya Zemlya	Central Cana-dian Arctic	Central Arctic	Eastern Siberian Sea	Western Siberian Sea	Leptev Sea	Canaldian Archipelago	East Greenland	
					which does not match any known sources						
Fratercula corniculata											VERY GOOD: This model is nearly spot-on with a few minor "blips".
Fulmarus glacialis	Sources show distribution of NOFU here, but model shows low RIO GOOD: Most sources show that NOFU extend a little further north than what we predict in our models, but we accurately pick up the niche in the Chukchi and in most of the Atlantic regions.					Sources show distribution of NOFU here, but model shows low RIO			Sources show		distribution of NOFU here, but model shows low RIO

Larus argentatus		i, v, ix and x do not show any breeding areas here, our model shows high RIO - Records exist for some breeding in Western Greenland - iii	ix and x claim no breeding here, our models show moderate to high RIO					i, v, ix and x do not show any breeding areas here, our model shows high RIO			MODERATE: This model seems to be suffering in quite a few places. We are predicting them to occur much further North than what is agreed upon in the sources used. No sources show northern Alaska as having Herring Gulls, but the authors have seen them there (non-breeders. Weiser (pers.com.) has seen hybrids near Prudhoe - indicating breeding.
Larus fuscus		Our model shows high RIO here, but no records for this species here. Note: records for breeding in western Greenland - iii									MODERATE: Model seems to perform well in Greenland and Barents seas, but is showing areas of high RIO in places where we have no records.
Larus glaucoides			i, ix and x do not show Iceland Gull here, our model has high RIO values here			Moderate RIO values in model, no Iceland gull records here	Moderate RIO values in model, no Iceland gull records here	i, ix and x do not show iceland gull here, our model has high RIO values here			POOR: There are presence points for Iceland Gull that occur quite far west (northern Yukon), but the literature is suggesting that is not possible (unless vagrant). This could be a case of mistaken identity with Thayer's Gull, which can occur further west than Iceland Gull
Larus hyperboreus											VERY GOOD: This species is essentially ubiquitous across the arctic, and our model predicts that quite well
Larus marinus											VERY GOOD: This species is essentially perfectly predicted in my opinion. Matches all sources very nicely.
Larus thayeri	Showing a band of moderate RIO values here, but										VERY GOOD: I think this model is nearly spot on for this species. Just a few strange places occur; good overall.

Table 10 (continued)

Common name (ITIS)	Region: Northeast Greenland	Northeast Canada	Novaya Zemlya	Central Cana-dian Arctic	Central Arctic	Eastern Siberian Sea	Western Siberian Sea	Leptev Sea	Canaldian Archipelago	East Greenland	Overall Assessment
	no records										
Pagophila eburnea			Model shows moderate RIO around island, ii only shows breeding colony at north tip								VERY GOOD: This model even does a good job of showing that Ivory Gull occur further north in Russia (away from mainland).
Rhodostethia rosea					No info-mation available here to help in assessing this region						MODERATE/GOOD: This model is interesting because it's the only one that really covers the central arctic. It is well possible that these birds fly over the ice to get from place to place.
Rissa tridactyla			ii, iv and x show breeding across both islands, our model shows high RIO values stop about 3/4 up the north island			iv and x shows breeding here, our model has low RIO	iv and x shows breeding here, our model has low RIO	iv and x shows breeding here, our model has low RIO			MODERATE: This model performs very well for Canadian Arctic and Chukchi seas as well as Greenland sea. But northern Russia is failing here quite badly.
Stercorarius pomarinus							ix claims to be breeding area, our model shows low RIO	ix claims to be breeding area, our model shows low RIO			GOOD: Northern Russia has patchy areas of higher RIO, so it's close to what is suggested by viii (needs Northern Russia data).
Stercorarius parasiticus								ix claims to be breeding area. our model is in partial agreement showing moderate Rio values			VERY GOOD: If viii is correct, then we require data for Northern Russia to complete the model.

Stercorarius longicaudus		ix claims no breeding on northern island, but our model shows high RIO						GOOD: Our model shows circumpolar distribution, but viii shows that they do not breed that far north. (That does not mean they don't travel there over the water).
Stercorarius skua								VERY GOOD: We have presence points only for western greenland, and we matched their distribution rather well. Western Greenland is shown to be part of their migration route according to viii.
Sterna aleutica	Model showing high RIO in places, but no records for Aleutian Tern					Model showing high RIO in places, but no records for Aleutian Tern		POOR/MODERATE: This model is not really a very good one because we are using just 1 presence point and many absence locations. This still works ok for the Chukchi. But it requires much more data for this model to make sense elsewhere.
Sterna paradisea					x shows breeding here, model shows low RIO			VERY GOOD: This model is great except Northern Russia which is again, failing due to lack of data.
Uria aalge	No sources show breeding colonies up here, but presence points for these birds exist up through							VERY GOOD: Everything here seems to match known distributions from literature.
Uria lomvia			iv and x show breeding colonies and migration through here, our model shows low RIO values	iv and x show breeding colonies and migration through here, our model shows low RIO values			xii and x show that TBMU occur here, but our model shows low RIO	GOOD: Northern Russia is again failing here probably due to lack of data. Eastern Greenland is also doing poorly, but the rest looks pretty good.

Table 10 (continued)

Common name (ITIS)	Region										Overall Assessment
	Northeast Greenland	Northeast Canada	Novaya Zemlya	Central Cana-dian Arctic	Central Arctic	Eastern Siberian Sea	Western Siberian Sea	Leptev Sea	Canaldian Archipelago	East Greenland	
Xema sabini											VERY GOOD: ix is an older reference - this model appears to be representative.

Empty fields indicate 'No Relevant Accuracy Concern' (for literature sources, please see Table 9)

temperature and several human-related predictors as key drivers for pelagic seabirds Arctic-wide. This finding has never been shown so strongly elsewhere (but see, e.g., Paneva 1989; Krasnov and Barrett 1995; Weiser 2010 for local impacts), and it leaves seabirds further exposed to human activities, e.g., urbanization, fishing/hunting, contamination, disturbance and climate change (Forsberg 1995; Schreiber 2002; Arctic Council 2004).

Seabird data, data integration and availability

Here, we provided the first taxonomic 'cross-walk' for 27 arctic seabirds (Table 1). We are aware that this table can potentially be extended with more specific studies and taxonomies (e.g., from Genbank, Sibley and Monroe, Clements, etc.), and this should be done for the research needs beyond distribution modeling. We believe though that here we have assembled the first management-relevant online taxonomy species cross-walk for Arctic seabirds, as a generally agreed platform for more progressive applications.

At least five basic types of datasets exist for Arctic seabirds: seabird survey data, nest location (colony) data, productivity data (at nests/colonies), telemetry data, and bird banding data. The majority of data discussed here deal with pelagic distributions: presence/absence and geo-referenced abundance data. Instead of pelagic survey data, it is surprising that a larger section of the data used here in this study and offered by GBIF (and OBIS Seamap) still consists of museum specimens (Tables 5 and 6 shows relevant sample sizes, and Online Resource 3 provides detailed percentages and contributors of raw data; see Graham et al. 2004 for the wider use of museum specimens in biology and species distribution studies). Publicly accessible high quality true pelagic density survey data are less common, and telemetry data are virtually still missing for informing our models (see also Vanden Berghe et al. 2010). Specific seabird productivity data suffer from the same lack of public availability. Here, a change is required that provides high-quality data with a 'fit for use' quality label for the global public and for best possible decision-making (as outlined by Huettmann 2007; Magness et al. 2010; Vanden Berghe et al. 2010).

Despite significant Arctic survey efforts and large research budgets of 'science' vessels, we found that high quality digital pelagic seabird data are still difficult to come by (Vanden Berghe et al. 2010). Efficient public data delivery is either not fully realized, or emphasized but not enforced (Costello 2009). If data exist, they are usually in a rather poor technical shape, lack a thorough statistical quality and review, lack a thorough geo-referencing, exist just for some limited survey months, are not fully compatible, and are difficult to interpret without metadata. This is specifically true for the wider polar regions (see also Huettmann 2007). CAFF (2004) mentions a wide variety of ongoing and completed pelagic seabird studies, but none of which really offer their data to the public or provide easy and trackable links to the raw data used (check at OBIS-Seamap). CAFF (2004), a study promoting specifically arctic seabird banding data, does not mention any database and data access details, and does not link to EURING, eBIRD (www.ebird.org) or ORNIS, for instance. A rich list of 14 Joint Russian–Norwegian seabird projects, 1990–1999, is presented in Anker-Nilssen et al. (2000). These projects apparently do produce much data but which are widely lacking in the public realm. Crucial seabird-related data from Isaksen (1995); Bakken and Gavrilo (1995) and Krasnov et al. (2002) are not readily publicly available in a digital format, nor are those from Eldridge et al. (1993), Hodges and Eldridge (1994) or Petersen (1994), or from most of the major industries and NGOs working in the Arctic regions (e.g., Truett and Johnson 2000; Smith and Smith 2009). The list of lacking public seabird data is virtually endless, and by now it has evolved into a culture of convenience which is divorced from scientific principles such as transparency, repeatability, sharing and efficient public service (Huettmann 2007). In this study, we found that seabird data being publicly and easily accessible present the exception rather than the rule for the Arctic, and we found it to be very harmful for best possible science-based management.

Because most pelagic Svalbard data are not publicly available, our study currently does not include any relevant data from Polish IPY projects, or any data from ongoing telemetry initiatives, e.g. Arctic Tern project (Egevang et al. 2010; http://www.arctictern.info/ supported by CAFF).

In addition to low quality or missing seabird data, the lack of metadata is also widespread (see Table 7). This must come as a surprise when such data are used in ‘scientific’ analysis (e.g., Irons et al. 2008). The survey data obtained through GBIF also lacked metadata. This precludes many meaningful interpretations, use and assessments by peers and the public, and requires a dramatic change (Huettmann 2009; Bluhm et al. 2010).

This extremely unfortunate situation in the seabird world differs widely when compared to other disciplines in the Arctic, e.g. research on helium or sea ice and plankton,

Table 11 International Arctic Conservation Status by species using IUCN, Bern and Bonn (CMS) Conventions (modified from Anker-Nilssen et al. 2000)

ITIS common name	ITIS scientific name	IUCN	Bern Convention	Bonn Convention
Razorbill	*Alca torda*	LC	III	
Dovekie	*Alle alle*	LC	III	
Kittlittz’s Murrelet	*Brachyramphus brevirostris*	E	III	
Pigeon Guillemot	*Cepphus columba*	LC	III	
Black Guillemot	*Cepphus grylle*	LC	III	
Atlantic Puffin	*Fratercula arctica*	LC	III	
Tufted Puffin	*Fratercula cirrhata*	LC	III	
Horned Puffin	*Fratercula corniculata*	LC	III	
Northern Fulmar	*Fulmarus glacialis*	LC	III	
Herring Gull	*Larus argentatus*	LC		
Lesser Black-backed Gull	*Larus fuscus*	LC		
Iceland Gull	*Larus glaucoides*	LC	III	
Glaucous Gull	*Larus hyperboreus*	LC	III	
Great Black-backed Gull	*Larus marinus*	LC		
Thayer’s Gull	*Larus thayeri*	LC	III	
Ivory Gull	*Pagophila eburnea*	NT	II	
Ross’s Gull	*Rhodostethia rosea*	LC	III	
Black-legged Kittiwake	*Rissa tridactyla*	LC	III	
Long-tailed Jaeger	*Stercorarius longicaudus*	LC	III	
Parasitic Jaeger	*Stercorarius parasiticus*	LC	III	
Pomarine Jaeger	*Stercorarius pomarinus*	LC	III	
Skua	*Stercorarius skua*	LC	III	
Aleutian tern	*Sterna aleutica*	LC	III	
Arctic tern	*Sterna paradisaea*	LC	II	II
Common Murre	*Uria aalge*	LC	III	
Thick-billed Murre	*Uria lomvia*	LC	III	
Sabine’s Gull	*Xema sabini*	LC	II	

Table 12 Overview of conservation monitoring and policies for the Arctic (*IPY* International Polar Year, *ArcOD* Arctic Ocean Diversity project, *CAFF* Convention of Arctic Flora and Fauna, *CITES* Convention Endangered Species, *CBMP* Circumpolar Biodiversity Monitoring Plan, *CMS* Convention of Migratory Species, AON Arctic Observing Network)

Metric	Name of conservation and monitoring program									
	IPY	ArcOD	RAM-SAR	CAFF	CITES	North American Migratory Bird Act	CMBP	EU Bird Directive	CMS	AON
Costs	Medium	Low	High	Medium	Medium	Medium	Low	Medium	Medium	Medium
Statistical rigor	Low	Medium	Poor	Low	Poor	Low	Low	Poor	Poor	Medium
Specific focus on endangered species	Low	Low	Low	Low	High	High	Medium	Medium	High	Low
Spatial coverage	Circumpolar	Circumpolar	Global	Circumpolar	Global	Americas	Circumpolar	EU and Old World	Global	Point locations circumpolar
Conservation achievement	Low	Medium	Medium	Medium	Medium	High	Low	Low	Medium	Low
Complexity	High	High	Medium	Medium	High	High	Medium	High	Medium	High
Funding security	Low	Medium	High	High	High	High	Medium	High	Low	Medium
Data publicly available and high-quality data management focus	High	High	Low	Low	Low	Low	Low	Very low	High	High
Future plans,ecological sustainability and vision	Low	Medium	Medium	Medium	Medium	High	Low	Medium	Low	Medium

benthos and fish specimens (see ArcOD website for taxonomic example http://www.arcodiv.org/IPY_cluster/ArcOD_IPY.html). The current state of seabird data, including a digital divide within the Arctic community, hampers any relevant data interpretation, data integration, synergies in science and management, and foremost, the sustainability of the resource and habitat. The existence of web-services, or links with Genbank/Barcoding, offer us huge opportunities here but which can virtually not be made use of yet.

A critique of seabird conservation, data management, policies and their effectiveness

Global ocean and seabird conservation is in 'dire straits' (Norse and Crowder 2005; Huettmann 2007 for data). Several species are already of conservation concern (Table 11), or are expected to be soon. In addition to huge unknowns and ignorances of the true impacts (Gaston 2004 for an example), traditional underlying 'objective' science concepts can also be labeled as misleading, delaying, not being pro-active or sensitive to real conservation threats (Bandura 2007; Schweder 2001). For instance, a delineation of independent 'populations' (e.g. "Valued Ecosystem Components"; Bakken et al. 1996) is based on no genetic support, due to a lack of sufficient genetic circumpolar seabird data with a robust and valid sampling design. Consequently, many metapopulations assumed to be safe are potentially not, and most statistical models requiring such knowledge might even violate the base assumptions, and thus carry large uncertainties (Cushman and Huettmann 2010; Drew et al. 2010).

Activities with a major destructive impact have already occurred in the Arctic, e.g. offshore oil development, shipping routes and climate change, and have virtually left out pelagic seabirds from a proper cumulative assessment and decision making. This is specifically true for non-breeding, year-round, international movement and subspecies seabird data (Gavrilo et al. 1998a, b), and is known to harm seabirds and their management (for concepts, see Braun 2005).

In the circumpolar Arctic, e.g. through the Arctic Council and CAFF, a single species and business as usual approach is still promoted and carried out, e.g. with the International Murre Conservation Strategy and Action Plan (CAFF 1996) and similarly with Ivory Gulls (Gilchrist et al. 2008) and eiders. The IUCN endangered species lists are another example of such old-fashioned species approaches, widely aspatial even (Cushman and Huettmann 2010). Instead, it would be highly beneficial to adopt a strategy of dealing with communities, ecosystem, spatial approaches, and pro-active management of the underlying root causes for endangerment (Huettmann and Czech 2006; Rosales 2008).

Social aspects must also be considered (Chapin et al. 2010). Considering the taxonomic confusions and unknowns of the species, and specifically on the subspecies level, a single one-by-one species approach cannot assure reliable species management. In addition, the impacts of economic growth and the global economy must be assessed and changed towards a global long-term sustainability goal, and strongly demanded for such goals (Rosales 2008). The Arctic and its seabirds have no other option in order to survive.

Many focused research efforts have been caused by Arctic shipping initiatives, e.g. INSROP and the North American Shipping Route. But all these underlying causes are mainly motivated by an economic growth promotion, and western/wealthy nations play a leading role in these schemes (Wilson Rowe 2009). The Norwegian-based INSROP, for instance, is mostly funded by three bodies (SOF/Japan; CNIIMF Russia and Fridtjof Nansen Institute, Norway) and got approved with encouraging project reviews from the U.S. Dept of Interior and the Canadian Wildlife Service. Goals of the involved stakeholders include the improvement of merchant fleet efficiency, advance modernization, and design of good support for future fleet development (Gavrilo et al. 1998a, b). Whereas these industrial goals might well have been reached, any relevant seabird and environmental goals are not explicitly expressed by these lobbies, e.g. invasive species targets or the "Gull-ization" of the Arctic (e.g. Weiser 2010 for discussion of some impacts), creating a widely unbalanced approach harming fragile ecosystems and ecological services globally.

A circumpolar and more holistic and meaningful seabird view is widely missing. A first conservation overview for specific Arctic regions was given by Anker-Nilssen et al. (2000) for the White Sea, Kara Sea, Barents Sea, Svalbard, Franz Josef Land, Novaya Zemlya and the Nenentski district. First single species assessments have been started, e.g. BNA accounts and CAFF (2001a). Not surprisingly, a combined conservation threat index analysis for these regions identifies oil and pollutants as the key problem. Despite loss of sea ice being among the strongest habitat threats known, a seabird community assessment has not yet happened. To show the magnitude of the problem growing with climate change and when sea ice becomes rare, here is a quote by CAFF (http://arcticportal.org/) for Ivory Gulls, "…annual aerial surveys conducted in 2002–2006 suggest that the Canadian breeding population has declined by 80–85% since the early 1980s; a decline from 2,450 breeding pairs down to 500 breeding pairs..." (Gilchrist et al. 2008). This stands in strong contrast to Textbox 1 and its legal achievements implied in that text, e.g. full protection by law and a well looked after species by the nations. The laws did not stop the declines and thus have not achieved.

Large Arctic monitoring initiatives exist, e.g. CAFF, CBMP (Circumpolar Biodiversity Monitoring Plan), plus an increasing number of treaties and policies such as the RAMSAR convention, CITES (Convention on International Trade of Endangered Species), the Migratory Bird Act, AEWA (African European Waterbird Agreement), NABCI (North American Bird Conservation Initiative) and the European Birds Directive (all these efforts entertain bold websites and can be found online). They usually include some Arctic seabirds, but do not achieve well in delivering their data in high quality to the global public and, hence, they fail to safeguard seabirds and to produce a better and more efficient management of the Arctic or its ecological services of global relevance (Table 12). Arctic seabirds need Arctic conditions, e.g. affiliated with snow and ice. The lacking ability of the legal mechanisms to stop the sea ice and habitat decline by dealing with the underlying causes makes this problem already very clear and urgent. Structural, institutional and cultural changes are required for relevant improvements (Young 2002; Cushman and Huettmann 2010).

International law is more a shaking of hands (Boersma et al. 2002). Overall, there is no shortage of well-meant wording and terminology, e.g. protection and sustainable development, in Arctic policy documents (see Textbox 1 for an example). However, an effective budget appropriation for seabird research does not follow these statements, nor do most nations and organizations truly enforce these efforts relevant to mankind and future generations. The realistic situation on the ground differs from what the words in the legal document imply. Further considering the huge climate change issues (Arctic Council 2004), and the set-up of Arctic protection efforts since the 1990s and even earlier, the approaches must be labeled by now as failed (see Mace et al. 2010 discussing failed biodiversity targets) and highly inefficient, awaiting an immediate overhaul. The repercussions for circumpolar seabirds are manifold: (1) they lost or will lose their habitat, and therefore their livelihood, (2) legal texts clearly try to achieve sustainability and no habitat loss ("spirit of the ESA and IUCN policies" states protection), and (3) best professional practices, and common sense, are not in support of the current situation. Such issues have already been widely and strongly expressed in the conservation literature and elsewhere (Huettmann and Czech 2006; Rosales 2008), but are not yet published and implemented in relevant polar, seabird and policy circles.

Holistic seabird monitoring on land and sea

Like most monitoring programs (Magness et al. 2008, 2010), seabird monitoring suffers from lack of true statistical design, performance evaluation, public digital data achievement and direct links with predictive modeling and adaptive management. For instance, Anker-Nilssen et al. (2000) presented a mapping status and suggested priorities for regions of the Barents Sea. However, their underlying statistical model is lacking and not cited, nor are data management and adaptive management needs addressed, e.g. a budget and policy framework. The lack of seabird data for the wintering period and non-breeders has already been outlined elsewhere (Gavrilo et al. 1998b). Another crucial angle, widely overlooked but somewhat present in seabird research early on, are parasites (e.g., Belopolskaya 1951 in Anker-Nilssen et al. 2000 for Razorbills; see Kerry and Riddle 2009 for Antarctica seabirds). Also, the ecological links seabirds sustain between their breeding and wintering grounds, or between marine and terrestrial ecosystems, are known to be relevant but lack many funded studies. The correlation that marine predators have with seabirds gets acknowledged though (Cairns et al. 2008). Lastly, assessing the impact of the human economy on Arctic seabirds is also widely missing, but requires study and major consideration (Huettmann and Czech 2006).

Towards efficient seabird management

It is our intent here to set the stage for modern seabird research in polar regions, and call for the foundation for an efficient, public and free digital information resource platform for the wider global community of managers, researchers and naturalists interested in the long-term sustainability of Arctic seabirds and their habitats. Good examples for such concepts already exist worldwide (Braun 2005; Spehn and Koerner 2009; Chapin et al. 2010; Huettmann 2010; Vanden Berghe et al. 2010).

Despite the large amount of research publications on seabirds, very few publications actually deal with seabird management (Nettleship 1991; U.S. Fish and Wildlife Service 1992; Anker-Nielssen et al. 1996), adaptive management (see for lack thereof in Gaston 2004) and how to set it up successfully (Truett and Johnson 2000; Boersma et al. 2002). The lack of peer-reviewed knowledge concerning seabird management during the pelagic part of their annual cycle is even more pronounced (see CAFF 1996, 2001b for grey literature), although a few recent efforts, e.g. on fisheries bycatches, are worth mentioning (Dietrich et al. 2009).

Our study focuses just on a subset of 27 pelagic species. However, for terrestrial Arctic applications, a wider view, or a community approach, is sometimes warranted, e.g. full inclusion of tundra and coastal species. Such additional species have already been named and included by other authors (see Online Resource 8 for details). The White-tailed Eagle is traditionally also excluded in such studies, and so are Gyrfalcon and Snowy Owl, but this carries no ecological justifications and they should also be included in future studies (see Booms et al. 2009 for Gyrfalcons). This is easily justified by the fact that many of the species of this list are already included in Arctic marine-related investigations, and because they can often be found far offshore (e.g., Huettmann 2000), as an inherent part of the pelagic food chain even.

Regarding circumpolar seabirds, we see the following general trend: Arctic seabirds are poorly inventoried with regards to statistical rigor, pelagic habitat, international movements, assigned budget and taxonomic expertise. Further, they carry no relevant and truly achieving protection status, they are often hunted (legally or illegally; CAFF 2001b), their habitat, e.g. sea ice and foraging sites near cliffs, is soon to be widely lost (projected losses in 50 years due to climate change, resource demands from a global population of by then 9 billion people, the opening of new sea routes, invasive species, and a poor management track record overall), international waters carry virtually no real-world protection, and their prey base will be further affected (see CAFF 2001a for already widely overfished Arctic Cod stocks). This leaves us with a bleak outlook for seabirds, their health, habitats and genetic diversity.

The future will generally hold an increased human footprint throughout the entire Arctic, as well as in the seabird wintering grounds. The Kara Sea, for instance, is predicted for an increase of oil and gas, shipping and tourism activities (Bakken 2000). And Alaska's Arctic is widely scheduled for more offshore oil and gas development and fisheries.

For better research and science-based management, we suggest the following efforts: increase a balanced and long-term research effort, update an outdated science philosophy, set up a seabird governance model that actually achieves sustainability, increase digital data sharing and standardize survey protocols with an efficient data flow, add ethics and social considerations, implement a modern adaptive management, start a discussion on how to define and reach global sustainability (e.g., no species loss, and adding individual animal behavior and welfare considerations in circumstances in which not all goals can any longer be reached anyways), assess gaps, and propose a reasonable agenda for reaching global sustainability.

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References

Anisimov OA, Vaughan DG, Callaghan TV, Furgal C, Marchant H, Prowse TD, Vilhjalsson HH, Walsh JE (2007) Polar regions (Arctic and Antarctic). In: Parry ML, Canziani OF, Palutikof JP, van der Linden PJ, Hanson CE (eds) Climate Change 2007: impacts adaptation and vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, pp 653–685

Anker-Nielssen T, Erikstad S-H, Lorentsen C (1996) Aims and effort in seabird monitoring: an assessment based on Norwegian data. Wildl Biol 2:17–26

Anker-Nilssen T, Bakken V, Strom H, Golovkin AN, Bianki VV, Tatarinkova IP (2000) The status of marine birds breeding in the Barents Sea Region. Norsk Polarinst. Rapport 113

Arctic Council (2004) Arctic Climate assessment. Fourth Arctic Council Ministerial Meeting, Reykjavik, Iceland

Artukhin YB, Burkanov VB (1999) Seabirds and marine mammals of the Russian Far East (in Russian). AST Press, Moscow

Bailey AM (1948) Birds of Arctic Alaska. Popular Series 8, Colorado Museum of Natural History, Denver, Colorado

Bakken V (2000) Seabird colony databases of the Barents Sea Region and the Kara Sea, 2nd edn. Norsk Polarinstitut, Tromso

Bakken V, Falk K (1998) Incidental take of seabirds in Commercial Fisheries in the Arctic Countries. CAFF Technical Report No1. Circumpolar Seabird working group

Bakken V, Gavrilo M (1995) Registration of seabirds in the Laptev, Kara and Barents Seas. – Swedish- Russian Tundra Ecology – Expedition -94. A cruise report. Stockholm, pp 264–275

Bakken V, Gavrilo M, Isaksen K, Strann K-B (1996) Selection of marine bird Valued Ecosystem Components and description of impact hypotheses in the Northern Sea Route Area. INSROP Working Paper No. 60

Bandura A (2007) Impeding ecological sustainability through selective moral disengagement. Int J Innov Sust Develop 2:8–35

Barrett RT, Bakken V, Krasnov Yu V (1997) Movements of kittiwakes *Rissa tridactyla* ringed in Norway. Ring Migr 18:25–32

Belopolsky L O (1957) Ecology of marine colonial birds of the Barents sea, Moscow and Leningrad, Publishing House of the Academy of Sciences of USSR (in Russian)

Birkhead T (1993) Great Auk Islands: a field biologist in the Arctic. Poyser, London

Birt VL, Birt TP, Goulet D, Cairns DK, Montevecchi WA (1987) Ashmole's halo: direct evidence for prey depletion by a seabird. Mar Ecol Prog Ser 40:205–208

Bluhm B, Watts D, Huettmann F (2010) Free database availability, metadata and the internet: an example of two high latitude components of the census of marine life. Chapter 13. In: Cushman S, Huettmann F (eds) Spatial complexity, informatics and wildlife conservation. Springer, Japan, pp 233–244

Boardman R (2006) The international politics of bird conservation: biodiversity. Regionalism and global governance. Edward Elgar, Cheltenham

Boersma PD, Clark JA, Hillgarth N (2002) Seabird conservation. In: Schreiber EA, Burger J (eds) Biology of marine birds. CRC Press, Boca Raton, pp 559–580

Boertmann D (1994) A annotated checklist to the birds of Greenland. Medd Grønland-Biosci 38:1–63

Boertmann D, Mosbech A, Falk K, Kampp K (1996) Seabird colonies in western Greenland, (60°–79° 3′ N. lat). National Environmental Research Institute, Denmark. NERI Technical Report No. 170

Booms T, Huettmann F, Schempf P (2009) Gyrfalcon nest distribution in Alaska based on a predictive GIS model. Polar Biol 33:1601–1612

BOU (1999) The British list 2000. Tring, Herfordshire; British Ornithologists' Union, England

Braune BM, Mallory ML, Gilchrist HG (2006) Elevated mercury levels in a declining population of Ivory Gulls in the Canadian Arctic. Mar Pollut Bull 52:978–982

Braun C (ed) (2005) Techniques for wildlife investigations and management. The Wildlife Society, Bethesda

Breiman L (2001) Statistical modeling: the two cultures. Stat Sci 16:199–215

Brinkley ES (2007) Field guide to birds of North America. Sterling, New York

Brooke MdeL (2002) Seabird systematics and distribution: a review of current knowledge. In: Schreiber EA, Burger J (eds) Biology of marine birds. CRC Press, Boca Raton, pp 57–86

Brown RGB (1986) Revised Atlas of Eastern Canadian seabirds. Canadian Wildlife Service

Brown RGB, Nettleship DN (1981) The biological significance of polyneas to Arctic colonial birds. Polynas in Canadian Arctic. Occas Pap Can Wildl Serv 45:59–66

Brown RGB, Nettleship DN, Germain P et al (1975) Atlas of eastern Canadian seabirds. Canadian Wildlife Service

Burger J, Gochfeld M (1996) Family Laridae (Gulls). In: del Hoyo J et al (eds) Handbook of the birds of the world, vol 3. Lynx Edicions, Barcelona, pp 572–623

CAFF (Conservation of Arctic Flora and Fauna) (1996) International murre conservation strategy and action plan. Conservation of Arctic Flora and Fauna, Reykjavik

CAFF (Conservation of Arctic Flora and Fauna) (2001a) Arctic flora and fauna: status and conservation. Edita, Helsinki

CAFF (Conservation of Arctic Flora and Fauna) (2001b) Seabird Harvest Regimes in the Circumpolar Nations. Conservation of Arctic Flora and Fauna, Technical Report No. 9

CAFF (Conservation of Arctic Flora and Fauna) (2004) Distribution of murres outside the breeding season. "Circumpolar Murre Banding Program" North Atlantic Regions. CAFF Technical Report No. 13. Conservation of Arctic Flora and Fauna, Reykjavik

Cairns D, Gaston AJ, Huettmann F (2008) Endothermy, ectothermy, and the global structure of marine vertebrate communities. Mar Ecol Prog Ser 356:239–250

Chapin FS, Kofinas GP, Folke C (eds) (2010) Principles of ecosystem stewardship: resilience-based natural resource management in a changing world. Springer, New York

Chapman AD, Wieczorek J (2006) Guide to best practices for georeferencing. Global Biodiversity Information Facility, Denmark, pp 1–80

Cioc M (2010) The game of conservation: international treaties to protect the world's migratory animals. Ohio University Press series in Ecology and History, Athens

Costello M (2009) Motivating online publication of data. Bioscience 59:418–427

Cramp S (1985) The birds of the Western Palearctic, vol IV. Oxford University Press, Oxford

Cramp S, Simmons KEL (1977) The birds of the Western Palearctic, vol I. Oxford University Press, Oxford

Cramp S, Simmons KEL (1983) The birds of the Western Palearctic, vo III. Oxford University Press, Oxford

Crane K, Galasso JL (1999) Arctic environmental atlas. Office of Naval Research, Naval Research Laboratory, Hunter College, New York

Cushman S, Huettmann F (2010) Spatial complexity, informatics and wildlife conservation. Springer, Japan

Daelemans FF (1994) Polychlorinated biphenyls and some selected organochlorine pesticides in seabirds and marine mammals from the Svalbard archipelago. Dr. thesis, University of Antwerpen

Day RH, DeGrange AR, Divoky GV, Troy DM (1988) Distribution and subspecies of the Dovekie in Alaska. Condor 90:712–714

De Korte J, Volkov AE (1993) Large colony of Ivory Gulls (*Pagophilea eburnea*) at Domashniy Island, Severnaya Zemlaya. Sula 7:107–110

del Hoyo J, Elliott A, Sargatal J (1992) Handbook of the birds of the world, vol 1. Lynx Edicions, Barcelona

del Hoyo J, Elliott A, Sargatal J (1996) Handbook of the birds of the world, vol 3. Lynx Edicions, Barcelona

Diamond AW, Gaston AJ, Brown RGB (1993) A model of the energy demands of the seabirds of eastern Arctic Canada. In: Montevecchi WA (ed). Studies of high-latitude birds. Canadian Wildlife Service, Occasional paper Number 77

Dietrich KS, Parrish JK, Melvin EF (2009) Understanding and addressing seabird bycatch in Alaska demersal longline fisheries. Biol Cons 142:2642–2656

Divoky GY (1976) The pelagic feeding habits of Ivory and Ross's gulls. Condor 3:229–243

Drew A, Wiersma Yo, Huettmann F (eds) (2010) Predictive modeling in landscape ecology. Springer, New York

Egevang C, Boertmann D (2008) Ross's Gulls (*Rhodostethia rosea*) breeding in Greenland: a review, with special emphasis on records from 1979 to 2007. Arctic 61:322–328

Egevang C, Stenhouse IJ, Phillips RA, Petersen A, Fox JW, Silk JRD (2010) Tracking of Arctic terns *Sterna paradisaea* reveals longest animal migration. Proc Natl Acad Sci USA 107:2078–2081

Eldridge VD, Hodges GI, Syroechkoksiy EV, Krechmar EA (1993) The Russian–American aerial waterfol surveys in the North East Asia in 1992. Russ Ornitol Zh 2:457–461 (in Russian)

Elith J, Graham CH (2009) Do they? How do they? Why do they differ? On finding reasons for differing performances of species distribution models. Ecography 32:66–77

Elith J, Graham C, NCEAS working group (2006) Novel methods improve prediction of species' distributions from occurrence data. Ecography 29:129–151

Erikstad KE, Bustnes KE, Vader W (1988) Duration of ship-following by kittiwakes *Rissa tridactyla* in the Barents Sea. Polar Res 6:191–1994

Evans PGH (1984) The seabirds of Greenland: their status and conservation. Princeton University Press, Princeton

Falk K, Moeller S (1995) Colonies of northern fulmars and black-legged kittiwakes associated with the Northeast Water polynya, Northeast Greenland. Arctic 48:186–195

Fauchald P, Erikstad KE, Systad GH (2002) Seabirds and marine oil incidents: is it possible to predict the spatial distribution of pelagic seabirds? J Appl Ecol 39:349–360

Forsberg M (1995) Ivory Gulls flock to former military station. WWF Arct Bull 3:15

Friesen VL, Montevecchi WA, Baker AJ, Barrett RT, Davidson WS (1996) Population differentiation and evolution in the Common Guillemot *Uria aalge*. Mol Ecol 5:793–805

Frolov IE, Gudkovich ZM, Karklin VP, Kovalev EG, Smolyanitsky VM (2009) Climate change in Eurasian Arctic shelf seas. Praxis

Full E (1999) The great auk. Abrams, New York

Furness RW (1987) The skuas. Poyser, Calton

Furness RW, Monaghan P (1987) Seabird ecology. Blackie, Glasgow

Gaston AJ (2004) Seabirds: a natural history. Yale University Press, New Haven

Gaston AJ, Jones IL (1998) The auks. Oxford University Press, Oxford

Gaston AJ, Elliot RD (eds) (1991) Studies of high-latitudes seabirds. 2. Conservation biology of thick-billed murres in the Northwest Atlantic. Can. Wildl. Serv. Occ. Paper 69

Gaston AJ, Nettleship DN (1981) The thick-billed murres of Prince Leopold Island – a study of the breeding ecology of a colonial high arctic seabird. Canadian Wildlife Service Monograph Series No 6

Gavrilo M, Bakken V, Isaksen K (eds.) (1998a) The distribution, population status and ecology of marine birds selected as valued ecosystem components in the Northern Sea Route area. INSROP Working paper No 123 II.4.2

Gavrilo M, Bakken V, Firsova L et al. (eds.) (1998b) Oil vulnerability assessment for marine birds occurring along the Northern Sea Route area. INSROP Working paper No 97

Gibson DD, Byrd GV (2007) Birds of the Aleutian Islands, Alaska. Nuttall Ornithological Club & The American Ornithologists' Union

Gilchrist G, Strom H, Gavrilo M, Mosbech A (2008) International Ivory Gull conservation strategy and action plan. CAFFs Circumpolar Seabird Group. CAFF Technical report No 18. September

Gilg O, Sane R, Solovieva RV, Pozdnyakov VI, Sabard B, Tsanos D, Zoeckler C, Lappo EG, Syroechkovski EE Jr, Eichhorn G (2000) Birds and mammals of the Lena Delta Nature Reserve, Siberia. Arctic 53:118–133

Gilg O, Sabard B, Kampp K, Andreasen C, Scheifler R, Ioset J, Schwoehrer C, Druesne C, Wiest JP, Schreiber M, Geoffroy L, Barrat J-A (2005) Ecopolaris – Tara 5 expedition to NE Greenland 2004. GREA, Francheville

Gilg O, Strøm H, Aebischer A, Gavrilo MV, Volkov A, Miljeteig C, Sabard B (2010) Post- breeding movements of the Northeast Atlantic Ivory gull populations. J Av Biol 41:532–542. doi:10.1111/j.1600-048X.2010.05125.x

Graham CH, Ferrier S, Huettmann F, Moritz C, Peterson AT (2004) New developments in museum-based informatics and applications in biodiversity analysis. Trends Ecol Evol 19:497–503

Grant PJ (1997) Gulls: a guide to identification, 2nd ed. Academic, London

Guisan A, Zimmermann NE (2000) Predictive habitat distribution models in ecology. Ecol Modell 135:147–186

Harrison P (1983) Seabirds: an identification guide. Houghton Mifflin, Boston

Hastie T, Tibshirani RJ, Friedman JH (2008) The elements of statistical learning: data mining, inference, and prediction. Springer, Berlin

Hegel T, Cushman SA, Evans J, Huettmann F (2010) Current state of the art for statistical modelling of species distributions. Chapter 16. In: Cushman S, Huettmann F (eds) Spatial complexity, informatics and conservation. Springer, Japan, pp 273–312

Hinzman LD, Bettez ND, Bolton WR, Chapin FS III, Dyurgerov MB, Fastie CL, Griffith B, Hollister RD, Hope A, Huntington HP, Jensen AM, Jia GJ, Jorgenson T, Kane DL, Klein DR, Kofinas R, Lynch AH, Lloyd AH, McGuire AD, Nelson FE, Nolan M, Oechel WC, Osterkamp TE, Racine CH, Romanovsky VE, Stone RS, Stow RA, Sturm M, Tweedie CE, Vourlitis GL, Walker MD, Walker DA, Webber PJ, Welker J, Winker KS, Yoshikawa K (2005) Evidence and implications of recent climate change in northern Alaska and other arctic regions. Clim Change 72:251–298

Hodges YI, Eldridge WD (1994) Aerial waterfowl surveys oon the arctic coast of Eastern Russia, 1993. Unpublished Report, U.S. Fish and Wildlife Service, Anchorage

Huettmann F (2000) Environmental determination of seabird distribution in the Northwest Atlantic. Unpublished PhD thesis, University of New Brunswick (UNB), Fredericton, New Brunswick, Canada

Huettmann F (2007) Constraints, suggested solutions and an outlook towards a new digital culture for the oceans and beyond: experiences from five predictive GIS models that contribute to global management, conservation and study of marine wildlife and habitat. In: Vanden Berghe E et al (eds) Proceedings of 'Ocean Biodiversity Informatics': an international conference on marine biodiversity data management Hamburg, Germany, 29 November–1 December, 2004. IOC Workshop Report, 202, VLIZ Special Publication 37, pp 49–61. http://www.vliz.be/vmdcdata/imis2/imis.php?module=ref&refid=107201

Huettmann F (2008) Marine conservation and sustainability of the sea of Okhotsk in the Russian Far East: an overview of cumulative impacts, compiled public data, and a proposal for a UNESCO world heritage site. In: Nijhoff M (ed). Ocean Year Book 22:353–374, Halifax, Canada

Huettmann F (2009) The global need for, and appreciation of, high-quality metadata in biodiversity work. In: Spehn E, Koerner C (eds) Data mining for global trends in mountain biodiversity. CRC Press, Boca Raton, pp 25–28

Huettmann F (2010) Modern adaptive management: adding digital opportunities towards a sustainable world with new values. In: Reck RA (ed) Climate change and sustainable development. Linton Atlantic, Cambridge

Huettmann F, Diamond AW (2001) Seabird colony locations and environmental determination of seabird distribution: a spatially explicit seabird breeding model in the Northwest Atlantic. Ecol Modell 141:261–298

Huettmann F, Czech B (2006) Taking marine seabird conservation seriously: towards a steady state economy for the pacific and beyond. Pac Seabirds 33(2):52–54

Huettmann F, Diamond AW (2006) Large-scale effects on the spatial distribution of seabirds in the Northwest Atlantic. Landscape Ecol 21:1089–1108

Huettmann F, Hazlett S (2010) Changing the arctic: adding immediate protection to the equation. Alaska Park Science, U.S. National Park Service, Fairbanks, pp 118–121

Humphries GRW (2010) The ecological niche of storm-petrels in the North Pacific and a global model of dimethylsulfide concentration. Unpublished MSc thesis. University of Alaska-Fairbanks. Fairbanks, Alaska

Hunt GL, Bakken V, Mehlum F (1996) Marine birds in the marginal ice zone of the Barents Sea in late winter and spring. Arctic 49:53–61

Irons DB, Anker-Nilssen T, Gaston A, Byrd GV, Falk F, Gilchrist G, Hario M, Hjernquis M, Krasnov YV, Mosbech A, Olsen B, Petersen A, Reid JB, Robertson GJ, Strom H, Wohl KD (2008) Fluctuations in circumpolar seabird populations linked to climate oscillations. Glob Change Biol 14:1455–1463

Isaksen K (1995) Distribution of seabirds at sea in the northern Barents Sea. Nor Polarinst Medd 135

Kadmon R, Farber O, Danin A (2004) Effect of roadside bias on the accuracy of predictive maps produced by bioclimatic models. Ecol Appl 14:401–413

Kampp K, Nettleship DN, Evans PGH (1994) Thick-billed Murres of Greenland: status and prospects. In: Nettleship DN, Burger J, Gochfeld M (eds) Seabirds on islands, threats, case studies and action plans. BirdLife Int., Conserv. Ser. No. 1, pp 133–154

Kerry KR, Riddle MJ (eds) (2009) Health of Antarctic wildlife: a challenge for science and policy. Springer, New York

Kessel B (1989) Birds of the Seward Peninsula. University of Alaska Press, Alaska

Knystautas A (1993) Collins guide to the birds of Russia. Collins, London

Kondratyev A, Litvinenko Ya, Kaiser GW (eds) (2000) Seabirds of the Russian Far East. Ottawa, Can Wildl Serv, Spec Publ

Krasnov YV, Barrett RT (1995) Large-scale interactions among seabirds, their prey and humans in the southern Barents Sea. In: Skjoda HR, Hopkins C, Erikstad KE, Leinass HP (eds) Ecology of fjords and coastal waters. Elsevier, Amsterdam, pp 443–456

Krasnov YV, Barrett RT (1997) The first record of North Atlantic Gannets *Morus bassanus* breeding in Russia. Seabird 19:54–57

Krasnov YV, Barrett RT, Nikolaeva NG (2007) Status of black-legged kittiwakes (*Rissa tridactyla*), common guillemots (*Uria aalge*) and Brünnich's guillemots (U. lomvia) in Murman, north-west Russia, and Varanger, north-east Norway. Pol Res 26:113–116

Krasnov YV, Goryaev, Nikolaeva NG, Shavykin AA, Gavrilo MV, Chernook VI (2002) The Atlas of marine birds of the Pechora Sea. Apatity (in Russian)

Krasnov YV, Shavykin AF, Spiridonov VA, Nikolaeva NG (2005) Problems of seabird protection in the time of the offshore hydrocarbon development in the Arctic seas. Proceedings of the 7th International conference on the Oil and Gas in the Russian Arctic and CIS continental shelf, St. Petersburg, 13–15 September 2005, pp 513–519

Krechmar AV, Andreev AV, Kondratyev AY (1991) The birds of northern plains. Nauka. St.Petersburg (in Russian with English summary)

Krupnik I, Jolly D (eds) (2002) The earth is faster now: indigenous observations of arctic environmental change. Arctic Research Consortium of the United States, Fairbanks

Leighton FA, Butler RG, Peakall DB (1985) Oil and Arctic marine birds: an assessment of risk. In: Engelhardt FR (ed) Petroleum effects in the Arctic environment. Elsevier, London, pp 183–215

Lock AR, Petrie J, Griswold A (1997) PIROP – a database for mapping seabird distribution. Canadian Wildlife Service, Atlantic Region

Lyngs P (2003) Migration and winter ranges of birds in Greenland: an analysis of ringing recoveries. Dansk Ornithologisk Forenings Tidsskrift 97

Mace GM, Cramer W, Diaz S, Faith DP, Larigauderie A, Le Prestre P, Palmer M, Perrings C, Scholes RJ, Walpole M, Walther BA, Watson JA, Mooney HA (2010) Biodiversity targets after 2010. Environ Sust 2:1–6

Magness DR, Huettmann F, Morton JM (2008) Using random forests to provide predicted species distribution maps as a metric for ecological inventory & monitoring programs. In: Smolinski TG, Milanova MG, Hassanien AE (eds) Applications of computational intelligence in biology: Current trends and open problems. Studies in computational intelligence, vol 122. Springer, Berlin, pp 209–229

Magness D, Morton JM, Huettmann F (2010) How spatial information contributes to the management and conservation of animals and habitats. Chapter 23. In: Cushman S, Huettmann F (eds) Spatial complexity, informatics and wildlife conservation. Springer, Japan, pp 429–444

Martin VG, Tyler N (1995) The 5th Wolrd Wilderness Congress: Arctic wilderness. The International Wilderness Leadership (WILD) Foundation. Ojai, California

Mehlum F (1990) Seabird distribution in the northern Barents Sea marginal ice-zone during late summer. Polar Res 8:61–65

Mehlum F (1997) Seabird species associations and affinities to areas covered with sea ice in the northern Greenland and Barents Seas. Polar Biol 18:116–127

Mehlum F, Nordlund N, Isaksen K (1998) The importance of the polar front as a foraging habitat for guillemots Uria spp. At Bjoenoeya, Barents Sea. J Mar Syst 14:27–43

Mendenhall VM, Anker-Nilssen T (1996) Seabird populations and commercial fisheries in the circumpolar region: do we need to worry? Circumpolar Seabird Bull 2:1–7

Merkel F, Barry T (eds) (2008) Seabird harvest in the Arctic. CAFF International Secretariat, Circumpolar Seabird Group (CBird), CAFF Technical Report No. 16

Moeller AP, Flensted-Jensen E, Mardal W (2007) Agriculture, fertilizers and life history of a coastal seabird. J Anim Ecol 76:515–525

Mordecai R, Laurent E, Moore-Barnhill L, Huettmann F, Miller D, Sachs E, Tirpak J (2010) A field guide to web technology. Southeast Partners in Flight (SEPIF). http://sepif.org/content/view/62/1/

Mosbech A, Dietz R, Boertmann D, Johansen P (1996) Oil exploration in the Fylla Area. An initial assessment of potential environmental impacts. National Environmental Research Institute, Technical Report No. 156

National Research Council [NRC] (2003) Cumulative environmental effects of oil and gas activities on Alaska's North Slope. National Academy Press, Washington

Nettleship DN (1991) Seabird management and future research: guest editorial. Colon Waterbirds 14:77–84

Nettleship D, Burger J, Gochfeld M (eds) (1994) Seabirds on islands, threats, case-studies and action plans. Birdlife International, Conservation series No. 1

Nettleship DN, Birkhead TR (eds) (1985) The Atlantic Alcidae: the evolution, distribution and biology of the auks inhabiting the Atlantic Ocean and Adjacent Water Areas. Academic, London

Nettleship DN (1996) Family Alcidae (Auks). In: del Hoyo J et al (eds) Handbook of the birds of the world. Lynx Edicions, Barcelona, pp 678–722

Newton I (2003) The speciation & biogeography of birds. Academic, London

Nikolaeva NG, Spiridonov VA, Krasnov YV (2006) In: Boere GC, Galbraith CA, Stroud DA (eds) Existing and proposed marine protected areas and their relevance for seabird conservation: a case study in the Barents Sea region. Waterbirds around the world. The Stationery Office, Edinburgh, pp 743–749

Norse EA, Crowder LB (2005) Marine conservation biology: the science of maintaining the sea's biodiversity. Island Press, Washington

Ohse B, Huettmann F, Ickert-Bond S, Juday G (2009) Modeling the distribution of white spruce (Picea glauca) for Alaska with high accuracy: an open access role-model for predicting tree species in last remaining wilderness areas. Polar Biol 32:1717–1724

Onley D, Scofield P (2007) Albatrosses, Petrels & Shearwaters of the world. Princeton University Press , Princeton

Oppel S, Huettmann F (2010) Using a random forest model and public data to predict the distribution of prey for marine wildlife management. Chapter 8. In: Cushman S, Huettmann F (eds) Spatial complexity, informatics and wildlife conservation. Springer, Japan, pp 151–164

Oppel S, Strobel C, Huettmann F (2009) Alternative methods to quantify variable importance in ecology. Technical Report Number 65, Department of Statistics. University of Munich, Germany

Overpeck J, Hughen K, Hardy D, Bradley R, Case R, Douglas M, Finney B, Gajewski K, Jacoby G, Jennings A, Lamoureux S, Lasca A, MacDonald G, Moore G, Retelle M, Smith S, Wolfe A, Zielinski G (1997) Arctic environmental change of the last four centuries. Science 278:1251–1256

Paneva TD (1989) Concentrations of nonbreeding gulls in the vicinity of Murmansk city. Ecology of birds on the Kola Peninsula 63-71 (in Russian)

Pearce J, Ferrier S (2000) Evaluating the predictive performance of habitat models developed using logistic regression. Ecol Model 133:225–245

Petersen AE (1994) Status and population changes of auks in Iceland. Circumpolar Seabird Bull 1:4–7

Petersen AE, Irons D, Anker-Nilssen T, Artukhin Yu, Barrett R, Boertmann D, Egevang C, Gavrilo MV, Gilchrist G, Hario M, Mallory M, Mosbech A, Olsen B, Osterblom H,Robertson R, Strom H (2008) CAFFs Circumpolar Biodiversity Monitoring Program: Framework for a Circumpolar Arctic Seabird Monitoring Network. CAFF CBMP Report

Pittmann S, Huettmann F (2006) Chapter 4 - Seabird distribution and diversity. In: Battista TR, Pittmann CS (eds) An ecological characterization of the Stellwagen Bank National Marine Sanctuary Region: Oceanographic, Biogeographic, and Contaminants Assessment. Prepared by NCCOS's Biogeography Team in cooperation with the National Marine Sanctuary Program. NOAA Technical Memorandum NCCOS 45. Silver Spring, Maryland, U.S.

Rosales J (2008) Economic growth, climate change, biodiversity loss: distributive justice for the Global North and South. Cons Biol 22:1406–1417

Rutzen I (2008) Predictive GIS-modeling of arctic mesozooplankton based on available public online data: Experiences from four copepod species (Calanus glacialis, C. hyperboreus, Metridia longa and M. pacifica). MSc thesis, University of Hannover

Schreiber EA (2002) Climate and weather effects on seabirds. In: Schreiber EA, Burger J (eds) Biology of marine birds. CRC Press, Boca Raton, pp 179–216

Schreiber EA, Burger J (2002) Biology of marine birds. CRC Press, Boca Raton

Schweder T (2001) Protecting whales by distorting uncertainty: non-precautionary Mis-management. Fish Res 52:217–225

Serreze MC, Walsh JE, Chapin FS III, Osterkamp T, Dyurgerov M, Romanovsky V, Oechel WC, Morison J, Zhang T, Barry RG (2000) Observational evidence of recent change in the northern high-latitude environment. Clim Change 46:159–207

Shuntov VP (2000) Chapter 2. Far East seas as habitats for seabirds. In: Kondratyev A, Litvinenko NM, Kaiser GW (eds) Seabirds of the Russian Far East. Special Publication. Canadian Wildlife Service, Ottawa, pp 21–36

Sinclair PH, Nixon WA, Eckert CD, Hughes NL (2003) Birds of the Yukon. UBC Press, Vancouver

Slyus R (1982) Geographical variation of the Kittiwake *Rissa tridactyla*. Gerfaut 72:221–230

Smith MA, Smith Q (2009) Atlas of the Chukchi and Beaufort Seas. Audubon Alaska, in cooperation with Oceana, Anchorage, Alaska

Spehn E, Koerner C (ed) (2009) Data mining for global trends in mountain biodiversity. CRC Press, Boca Raton

Stempniewicz L (1992) Manuring of tundra near a large colony of seabirds on Svalbard. In: Opalinsky KW, Klekowski RZ (eds) Landscape, life world and man in high Arctic. Inst. of Ecology, Polish Academy of Sciences, pp 255–269

Stishov MS, Pridatko VI, Baranyuk VV (1991) The birds on the Wrangel Island. Nauka, Novosibirsk.(in Russian)

Strann K-B, Vader W (1992) The nominate Lesser Black-backed Gull *Larus fuscus fuscus*, a gull with a tern-like feeding biology, and its recent decrease in northern Norway. Ardea 80:133–142

Syroechkovkiy EE, Rogacheva EV (1994) The Great Arctic Reserve: problems of the Arctic Nature conservation. In: Arctic Tundras of Taimyr and Kara sea islands: nature, fauna and conservation problems, vol 1. Moscow, pp 17-43

Thomassen J, Lovas SM, Loset S (1994) Environmental impact assessment – preliminary design. INSROP Discussion Paper

Truett JC, Johnson SR (eds) (2000) The natural history of an Arctic oil field: development and biota. Academic Press, San Diego

Uspenski SM (1956) The bird bazaars of Novaya Zemlya. Canadian Wildlife Service Translation of Russian Game Reports, vol 4. Ottawa (Translated from Russian, 1958)

Uspenski SM, Beme RL, Velizhanin AJ (1963) Avifauna ostrova Wrangelya (Avifauna of Wrangel Island). Ornitologiya 6:58–67

Uspenski SM (1969) Zhizn v vysokikh shirotakh na primere ptits. (Life in high latitudes. Demonstrated mainly on birds). Moscow, Mysl

U.S. Fish and Wildlife Service (1992) Alaska Seabird Management Plan. Unpublished report, U.S. Fish and Wildlife Service, Anchorage, Alaska

Vaughan R (1991) In search of Arctic birds. Black, London

Vanden Berghe E, Stock KI, Grassle JF (2010) Chapter 17: data integration: the ocean biogeographic information system. In: McIntyre AD (ed) Life in the world's oceans: diversity, distribution, and abundance. Census of Marine Life (COML) and Wiley-Blackwell, Oxford, pp 333–353 (hardback)

VanDerWal J, Shoo LP, Graham C, Williams SE (2009) Selecting pseudo-absence data for presence-only distribution modeling: how far should you stray from what you know? Ecol Model 220:589–594

Van Franeker JA, Camphuysen CJ, Mehlum F (1998) The birds of Jan Mayen. Circumpolar J 13:28–43

Vuilleumier F (1996) Birds observed in the Arctic Ocean to the North Pole. Arct Alpine Res 28:118–122

Walter KM, Zimov SA, Chanton JP, Verbyla D, Chapin FS (2006) Methane bubbling from Siberian thaw lakes as a positive feedback to climate warming. Nature 443:71–75

Wannhoff U, Toermer K (1997) Commandor: Leben am Ende der Welt. Eigenverlag, Dresden

Wayland M, Hoffman DJ, Mallory ML, Alisauskas RT, Stebbings KT (2010) Evidence of weak contaminant-related oxidative stress in Glaucous Gulls *(Larus glaucoides*) from the Canadian Arctic. J Toxic Env Health Part 1 73:1058–1073

Weiser E (2010) Use of Anthropogenic Foods by Glaucous Gulls (*Larus hyperboreus*) in Northern Alaska. MSc thesis, University of Alaska, Fairbanks

Wiese F, Robertson G, Gaston A (2004) Impacts of chronic marine oil pollution and the murre hunt in Newfoundland on thick-billed murre *Uria lomvia* populations in the eastern Canadian Arctic. Biol Cons 116:205–216

Wilson Rowe E (ed) (2009) Russia and the North. University Ottawa Press, Canada

Worm B, Myers RA (2003) Meta-analysis of cod-shrimp interactions reveals top-down control in oceanic food webs. Ecol 84:162–173

Yen P, Huettmann F, Cooke F (2004) Modelling abundance and distribution of Marbled Murrelets (*Brachyramphus marmoratus*) using GIS, marine data and advanced multivariate statistics. Ecol Model 171:395–413

Yergin D (1991) The epic quest for oil, money, and power. Simon & Schuster, New York

Young OR (2002) The institutional dimensions of environmental change: fit, interplay, and scale. MIT Press, Cambridge

Young O, Steffen W (2009) The earth system: sustaining planetary life-support systems. In: Chapin FS, Kofinas GP, Folke C (eds) Principles of ecosystem stewardship: resilience-based natural resource management in a changing world. Springer, New York, pp 295–318