

## OPINION

# Arctic marine fishes and their fisheries in light of global change

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## Abstract

In light of ocean warming and loss of Arctic sea ice, harvested marine fishes of boreal origin (and their fisheries) move poleward into yet unexploited parts of the Arctic seas. Industrial fisheries, already in place on many Arctic shelves, will radically affect the local fish species as they turn up as unprecedented bycatch. Arctic marine fishes are indispensable to ecosystem structuring and functioning, but they are still beyond credible assessment due to lack of basic biological data. The time for conservation actions is now, and precautionary management practices by the Arctic coastal states are needed to mitigate the impact of industrial fisheries in Arctic waters. We outline four possible conservation actions: scientific credibility, ‘green technology’, legitimate management and overarching coordination.

**Keywords:** Arctic fisheries, Arctic fishes, bycatch, conservation actions, zoogeography

Received 12 July 2013; revised version received 2 September 2013 and accepted 5 September 2013

‘Humans are now the most significant driver of global change, propelling the planet into a new geological epoch, the Anthropocene’. This landmark statement from the Stockholm Memorandum (2011) is supported by an overwhelming consensus in the scientific literature (Cook *et al.*, 2013). It is crucial to acknowledge, however, that several of Earth’s ecosystems are still little affected by direct human activity, and appropriate conservation measures are fully feasible and should be enforced accordingly (Caro *et al.*, 2012). Arctic marine ecosystems belong to this category.

Global warming is most intense in the Arctic region (Hoegh-Guldberg & Bruno, 2010). In recent years, Arctic seas are put under heavy pressures from ongoing ocean warming and escalating human intervention. Petroleum activities and industrial fisheries are becoming the major human stressors, and a strict precautionary approach towards the fish fauna native to Arctic waters is imperative and timely. The Arctic Council (<http://www.arctic-council.org>) plays a key role in conservation of Arctic flora and fauna, and its six member states neighbouring the Arctic seas – Canada, Greenland/Denmark, Iceland, Norway, the Russian

Federation, the USA – all share the principal responsibility against rash exploitation of Arctic marine resources.

Based on the Arctic Biodiversity Assessment report (CAFF, in press) commissioned by the Arctic Council, we opine that marine fish species native to Arctic seas are particularly vulnerable to large-scale industrial fisheries. In context of zoogeography, we argue that present-day ‘Arctic fisheries’ target and manage boreal stocks and not Arctic species. In light of ocean warming, however, boreal stocks (and their fisheries) move into yet unexploited parts of the Arctic seas. This will radically affect the local fish fauna as it turns up as unprecedented bycatch. Arctic marine fishes *sensu stricto* are still beyond credible assessment due to lack of basic biological data and, consequently, we outline four workable conservation actions to counteract negative effects of industrial fisheries in Arctic seas: scientific credibility, ‘green technology’, legitimate management and overarching coordination.

## Arctic marine ‘Klondike’ emerging

The Arctic ice melt and subsequent consequences for geopolitics and biota arouse not only scientific concern but also engage the broad public (Berkman & Young, 2009; NY Times, 2013). An Open Letter signed by more than 2000 scientists, and broadcasted at the International

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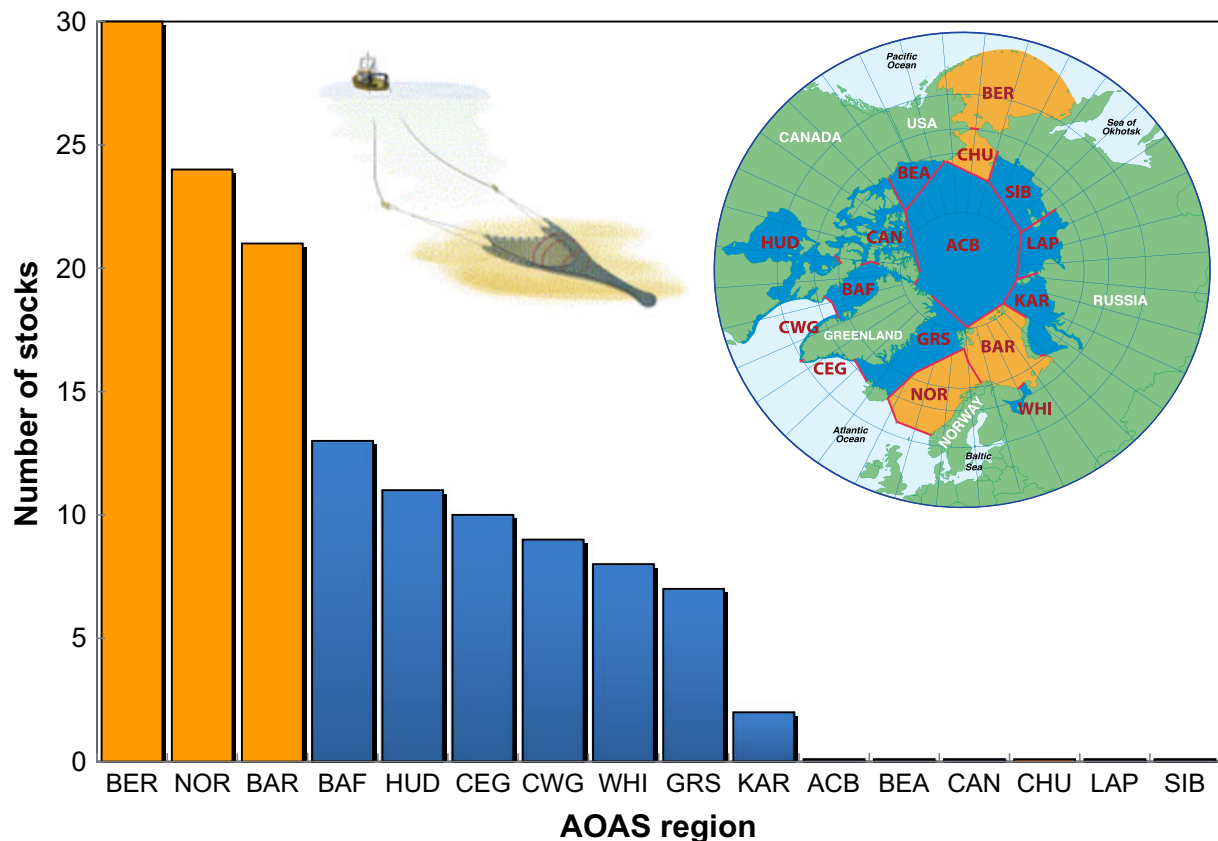
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Polar Year Conference (IPY) in Montréal 22 April 2012, expresses justified alarm and strongly advocates for a fisheries moratorium in unregulated Arctic waters (PEG, 2012).

The IPY-letter brings to mind fisheries history which repeatedly shows that large-scale exploitation of our seas outruns scientific insights and often with unforeseen and infamous consequences (Howarth *et al.*, 2013; Pitcher & Cheung, 2013). The loss of summer sea ice is turning the Arctic Ocean and shelves into a veritable ‘Klondike’ by boosting the transition from fragmentary scientific exploration into big business and rampant exploitation of minerals and living natural resources: petroleum and mining industries are in work and develop hastily (Schiermeier, 2012), industrial fisheries have begun (AFWG-ICES, 2013), aquaculture is pushing its limits northward and cargo and cruise ships are in operation with novel pollutants, such as antifouling, ballast water and noise in their wake (Smith & Stephenson, 2013). Legitimate grounds for

concern can be ascribed marine bioprospecting enterprises which extract compounds and patent genomes from otherwise little known Arctic fishes and other organisms (Leary, 2008).

Climate change is an indisputable fact, but it is an intricate task to disentangle the consequence of large-scale climate drivers from those attributed to direct human activity. Regardless the contribution of the respective stressors, they in concert will inevitably alter Arctic marine ecosystems profoundly albeit the magnitude of impact is as yet speculative. Impacts of human intervention on Arctic biota differ greatly, and tailored conservation actions are needed to counteract specific human activities. For example, petroleum activities and fisheries are closely coupled in public debates (Misund & Olsen, 2013) and illustrate well the diverging opinions of what proper conservation is. Here, we focus mainly on possible conservation actions in relation with industrial fisheries in Arctic seas.



**Fig. 1** Number of marine fish species (‘stocks’) currently harvested by industrial fisheries in the Arctic Ocean and adjacent seas (AOAS). The examined AOAS regions are shown in the inserted map. Geographic delineation follows the International Hydrographic Organization (<http://www.iho.int>). The Arctic gateways are shown in orange and the Arctic seas in deep blue. Regional codes are ACB, Arctic Central Basin; BAF, Baffin Bay; BAR, Barents Sea; BEA, Beaufort Sea; BER, Bering Sea; CAN, Canadian Arctic Archipelago; CEG, Coastal East Greenland; CWG, Coastal West Greenland; CHU, Chukchi Sea; GRS, Greenland Sea; HUD, Hudson Bay Complex; KAR, Kara Sea; LAP, Laptev Sea; NOR, Norwegian Sea; SIB, East Siberian Sea; WHI, White Sea. Note that the same species may be harvested in more than one region. Inserted drawing and map: courtesy of FAO, SEAFDEC and F. Strand.

**Table 1** Marine fishes in the Arctic Ocean and adjacent seas (AOAS). 'TARGETED' denotes the number of species ('stocks') currently harvested by industrial fisheries in the AOAS, and their zoogeographic affiliation. 'BYCATCH' denotes the number of prospective Arctic bycatch species as industrial fisheries move poleward. 'IUCN' is the International Union for Conservation of Nature (<http://www.iucn.org>, accessed 10 July 2013). 'Other scientific bodies' embrace national and international marine fisheries services such as FAO and ICES. 'Biological knowledge' includes e.g. analyses on demographic structuring, abundance and trends

Category	TARGETED ( <i>n</i> = 59)			BYCATCH ( <i>n</i> = 60)
	Arctic	Arctic-boreal	Boreal	Arctic
Number of species	3	6	50	60
Evaluated by IUCN	1	0	7	4
Evaluated by other scientific bodies	3	6	50	0
Biological knowledge	Poor to moderate	Moderate	High	Negligible

### Sub-Arctic and Arctic fisheries

There is no clear-cut definition of what the Arctic is, and borderlines may be set by commercial, political or biological arguments (CAFF, in press). For example, sea ice serves as a dynamic and essential habitat for Arctic biota, and the maximum extent of sea ice (usually in March) forms a natural border between fishes of sub-Arctic/boreal and ice-laden Arctic waters. Following this definition, the Arctic marine border is far from static but varies in conjunction with season and ongoing climate change.

Here, we broadly define the Arctic Ocean and adjacent seas (AOAS) as the Arctic gateways and the Arctic seas (Fig. 1). The Arctic gateways are the seas that connect the Atlantic and Pacific Oceans with the Arctic Ocean and shelves along Arctic Eurasia, Siberia and North America. The Arctic gateways include the sub-Arctic/boreal Norwegian and Barents Seas in the Atlantic sector and the sub-Arctic/boreal Bering Sea and the Arctic Chukchi Sea in the Pacific sector.

Currently, 59 marine fish species ('stocks') *in toto* are targeted by industrial fisheries in the AOAS (Fig. 1; Table 1; CAFF, in press). These are all bony fishes (Actinopterygii) although sharks and allies (Chondrichthyes) constitute a worrying but largely unreported

bycatch (Lynghammar *et al.*, 2013). The largest fisheries, by far, are confined to sub-Arctic/boreal waters, i.e. the Bering Sea (*n* = 30 stocks) and the Atlantic Arctic gateway (*n* = 21–24 stocks). Significant fisheries also take place in Baffin Bay, along the west coast of Greenland and in the Greenland Sea (*n* = 9–13 stocks; Fig. 1).

The freezing Arctic seas, on the other hand, are characterized by small-scale subsistence fisheries among indigenous peoples (Fig. 1; Berkes, 1990). During the period 1950–2006, subsistence catches for a range of species, mostly freshwater and diadromous fishes, accumulated to about 950 000 tonnes (Zeller *et al.*, 2011). This is minuscule compared with, for example, annual landings of >1 million tonnes (mean for years 2000–2011) from a single stock of Atlantic herring (*Clupea harengus*) in the northeast Atlantic fisheries (WGWIIDE-ICES, 2013). Overall landings from industrial fisheries in northern seas are huge with for example 7.5 million tonnes in the northeast Atlantic (FAO area 27) and 15.8 million tonnes in the northwest Pacific (FAO area 61) in 2011 (FAO, 2013).

Marine fishes in the AOAS may be grouped into one of four zoogeographic categories determined mainly by their thermal habitat of reproduction (Table 1; Mecklenburg *et al.*, 2011; CAFF, in press). Arctic species are confined to ice-laden seas and spawn solely at sub-zero temperatures. They are only infrequently found in sub-Arctic seas. Arctic-boreal species are distributed in Arctic and sub-Arctic/boreal seas, and they may spawn either at subzero or positive temperatures. Boreal species are distributed in sub-Arctic/boreal seas and spawn solely at positive temperatures but they may enter subzero waters for feeding excursions as juveniles and adults. Finally, widely distributed species are common in boreal and subtropical waters and also in or below the warm waters of at least two oceans (or they are known from the southern hemisphere). They occur only rarely in the Arctic. Many deep-sea and highly migratory fishes belong to this group. Given these zoogeographic categories, targeted fishes in the AOAS include fifty boreal (~85%), six Arctic-boreal (~10%), e.g. capelin (*Mallotus villosus*), and only three Arctic (~5%) species (Table 1; CAFF, in press). Arctic species are harvested to a limited extent by Russia in the Barents, White and Kara Seas – i.e. the gadoids polar cod (*Boreogadus saida*) and navaga (*Eleginus nawaga*) and the Arctic flounder (*Liopsetta glacialis*) (Karamushko, 2012; Hop & Gjørseter, 2013).

The term 'Arctic' holds an aura of exotic, healthy and pristine qualities keenly used by tourism and seafood enterprises. Geographic borders are drawn opportunistically and include regions also outside the Arctic proper. For example, governance and management rhetoric claims a broad spatial view on 'Arctic fisheries'

by counting also sub-Arctic/boreal seas (Molenaar & Corell, 2009; AFWG-ICES, 2013). Although the term 'Arctic fisheries' displays >5 million Google hits (30 August 2013), this does not detract from the fact that, in context of zoogeography, present-day industrial fisheries in the AOAS are undoubtedly boreal – not Arctic (Table 1).

Ocean warming affects Arctic ecosystem dynamics in general and pelagic-benthic couplings in particular (Wassmann *et al.*, 2011). Fisheries exploitation patterns are also changing as harvested species move poleward into hitherto unfished parts of the Arctic seas (AFWG-ICES, 2013; Cheung *et al.*, 2013). Geographic distribution shifts to temperature differ among fish species (Perry *et al.*, 2005). Some species are deemed to have a strong potential for northward displacements such as the boreal beaked redfish (*Sebastes mentella*) and the Arctic-boreal Bering flounder (*Hippoglossoides robustus*) (Hollowed *et al.*, 2013; A.B. Hollowed, pers. comm.). The boreal Atlantic cod (*Gadus morhua*) has already become abundant north in the Barents Sea (latitude ~80° N), and industrial fisheries are beginning to harvest the Arctic shelves around Svalbard archipelago (AFWG-ICES, 2013; Johansen *et al.*, 2013).

Demersal or groundfish fisheries harvest near the seabed, whereas pelagic fisheries harvest the water column. Several technologies are employed in the AOAS fisheries, but bottom trawls for groundfishes and purse seine nets in the pelagic fisheries are undoubtedly amongst the most widely used gears. Bottom trawls are almost the sole gear used by Russia in the fisheries for groundfishes in the Barents Sea (Wienerroither *et al.*, 2011). The increasing dominance of harvestable groundfishes in Arctic waters followed by intensified bottom trawling will inevitably have direct and instant effects on the sea bed and nontargeted Arctic fishes as they turn up as unwarranted and unprecedented bycatch.

The term 'bycatch' is exclusively anthropocentric, and comprises species and/or sizes of no immediate commercial value (Hall, 1996). But fish bycatch embraces also those species that are indispensable to structuring and functioning of marine ecosystems. For example, Arctic bycatch fishes play a fundamental role in the transfer of bioenergy from lower trophic levels to seabirds and marine mammals – i.e. wildlife that forms the livelihood of indigenous peoples.

### Fragmentary knowledge

Presently, 633 marine fish species are scientifically described in the AOAS (CAFF, in press). About 10% (63 species) are considered Arctic (Table 1) whereas the remaining 570 species belong to the other zoogeographic categories.

Among the AOAS fishes, only eight targeted (13.6%) and five Arctic species (7.9%) are evaluated according to the Red List criteria of the International Union for Conservation of Nature, IUCN (Table 1). These Arctic species are all assigned the 'Least Concern' (LC) category employed by the IUCN: Arctic skate (*Amblyraja hyperborea*), fourhorn sculpin (*Myoxocephalus quadricornis*), shulupaoluk (*Lycodes jugoricus*), Paamiut eelpout (*Lycodes paamiuti*) and the targeted Arctic flounder. A LC-classification may seem reassuring, but here it actually reflects that Arctic nontargeted species are thought safeguarded because they are outside the current range of industrial fisheries – a situation that is about to change drastically as large-scale exploitation moves northward and into deeper waters (Lynghammar *et al.*, 2013).

In fact, there is a vast disparity in biological knowledge for targeted and Arctic marine fishes, respectively (Table 1). Although sparsely assessed by the IUCN, targeted species are all closely surveyed and monitored by national and international scientific fisheries services such as the Institute of Marine Research (IMR, <http://www.imr.no>) in Norway, Knipovich Polar Research Institute of Marine Fisheries and Oceanography (PINRO, <http://www.pinro.ru>) in Russia, National Oceanic and Atmospheric Administration (NOAA, <http://www.noaa.gov>) in the USA, the International Council for the Exploration of the Sea (ICES, <http://www.ices.dk>) and the Food and Agriculture Organization of the United Nations (FAO, <http://www.fao.org>). This is in stark contrast with Arctic marine fish species, which are beyond assessment due to lack of biological data. Being an Arctic keystone species, the targeted polar cod makes a notable exception as it has received increasing scientific attention in recent years (Hop & Gjørseter, 2013).

It is worrying to realize that vital biological issues are hardly addressed for the sixty prospective bycatch species native to Arctic waters (Table 1). We argue that Arctic marine fishes suffer from three shortfalls as outlined by Mokany & Ferrier (2011). A 'Linnaean shortfall' is revealed by the unsettled and controversial taxonomy, especially for putative species-rich families such as sculpins (Cottidae and Psychrolutidae), snailfishes (Liparidae) and eelpouts (Zoarcidae) (Mecklenburg *et al.*, 2011; CAFF, in press). Intraspecific phenotypic variation is pronounced, and barcoding has shown that supposedly valid species are actually one and the same species (Rees & Byrkjedal, 2013). On the other hand, morphological and genetic studies have revealed several cryptic species in the AOAS. For instance, spotted spiny dogfish (*Squalus suckleyi*) in the Bering Sea was recently resurrected as a species of its own different from its Atlantic and South Pacific sister



species picked dogfish (*S. acanthias*) (Ebert *et al.*, 2010), and nebulous snailfish (*Liparis bathyartcticus*) was resurrected from synonymy with the partly sympatric variegated snailfish (*L. gibbus*) (Chernova, 2008; Mecklenburg *et al.*, 2011). Species new to science are also likely to be discovered in poorly studied Arctic seas (Mecklenburg *et al.*, 2011).

A 'Wallacean shortfall' is revealed by the fact that Arctic shelves and deep-sea are notoriously undersampled, knowledge of temporal and spatial distribution is poor and the conspicuous lack of time-series preclude trend analyses for Arctic marine fish communities. Correlations between past and opportunistic snapshots of species occurrences and ongoing climate change are obviously fallacious. Finally, a 'Hutchinsonian shortfall' is revealed by lack of quantitative data on demographic structuring (e.g. von Bertalanffy's growth functions), body size spectra, longevity and life history traits.

Arctic and Antarctic fishes have evolved a suite of exceptional life-supporting adaptations to tackle subzero temperatures close to the freezing point of seawater ( $-2^{\circ}\text{C}$ ). Freeze avoidance by means of antifreeze proteins and glycoproteins in body fluids (DeVries & Cheng, 2005), and build-up of energy-rich lipid stores to mitigate seasonal food shortage (Meyer Ottesen *et al.*, 2011) are well-documented cases. A putative disadvantage of specialized physiologies to frigid waters, however, is loss of genetic variability at adaptive loci (Patarnello *et al.*, 2011) and a truncated flexibility to meet novel stressors, such as climate change and pollutants. Indeed, physiological responses to heat and a warming ocean are critical but understudied issues among polar fishes (Christiansen *et al.*, 1997; Bilyk *et al.*, 2012).

Besides industrial fisheries, petroleum exploitation by member states of the Arctic Council raises serious and timely concerns. For example, the Government of Greenland has recently approved hydrocarbon licensing in ice-laden waters off the world's largest national park in northeast Greenland (<http://www.bmp.gl/petroleum>). Together with the fjords and shelves in northeast Greenland, the east Greenland drift ice (GL 'Sikorsuit') forms a unique marine habitat under climate change that is scarcely studied (Christiansen, 2012; McKinney *et al.*, 2013).

Simplistically, the quest for petroleum and other hydrocarbons comprises two successive phases: search and extract. The latter phase is associated with biological consequences of leakages into the environment, hardly known for Arctic waters, and polar cod has become a sentinel species in studies of Arctic marine pollutants and their toxicity (Nahrgang, 2010).

The search phase involving seismic surveys evokes particular and warranted alarm, and recent studies

suggest that underwater noises disrupt communication and migration patterns among Arctic whales (Heide-Jørgensen *et al.*, 2013). The booming seismic activity in subzero seas has unknown consequences for Arctic fishes: the exposure to human-generated noises such as seismic air-guns causes species-specific physiological responses ranging from negligible to massive damages to the octavolateralis system, a vital organ in fish communication (Larsson, 2009; Popper & Hastings, 2009). This clearly calls for caution against uncritical generalizations across fish species and marine eco-zones.

Once patterns of marine biodiversity surface, it is essential to identify the underlying processes to counteract negative trends for conservation (CAFF, in press). Conservation of Arctic marine fishes is clearly in its exploratory phase. We argue that baseline time-series and diagnostic data on functional biodiversity represent the most severe shortfall for credible conservation actions and a legitimate management of Arctic marine fisheries *sensu stricto*, although recent developments in statistics and modelling attempt to bridge empirical gaps in data deficient fisheries (Astles *et al.*, 2009).

### Possible conservation actions

Fisheries sciences and conservation biology must be based on strict scientific rigour to secure credibility but it is also compulsory that they contribute to policymaking and societal legitimacy (Rice, 2011). Arctic societies are founded on living natural resources and their socio-economic progress is inevitably rooted in sound ecosystems. Conflicts between Arctic societies and large-scale human activity are emerging, and Arctic marine fishes of unknown biology and resilience are laid bare for unprecedented industrial fisheries. How, then, are sustainable Arctic fisheries achieved? Although far from exhaustive, we propose four principal avenues that might be explored in concert, to raise our present knowledge to a level where credible hypotheses can be advanced and tested and legitimate conservation actions effected in relation with large-scale Arctic fisheries.

First, biological credibility: scientific uncertainty is a hallmark in Arctic marine biodiversity assessments and underlines the necessity of precautionary approaches. Taxonomic inventories are not mere 'stamp collections': identification of valid species and demarcation of populations are at the heart of biodiversity and conservation biology and to our understanding of how ecosystems work (Zachos, 2013).

Morphological traits and phenotypic plasticity among Arctic fishes are inextricably linked to functional biodiversity, and classic taxonomy – a critically endangered scientific discipline and craftsmanship – cannot be substituted by DNA profiles and gigabytes

(Scotland & Wood, 2012). The combination of classic taxonomy (the phenotype) and a molecular approach (the underlying genotype) will provide not only information but also knowledge about phylogeography and functional biodiversity of Arctic marine fishes (Naish & Hard, 2008). Hence, training programs in taxonomy *sensu lato* and biogeography for young researchers should be encouraged. Natural history collections (NHC) hold essential information for studies of biodiversity and conservation (Drew, 2011), and information from fisheries logbooks has proven valuable in historical analysis of population trends (Alexander *et al.*, 2009). NHCs should be continuously upgraded and archival data critically examined and employed to reconstruct and build long-term time series for the Arctic seas.

Second, 'green technology': technological innovations are essential for the Arctic fishing fleet. Green ship technology on ballast water, emission of greenhouse gasses and noise is duly addressed by international forums such as the International Maritime Organization of the United Nations (<http://www.imo.org>). By contrast, fishing gear technology designed for sustainable fisheries in Arctic waters is barely explored.

Bottom trawling is the aquatic analogue to ploughing of farmland (Puig *et al.*, 2012) but in the case of the former activity there is no subsequent sowing. Multidecadal datasets from the North Sea bottom trawl fisheries are unequivocal. Conventional bottom trawl fisheries for groundfishes are highly destructive as they reshape bottom morphology and impoverish, perturb and change the functional composition of benthic communities (Thurstan *et al.*, 2010; Puig *et al.*, 2012). Importantly, most Arctic marine fishes are bottom-dwelling and territorial (Karamushko, 2012) and because Arctic groundfish fisheries are expected to increase in coming years, this particular fish fauna will be acutely at risk to conventional fishing practices and habitat destruction.

Paradoxically, for the sake of gathering vital biological data, scientific activities *per se* may pose a threat to biodiversity and undermine conservation aims. For example, intense scientific bottom trawl surveys are conducted regularly on the Arctic shelves around Svalbard archipelago (IMR, <http://www.imr.no>), and complementary and noninvasive methods to detect Arctic biodiversity such as analysis of environmental DNA should be considered (Thomsen *et al.*, 2012).

Third, legitimate management: politics, big business and fisheries sciences are tightly entwined. Member states of the Arctic Council set their own rules for exploitation of marine fisheries resources within their respective Exclusive Economic Zone (EEZ) and, consequently, management regimes differ vastly among

national EEZs. Some AOAS areas are subjected to strict management regimes such as the heavily fished Barents and Bering Seas, whereas yet unexploited parts of the Arctic shelves are not actively managed. The international waters of the Arctic Central Basin, on the other hand, are not regulated at all (Fig. 1; PEG, 2012).

Should the wanted fisheries moratorium in understudied Arctic waters be adjourned, other precautionary approaches must be considered in wait of credible scientific advice. Bans on industrial fisheries into the Chukchi and Beaufort Seas are currently in place in the USA (<http://alaskafisheries.noaa.gov>), and the ecological significance of marine protected areas is much debated also for the Arctic region (Barry & Price, 2012).

Abrupt shifts in biodiversity and species abundance are warning signals for conservation (Howarth *et al.*, 2013), and accurate bycatch statistics in large-scale Arctic fisheries are crucial and call for adaptive monitoring plans and policies to meet conservation aims (Lindenmayer *et al.*, 2011). A range of management policies for marine fisheries are in operation worldwide (Pitcher & Cheung, 2013), and fisheries founded on balanced rather than selective harvesting are currently debated (Garcia *et al.*, 2012). Balanced fisheries harvest proportionally across targeted and nontargeted species alike and appear theoretically compelling, although impractical given the lack of basic quantitative data for Arctic bycatch species (Table 1). No single harvesting practice is foolproof, but any management policy would be weighty if it relies on the principle of full accountability – that is a procedural change from the present-day selective fishing and fixed landing quotas of targeted species to capture quotas, *sensu* Hall (1996), which embrace the entire biomass extracted from the sea, i.e. targeted and nontargeted species joined. For example, Catch Quota Management seems a promising policy that is tentatively implemented in the North Sea fisheries by some member states of the European Union (Kindt-Larsen *et al.*, 2011). Noteworthy, ICES advice on fish stocks for 2014 will be based on capture rather than landing statistics (ICES, 2013). Combined with taxonomic expertise on Arctic marine fishes (cf. the first point), management practices enforcing capture quotas may well be the immediate and first step towards obtaining credible and urgently needed bycatch statistics as a precautionary measure for upcoming Arctic fisheries *sensu stricto*.

To sum up the repercussions of large-scale Arctic fisheries, one should bear in mind the divergent agendas of management practitioners serving governmental institutions and conservation biologists affiliated with 'independent' universities (Redpath *et al.*, 2013). Fisheries scientists account fishes mainly as a commodity (i.e. targeted species only), while taxonomists and ecologists

are concerned with the entire scale of biodiversity and wildlife. It is also essential to acknowledge that the Arctic is neither 'remote' nor a 'frontier' but the very centre of livelihood for indigenous peoples and, in light of the poleward displacement of commercial fish stocks, conflicts between subsistence and industrial fisheries are conceivable.

The Inuit Circumpolar Council (<http://www.inuit.org>) and Arctic indigenous peoples demand due respect for their perception and utilization of natural resources, and the call for joining traditional knowledge and science has become increasingly actualized (Huntington, 2011). Traditional Ecological Knowledge (TEK) is not science *per se* as it lacks the analytic tools embedded in science, but TEK would generate valuable and complementary information as it often detects local changes in climate and wildlife much faster than do science. Furthermore, TEK integrates knowledge of species, ecosystems, weather and climate across and beyond scientific disciplines (Chapman, 2007; Saslis-Lagoudakis & Clarke, 2013). Examples of TEK-derived information of vital scientific value include seasonal timing of biological events (phenology), changes in habitats and species distributions and identification of sites for biodiversity monitoring and protection cf. Circumpolar Biodiversity Monitoring Program (<http://www.caff.is/monitoring>). Rather than being regarded merely as decorum, TEK should be scrutinized in its own right and critically considered by science to strengthen the legitimacy of Arctic marine biodiversity assessments. This would require a novel and designated setting of TEK-informants and scientists to ensure that trust-building and respectful and equal sharing of information and methods are also put into practice.

Fourth, overarching coordination: an ambitious interdisciplinary science plan across social and natural sciences, and involving Arctic residents, should be outlined and implemented as a precautionary and fundamental measure to meet large-scale human intervention in understudied Arctic waters (cf. PEG, 2012). Issues on Arctic marine biodiversity and conservation are addressed by a plethora of intergovernmental forums and nongovernmental organizations (NGOs) such as the Arctic Council, Census of Marine Life (CoML), ICES, IUCN, Ramsar Convention on Wetlands (RAMSAR) and World Wildlife Fund (WWF). Unfortunately, the assessment work is done often in parallel and seems frustratingly disorganized for the scientists involved. Academic institutions, in charge of training prospective scientists, are also little consulted, and an equal participation of applied and basic science from management and universities alike would benefit both parties and the assessment work as a whole.

Therefore, a much stronger coordination among (and within) these bodies is called for to harmonise assessments and mitigate the move from general principles to operational conservation actions, cf. the committing slogan of IPY-Montréal 2012 'From Knowledge to Action'. The time for action is now. The responsibility and the appropriate forum for an overarching coordination of scientific efforts in Arctic waters would be the Arctic Council and its member states.

## Acknowledgements

We are indebted to Hans Meltote, chief scientist of the Arctic Biodiversity Assessment report (<http://www.arcticbiodiversity.is>) and Tom Barry and Courtney Price at the CAFF-International Secretariat (<http://www.caff.is/secretariat>). We thank Ingvar Byrkjedal (University Museum of Bergen), Erik Gant (IPS Secretariat, <http://www.arcticpeoples.org/home>), Malcolm Jobling and Arve Lynghammar (UiT – The Arctic University of Norway), Tero Mustonen (Snowchange Cooperative, <http://www.snowchange.org>), Peter D. R. Møller (University of Copenhagen) and Mogens Schou (Aquamind, <http://www.aquamind.dk>) for valuable references and discussions. Three anonymous reviewers gave constructive comments. This is a contribution to the TUNU-Programme at UiT – The Arctic University of Norway.

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