Towards Arctic Resource Governance of Marine Invasive Species

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Scientific and policy-oriented publications highlighting the magnitude of uncertainty in the changing Arctic and the possibilities for effective regional governance are proliferating, yet it remains a challenging task to examine Arctic marine biodiversity. Limited scientific data are currently available. Through analysis of marine invasions in the Arctic, we work to identify and assess patterns in the knowledge gaps regarding invasive species in the Arctic that affect the ability to generate improved governance outcomes. These patterns are expected to depend on multiple aspects of scientific research into invasive species threats in the Arctic, including the ways in which known marine invasions are related to different stakeholder groups and existing disparate national and international experiences with invasive species. Stakeholder groups include dominant industries (fishing, shipping, tourism, resource exploration) and indigenous communities (regarded as resource users, citizen scientists, and recipients of goods shipped from other locations). Governance gaps are examined in the context of applied national policies (such as promoting or intercepting intentional introductions), international agreements (regarding introductions and mitigations) and existing prevention programs (regional, national and international). We intend to help focus domestic and international governance and research initiatives regarding introduced species on the most valuable, cost effective options, given the knowledge gaps derived from systematic research limitations and opportunities in the Arctic environment.

Introduction

Decades of rigorous scientific research on the Arctic marine environment have provided useful insights on its rapidly changing and dynamic nature. Marine invasions present a significant harbinger of ecosystem boundary shifts, and with the Arctic's increasingly weaker barriers a growing number of new species are expected to arrive soon on their own. The propensity to highly value anticipated benefits from increased human activities in the Arctic amplifies the risks of new species introductions. Additionally, the changing climate increases significantly the chances of new introductions eventually succeeding as invasions. While seasonal light conditions will not evolve with changing temperature and

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ice-cover, the photic zone is expected to experience complex shifts as ice and algal conditions evolve (David, Lange, Rabe, & Flores 2015; Tremblay & Gagnon 2009). Experience to date, including both intentional and accidental introductions that have established and spread in the Barents Sea, suggests that species which are not directly affected by seasonal darkness, such as benthic habitat dwellers, are perhaps most likely to be initially advantaged by the new ecological opportunities. Thus we focus this discussion with examples of existing and potential benthic crustacean species in order to clearly highlight the ecological and economic interactions that foster marine invasive species threats.

Existing research includes a significant degree of uncertainty that we argue incorporates systematic biases introduced by variations in the cost of accessing information in the research. As one important example, the harsh climatic conditions in the Arctic have so far allowed almost exclusively seasonal (summer) sampling and measurements, which emphasizes that our current knowledge of the Arctic marine environment is fraught with uncertainties that must be incorporated into decision-making. The resulting lack of a robust scientific baseline and incomplete knowledge of the Arctic marine world further complicate the scientific framework for data collection/sampling where emphasis has been put on certain high-visibility species (e.g charismatic megafauna or resources considered under pressure influencing commercial and subsistence fisheries) at the expense of others (e.g microfauna, diseases or parasites). These latter biases are not unique to the Arctic (Clark & May 2002; Duarte, Dennison, Orth & Carruthers 2008; Leather 2013; Tisdell & Nantha 2007) but further emphasize the biases derived from the allocation of limited resources available for research that may favor direct human resource use over more complex ecosystem relationships.

Awareness of these biases should motivate both scientists and policy makers to engage themselves in an effort to better characterize the essential parameters governing Arctic marine ecosystem productivity. Until the point however when it becomes possible for the scientific community to devise some way to answer the numerous pending questions and thus adequately justify the research protocols to be applied, it is recommended to develop an umbrella strategy in order to avoid putting the ecosystem into peril. Building a consistent, credible and solid basis able to defend and protect the ecosystem from undesired introductions and ripple effects counsels adherence to approaches that appropriately incorporate both risk, where probability distributions over potential expected events can be defined, and uncertainty, where likelihoods of future events, or even the existence of future events, remain unknowable. Some definitions of the "Precautionary Principle", such as the one provided by Gollier, Jullien & Treich (2000), where scientific uncertainty with regard to the distribution of the likelihood of realizing a future risk provides society with incentives for stronger prevention measures to shift this distribution and the expected damages, fit this bill. It is therefore advisable for research investments themselves to follow closely a set of premises within such a precautionary-protection-prevention context since it is expected to confer a number of advantages, regardless of any additional policy challenges.

Brief exposition of the challenges of marine invasive species in the Arctic

Overview of the problem

Biological invasions in marine habitats have been historically growing with trade and increased global transport for centuries, with the literature on an international level pointing out various different bio-economic patterns (Costello, Springborn, McAusland & Solow 2007; Ruiz, Fofonoff, Carlton, Wonham & Hines 2000). Presently, such impacts are coming to the Arctic in concert with climatic changes. Northern ecosystems can, in general, be characterized as "native" sink host destinations for invaders since the continuous climatic warming shift ecosystems away from the equator and towards the poles, with Arctic waters presenting the northernmost marine ecosystem that northward-moving species can reach. Meanwhile, climate change, together with a series of other parameters, has contributed to significant transformation of the Arctic environment, so that distinction between a "New," more open and integrated Arctic system, and an "Old," ice-defended and more ecologically pristine Arctic, is being increasingly adopted.

The transition has the potential for significant negative environmental and ecological side effects, not least of which are introductions of invasive species with noticeable and potentially irreversible impacts. The Old Arctic's colder temperatures have generally fended off negative impacts on ecosystem services of such introductions, including reductions in productive ecological capacity due to pathogens, parasites, microbes or other disease carriers. The ecological and economic characteristics of the New Arctic, and its success in sustaining human and natural habitats, will depend on the ability to adapt basic tenets of precaution in multiple dimensions. These tenets include costly activities such as (potentially incomplete) inspections of traded goods and vessels or quarantines for pathogens in disease prevention. According to the Precautionary Principle as defined in the Rio Declaration in Principle 15 (UNEP 1992), in cases of threats for serious or irreversible damage, cost-effective measures for preventing environmental degradation shall not be postponed in view of lack of full scientific certainty, urging states to apply the precautionary approach "according to their capability." This expression has been widely criticized in the literature as rather weak, incomplete, and ambiguous from both an environmental and a legal perspective. The ITLOS Seabed Dispute Chamber released an advisory opinion according to which the Precautionary Principle in Rio's Declaration was not regarded as binding, but since it was already "incorporated into a growing number of international treaties and other instruments," a "trend towards making this approach part of customary international law" evolved (ITLOS 2011).

Interdependencies between countries in the dynamically changing Arctic environment hold a prominent position in determining the future of marine invasions and thus cannot be overlooked. They add significant complexity to the situation, attributable to the multiple confounders they bring along. Certain Arctic marine invasions clearly display the interplay of ecology and economic behavior. Invasive crustacean species, for example, have pitted potential economic gains against other predominantly negative though uncertain ecological impacts/changes. The Red King Crab (RKC) *Paralithodes camtschaticus* is probably the most well-known example of a deliberately introduced species leading to invasion. Originally introduced in the Barents Sea by Soviet Union scientists in the 1960s (Orlov & Ivanov 1978) with the intent to create a profitable new resource for fisheries, it was only identified years afterwards as a potential threat for benthic diversity and biomass and thus for habitats and nutrient cycling in the Arctic marine environment (Falk-Petersen, Renaud & Anisimova 2011). In a conceptual framework and always within the geopolitical context, one of the reasons why joint management of resources is considered of utmost significance when it comes to invasions is the fact that the exclusion and control of those invasive species can be considered as a "weakest-link" or "weaker-link" public good. In view thereof it is in fact the least effective provider (Burnett 2006; Perrings et al. 2002) that actually determines whether the ecosystem's overall balance and well-being will not go out of kilter. In other words, the introduction, establishment and magnitude of spread of a new species hinges on those (countries) that exert the least effort to prevent and/or control purposeful or accidental invasions, noting decisions about prevention might differ decidedly between deliberately introduced and accidentally introduced invasive species. Effective control of biological invasions in the multi-state Arctic is a weakest-link public good and a driving force for coordinated proactive action.

Climate change has also aided species movements that take on characteristics of invasions. The North East Atlantic mackerel have been moving westward and northward with shifts in oceanic temperatures and related properties, and this has sparked disputes between Iceland and the Faroe Islands on the one hand and Norway and the EU on the other hand. While information on the stock of the mackerel and the ability to estimate the overall quota to maintain a healthy fishery is well understood and widely distributed through the International Council for the Exploration of the Sea (ICES 2013, 2014, 2015), the negotiations for joint quotas covering how the catch should be distributed have been very problematic so far. This is particularly true regarding the newly viable coastal fisheries developing around Iceland where there has been a tremendous increase in stocks in recent years (Ellefsen 2013; Ørebech 2013). The species distribution has changed significantly since the mid-2000s, having spread quite a lot into East Greenlandic and Faroese waters as well, while overall stock size has also increased (Dankel et al. 2015). Those changes in population dynamics have apparently hindered agreements between mackerel fishing countries on the Total Allowable Catch, but both the competitive role of mackerel within the food-web (preying on other species) and the overwhelming dependence on those fisheries urgently call for an effective and optimal management scheme (Ørebech 2013).

Human assisted invasive species introductions

Directly, the role of industrial development in increasing the probability of successful invasions must be addressed. The burden of costs and the sharing of benefits of such measures are not evenly distributed, and will depend on the policy choices made (including lack of policy or implementation). These policies, for example, might include assignment of liability to sources of invasive species, such as shipping, tourist or fishing vessels that transverse a variety of sensitive ecosystems with their gear, or resource extractors who develop infrastructure that creates substrate and creates increased traffic flows to new marine locations places, in order to affect the incentives on industry and development to prevent damages. As an example, New Zealand's 1993 Biosecurity Act, Section 154 includes liability for importers/exporters to address marine invasive species (Fernandez 2011). Alternatively, the absence of such liability places the burden on affected communities to deal with invasions in other ways – often ex post when they are significantly more costly (Olson 2006; Thomas & Randall 2000).

On a theoretical level, assigning liabilities for environmental damages, especially in cases where information is scarce and expensive, such as species introductions, should provide powerful incentives for investing in protection measures and preventive action. In reality there are practical challenges that include identification of the specific sources, and counter-incentives to hide behavior to avoid detection (Bernstein 1993). There are high transactions costs to determine causality and loss with legal processing (Fernandez 2008). Tort liabilities can be very tough to allocate when multiple tortfeasors are involved, which is not uncommon in cases of marine invasions. Thus far, the only internationally ratified policy entered into force, with 71 sovereign states and 84% of the gross tonnage of merchant shipping included, is the Antifouling Convention of 2001 that bans antifouling substances containing organotins and biocides with tributyltin from use. Violation of the ban involves penalties for those liable. The organotin and tributyltin substances had been commonly used to ward off sessile marine invasive species on hulls of ships (commercial, recreational) as well as prevent extra weight and fuel use from the biofouling marine invasive species create (Fernandez 2008). That convention did not advocate alternative antifouling substances. Segerson (1990) suggests combining liability with an ex ante policy, such as paying in to an insurance fund that could cover prevention and/or remediation activities, since liability is ex post.

Another pathway for marine invasive species via maritime shipping, ballast water, has legally enforceable regulations developed by different states all over the world. However IMO's (International Maritime Organization) BWM Convention (International Convention for the Control and Management of Ships' Ballast Water and Sediments), cannot yet enter into force as an international treaty (Miller 2014). Thus the limited feasibility of liability rules among states for compensating after environmental damages occur, coupled with the predicaments existing in international agreements for prevention, generate a perplexing situation.

Legal precedents where liabilities have been imposed for invasive species exist, but are limited to some disputes regarding insects, weeds and cattle that had escaped from properties. This can potentially provide the necessary analogies for applying tort laws (Courtney 2006). Quarantines in e.g. Australia, New Zealand and Hawaii require ex-ante action in that deliberately introduced species must go through quarantines and trials funded by those intending to make the introductions in order to demonstrate that there should be no unexpected and costly invasions. Those introducing the species generally remain liable after the introduction as well (USDA 2015 - State Laws and Regulations, Hawaii). Another legal example is provided by Colorado Division of Wildlife v. Cox, (1992), which determined that exotic-free ecosystems and biodiversity are to be regarded as public rights encompassed by public nuisance law, with the Colorado statute referring to defendants as "liable" (Larsen 1995). Marine invasions are indisputably more difficult to handle, and none of these directly account for the potential of unintentional introductions, but as Larsen (1995) notes, public nuisance liability is expected to alter the behavior of shipping actors while also effectively contribute to prohibiting high-risk activities.

As mentioned, the RKC was intentionally introduced in the Barents Sea by Soviet scientists in order to create a new lucrative fishery. The introduction proved successful and thus profitable for Russia, but the species unexpectedly spread west. The need for cooperative international management became apparent as the crab moved into Norwegian waters in the 1970s, and other species were being simultaneously jointly managed under the newly established Joint Russian-Norwegian Fisheries Commission (1974). RKC cooperation initially consisted of Norwegian agreement not to harvest the crabs, which were appearing there in small numbers. By the 1990s, however, economic damages and larger populations west of the Norwegian-Russian border caused renegotiation so that Norway began to harvest crabs, in compensation for damages to cod and capelin gear from crab bycatch. When broader potential ecological impacts became more widely recognized and eventually accepted by both the scientific community and the policy makers in Norway, a spatially differentiated internal Norwegian management plan was initiated to accommodate both the economic interests of fishermen and the ecological interests of a broader community (Sundet 2014b).

The most identifiable effects of the species are believed to be on the Arctic benthic habitat, despite the lack of adequate knowledge regarding its contribution to ecosystem services (Kaiser et al. 2015). With the Norwegians treating the species as invasive west of 26^{o} E and at the same trying to maintain a long term fishery on the eastern part, and the Russians managing it only as long-term fishery, international interests seem to be at odds and Norway's internal goals conflicting (Kaiser et al. 2015). Despite the spatially split management regime that was developed for maintaining a long term quota regulated within a restricted area and thus afterwards limiting its spread beyond the area in which it is currently established, tracing with accuracy its distribution (at least in Norwegian waters) has been riddled with difficulties (Sundet 2014b). This is in large part an outcome of research funding biases that favor direct economic interests over indirect ones; systematic surveying west of the 26^{o} E line does not occur, since the fishery is not regulated. Its spread in Norwegian waters has been westwards near coasts but has been at the same time characterized as "discontinuous" due to small populations identified by sporadic reports of spatially distinct individual catches in inner parts of more southwesterly fjords (Sundet 2014b, see Fig.1). The current prevalent assumptions indicate a continuous westward spread (Kaiser et al., 2015) and more particularly around Tromsø about 12–15 nm off shore (Sundet 2014b, see Fig. 1).

The Snow Crab (SC) *Chionoecetes opilio*, a more recent crustacean invasion in the Barents Sea, was first identified in its eastern part in 1996 by Russian fishermen (Kuzmin, Akhtarin & Menis 1998). Its origin of introduction is still being disputed, and genetic analyses trying to identify it are still under way. Its native distribution area is along the Bering Sea and the northwestern Atlantic, including the eastern coast of Canada and the western coast of Greenland (Sundet 2014b). Its introduction was initially assumed by Kuzmin et al. (1998) to have been unintentional (either though larval drift or ballast water) taking into consideration its limited migrating capabilities since it had neither managed to independently reach the seas of the Northern European Basin nor to migrate from the western to the eastern coast of Greenland and then to Icelandic waters. The spread of the species is indisputably progressing at an alarming rate (Bakanev 2014; Sundet 2014a). The crab's tolerance for cold temperatures suggests a highly likely potential expansion further north towards the more pristine areas of the "High Arctic", beyond the current and expected range of the RKC invasion. The current evidence indicates a rather successful establishment of the species in the Barents Sea, with data such as site identification (depths) and body structure characteristics (size) pinpointing nursery areas proving its successful recruitment (Agnalt, A.-L. & Jørstad 2010).

There are both serious questions about the impacts of both species on the one hand (since they have not yet been fully identified) and growing interest from the fishery industry that sees favorable market conditions on the other hand. Fears that these economic hopes will overshadow or bias measurement of ecological consequences of the invasions and their spread are well founded – the RKC fishery in the Barents is particularly lucrative at the moment, while for SC there is also a growing interest from the seafood and fishery industries (Grimsmo 2015; Olsen 2015; Ripman 2015). With SC estimated to produce between 25,000-75,000 tons per year within the next ten years (Hvingel & Sundet 2014), this attractive economic gain may hasten activities that should be delayed for improved information regarding the potential damages to the benthic habitat. The economic gains may even promote decisions that delay the research in order to avoid knowing the true ecosystem costs, creating additional bias in the types of scientific research undertaken.

Climate change induced invasions

Indirectly, climate change impacts, considered the main underlying cause of northward habitat migration, must also be addressed in efforts to maintain existing Arctic ecosystem function at risk from invasions. Habitat migration is fraught with uncertainties while often uncontrollable at local or even regional scales, which is an indicative example of why the benefits of the colder "Old Arctic" cannot be easily replaced. This initiates discussions on examining related costs within different contexts (economic behavior, climate change mitigation costs, etc.) in terms of endeavors to more appropriately distribute them amongst global inducers of climate change and/or among the above mentioned "development players," rather than, through inaction, pushing the costs on to ecosystems and those who rely on their current services.

Climatic changes have significant ramifications in Arctic marine ecosystems while the realm of impact categories differs across the scale of analysis and evaluation approaches. When it comes to marine invasions, two major types of introductions are being identified: the ones that pertain to species already ecosystem adapted (Arctic or sub-Arctic species) and the ones that pertain to species that have managed to adapt to Arctic climatic conditions and/or are able to survive in the ecosystem thanks to the increasing temperature of the water (usually northward moving species).

Transarctic invasions are not a new phenomenon. Historical experience underlines such invasions about 3.5 million years ago, during the warm mid-Pliocene epoch when hundreds of marine lineages managed to colonize out through the Bering Strait, resulting in enriched Arctic and North Atlantic biotas (Vermeij & Roopnarine 2008). According to Reid, Edwards & Johns (2008) there is mounting evidence that interoceanic exchange is already re-occurring, with the presence of a Pacific planktonic diatom (*Neodenticula seminae*) in the Labrador and Irminger Seas that is generally found in the North Pacific and the Bering Sea. Reid, Edwards & Johns (2008) thus consider the return of the species in the North Atlantic as a sign of trans-Arctic migration, potentially leading to invasions of large scale similar to the ones that took place in the Pliocene trans-Arctic interchange.

Indicatively, as the literature points out (Vermeij & Roopnarine 2008), 56 molluscan lineages that are currently present in the Bering and Chukchi seas, as well as the Pribilof Islands and Anadyrski Gulf, and that did not participate in the aforementioned trans-Arctic expansion are considered potential invaders. The SC may indeed be one such current example. Current theory suggests that the species has moved to the Barents Sea through natural dispersal routes from the Pacific Arctic (Sokolov 2015), while it certainly did not come from Greenland (Agnalt 2015).

Northward migration, on the other hand, seems to explain the introduction of the Hanasaki King (spiny) Crab (*Paralithodes brevipes*), first witnessed in Norton Sound, AK in 2003, and growing to a population large enough that the state of Alaska allowed commercial fishing for the crabs in 2014 (Campbell & Regnart 2014; Webb 2015). The state is concerned about effects of this less marketable crab on the other Alaska King Crab harvests (Webb 2015). Its formal inclusion in the fishery allows for greater oversight, yet could exacerbate the ecological and economic consequences if private capture of market benefits increases incentives to accommodate the species' introduction into the ecosystem rather than extinguish its presence.

Institutions and policies towards invasion threats in Arctic Coastal states

Besides regional and national policies on reducing risks of marine invasions, the first coordinated effort on an international level originates from IMO's BWM Convention which was adopted in 2004 (Miller 2014). It is worth mentioning that despite not having entered into force, awaiting ratification from more than 30 maritime countries constituting 35% of the global shipping merchant tonnage, there are already 44 contracting states the combined merchant fleets of which constitute approximately 32.86% of the gross tonnage of the world's merchant fleet (IMO 2015), which practically means that it might actually be ratified shortly. As for the Arctic region, not all eight member states of the Arctic Council have ratified the IMO BWM Convention (the U.S and Iceland have not, Finland has signed though not ratified), which might look discouraging at first for a consistently organized fight against invasions in the pristine Arctic marine environment, but in practice at least, the federal regulations in the U.S. require mandatory ballast water reporting and ballast water treatment verification through the U.S. Federal Clean Water Act. There seems to exist among the Arctic states a common acknowledgment of the risk for marine invasions as well as of basic principles of ballast water management that help minimize risks (Miller 2014). Unfortunately, those risks arising from invasions are not stressed in the Polar Code; rather it pertains mostly to separate sovereign Arctic countries over search, rescue and operation safety (Fernandez 2014). The Polar Code applies to ships active in the Arctic and Antarctic, and is expected to enter into force within the next 2 years. The first draft, released in January 2014, has so far received a great deal of criticism for leaving out significant environmental threats arising from maritime activities, including marine invasions from ballast water discharge, hull fouling and development of maritime structures (Miller 2014). Recently, (68th session 11-15 May 2015), MEPC (IMO's Marine Environment Protection Committee) adopted the environmental requirements of the Polar Code through existing MARPOL (International Convention for the Prevention of Pollution from Ships) amendments, aside from the safety and rescue requirements of SOLAS (International Convention for the Safety of Life at Sea). The Polar Code still lacks any component regarding maritime requirements regarding the threat of marine species invasions. With sea ice becoming less reliable as a permanent natural barrier, the impacts of activities in the Arctic, including fishing, shipping, tourism, resource extraction, etc., rank very highly in importance both with respect to the economic future of the Arctic, and the threat of marine invasive species, particularly for Arctic Coastal states. Already highlighted in the report by CAFF (2013), both Canada and U.S. seem to be aware of how costly invasions can prove out, with billions of dollars in expected annual damages from invasive species. Fernandez (2007, 2008, 2011, 2014) includes these countries in analyses of the effectiveness of policies and economic incentives between countries with and without marine invasive species policies extending into the Arctic from international maritime trade, aquaculture and aquarium trade pathways of invasion. Besides policies regarding ballast water that were previously described, the U.S. has also prioritized management and further exploration of invasive species in the Arctic, within the National Strategy for the Arctic Region Implementation Plan (NSAR IP). The recent U.S. chairmanship of the Arctic Council is also expected to address the issue, with its working groups such as CAFF (2013) and PAME (2013) already partly working and having committed to work further towards that direction.

Iceland has significant experience from at least 14 marine species identified as non-native within the last 58 years, with nine of these approximately in the last decade (Thorarinsdottir, Gunnarsson & Gíslason 2014). The national policy indicates precaution rather than eradication which is interpreted practically in regulations for ballast water in force since 2010 for the prevention of discharge within the Icelandic 200 mile EEZ jurisdiction (Thorarinsdottir et al. 2014), as agreed through the OSPAR and Helsinki Commissions. Though these commissions provide some assistance for monitoring and enforcement (OSPAR 2015), it must be expected that such measures may at times be violated with relative impunity.

Denmark's policy (representing Greenland's interest in the Arctic) lies in the recognition of the significant threat and thus the implementation and ratification of the Ballast Water Convention. However Denmark's ratification of BWC does not apply for Faroe Islands and Greenland (IMO 2015). Note that all Arctic states that are sovereign members of the IMO, and the Faroe Islands as an Association Member of IMO, did sign the Antifouling Convention that is in force. In Greenland, all vessels and drilling units involved in hydrocarbon activities need to follow IMO guidelines or the relevant Canadian regulations with respect to ballast water discharge (Frederiksen, Boertmann, Ugarte & Mosbech 2012).

Russia and Norway have confirmed marine invasions in their waters (at a minimum, RKC and SC), and have been working hard towards identifying, with as much accuracy as possible, impacts on the ecosystems and justifying rational and effective management strategies, despite the fact that the aims seem to differ. While both counties have policies to address marine invasive species (Sundet 2014b;

Sustretova, Zakharov & Etin 2012), the RKC is not being treated as an invasive species by the Russians, while the Norwegians act uncertain about their classification.

As for the much newer SC invasion, management plans and intentions have not been finalized in either the Norwegian or in the Russian zone, since there is still ongoing research on the species itself as well as discussions on the desired results. The process of resolution of the scientific uncertainty is a case where research outcomes directly influence international policy, and where long-standing international policy intended for very different shared natural resources will impact incentives over governance of the species. This is due to the debate about whether the crab is a 'sedentary species', and therefore not regulated under the UN Fish Stocks Agreement[1] but rather under international regulation that would give Russia decision-making power over what is now the "Loophole" of Barents' international waters, where most SC fishing is currently occurring. This debate appears close to resolution, in favor of the SC being designated a sedentary species and closing the international loophole for SC fishing (Hoel 2015; Hansen 2015). Meanwhile, it is clear that there are significant hopes that the crab will bring new economic opportunities to the Barents Sea (Hvingel 2015). Interest in the question of whether the SC is a sedentary species is particularly poignant in the Barents Sea because at the moment there is no authorization on fisheries on the outer continental shelf. The northwest spread of the species, in particular toward Svalbard, has created concerns that would recommend harvesting above sustainable fishery levels to reduce the spread and potential damages of a large and expanding SC population into more clearly valued marine habitat (Hop et al. 2002; Jørgensen & Spiridonov 2013; Sætra 2011), evidenced not least by the scientific effort put in to determining the ecosystem functioning, and will require concerted efforts to address its management in the Barents Sea between Russia and Norway.

The borders between nations provide both opportunity and risk pertaining to invasive species. While international trade requirements may facilitate inspections, quarantines, and other preventative measures, borders also determine the extent of a nation's direct control over monitoring and enforcement and over incentives to reduce being a source of invasive species to a neighbor. Again, the RKC experience in the Barents presents an example of the gaps that come at borders if research and information are not properly shared. When the Norwegians agreed not to harvest RKC in the 1970s, they had little information on the Russian's actions to transplant the crab to the Barents and the potential for the species to become a significant presence in their waters. This led to unanticipated costs to Norwegian cod and capelin fishermen in the early 1990s and inefficient policy over containment of the RKC in Norwegian waters, in addition to the current conflicting Norwegian internal policy.

Synthetic analysis of existing research

Misplaced emphasis? Dearth of data and existing knowledge gaps

Before deepening the discussion of abatement costs/investments and assigning burdens, we first need to acquire an adequate understanding of why the above mentioned impacts are of such great importance. Invasions, together with the various disease vectors and pathogens, can have critical interactions with other drivers of ecosystem change thus causing a series of cascading effects both on human health and economic well-being, besides changing ecosystem dynamics.

Nevertheless species under-representations (usually microorganisms such as invasive microbes) (Amalfitano, Coci, Corno & Luna 2015; Thomaz, Kovalenko, Havel & Kats 2015) and other bio-economic biases such as funding uncertainties (Kaiser & Burnett 2010), and policy gaps between stages of invasions (Burnett, D'Evelyn, Kaiser, Nantamanasikarn & Roumasset 2008; Burnett, Kaiser, Pitafi & Roumasset 2006; Kaiser 2006) frequently present themselves in invasion-related research. The lower level of difficulty in detecting and fighting invasive macroorganisms compared to microorganisms is indisputable, but lately there has been mounting evidence for the greater significance of alterations in community structure and ecosystem functioning caused by the latter (Vincent 2010) that ranges from the contribution of microbial food webs to marine productivity, to outbreaks of diseases and parasite transmission caused by microscopic pathogens (CAFF 2013). Additional research concentration in these areas may have high potential net benefits.

Microorganism bio-invasions are a rather conspicuous feature of marine ecosystems overall, particularly because of the ballast water tanks which may carry hundreds of trillions (Society for General Microbiology 2008) of microorganisms on just a single tank or a hull can harbor whole ecosystems of microorganisms. The chances of their individual survival might be relatively low, but the increasing shipping activity in the Arctic increases the overall threat level. Fighting the challenge of microorganism invasions and managing them effectively has never been easy. One can argue that preventing introduction and new infestation would be an optimal solution but the limited amount of research to date does not allow strong conclusions (Burnett et al. 2008; Burnett, Pongkijvorasin & Roumasset 2012; Kaiser & Burnett 2010). Besides the general experience obtained so far, which indicates that particularly for marine ecosystems, preventing invasions has proved the most effective and economically viable way to mitigate their impacts (Carlton 2001; Williams et al. 2013), the diverse realm of Arctic invasions paves the way towards intensifying joint prevention efforts.

Apart from the microorganisms discussed above, existing fears for future invasions are also informed by northward migrations in temperate waters and include species that range from the European green crab (*Carcinus maenas*) (deRivera, Steves, Ruiz, Fofonoff & Hines 2007), which as a voracious predator may pose a significant threat to Arctic marine life, to salmon (Nielsen, Ruggerone & Zimmerman 2013). Additionally to the above, other non-indigenous species have also been identified in Arctic and sub-Arctic waters but cannot yet be listed as confirmed invasions (Molnar, Gamboa, Revenga & Spalding 2008):

Table 1: Suspected Arctic introductions

Species name	Binomial name	Higher Taxa	Ecoregion/ location of identification
Soft-shell clams	*Mya arenaria*	Invertebrate Mollusc	North and East Iceland

Hydroid	*Ectopleura crocea*	Invertebrate Cnidarian	Eastern Bering Sea
Naval shipworm	*Teredo navalis*	Invertebrate Mollusc	Eastern Bering Sea
			East Greenland Shelf
			West Greenland Shelf
			Northern Grand Banks - Southern Labrador
			Northern Labrador
			Baffin Bay - Davis Strait
Acartia copepod	*Acartia tonsa*	Invertebrate Arthropod Crustacean	White Sea
Zebra mussel	*Dreissena polymorpha*	Invertebrate Mollusc	Hudson Complex
Marine pill bug	*Sphaeroma walkeri*	Invertebrate Arthropod Other	Beaufort Sea - continental coast and shelf

Source: (Molnar et al., 2008)

Questions to be answered about these species include the means through which, and the time at which, they arrived at the aforementioned destinations either purposefully or accidentally. More importantly, perhaps, questions include what ecological and economic damages should be expected from these introductions if they spread, and what policy actions can and should be taken to minimize these damages (Burnett et al. 2006; Fernandez & Sheriff 2013; Fernandez 2007, 2008, 2011, 2014; Kaiser 2006). It is worth mentioning that it is a viable hypothesis for all of them to have been transported through hull fouling and ballast water discharge. What is highly likely though, as suggested by Ruiz & Hewitt (2009), is that our limited taxonomic knowledge and respective capacity for biogeographic and taxonomic resolution together with potential biases in search efforts may have resulted in limited observed differences in nonnative species richness and thus in underestimation of nonnative species. Here again, biases in our understanding of Arctic ecosystems limit our ability to answer these questions. While observations of ecosystem behaviors by indigenous Arctic peoples have come to be greatly appreciated for their astuteness and breadth (Krupnik & Jolly 2002; Lopez 1986), such observations focus on direct food sources and/or threats to survival, and cannot be expected to include comprehensive submarine surveillance that might allow specific identification of the details of long run benthic habitat changes, instead of primarily the bio-economic consequences of such changes.

The scale of concern for such diverse invasions and their potential consequences is very different but still joint consideration and common prevention strategies focused on disruption of human-induced introduction pathways (such as broad actions, like mitigating climate change impacts, or locally specific requirements, such as ballast water exchange regulations, etc.) offer considerable economies of scope.

Fighting against more than one species at a time can be expedient towards developing common policy channels that will enable effectively attacking the invasion threat at once.

Conclusions

The threats of invasive species' introductions in the Arctic are increasing as economic and ecological shifts increase opportunities for both introduction of new species and their establishment (Fernandez et al. 2014). In the Arctic Ocean, intentional and unintentional invasions are already underway. The invasions about which we have the greatest evidence are also directly profitable crustacean species. Two of these species, the RKC and the SC, are introductions in the Barents Sea involving international agreements between Russia and Norway. While the two countries have been able to agree on all other shared fishing stocks, they cannot agree on management of the crabs because they have different expectations over the potential costs of the continued presence and spread of these species. Furthermore, as the invasion frontier in the case of the RKC, Norway has international considerations with the rest of the North Atlantic that may affect its governance choices.

There are many more potential invaders, and yet our scientific understanding of Arctic marine ecosystems is sufficiently poor that we do not have an adequate baseline to know what invasions might threaten or indeed if new observations of species are new introductions or just new data on native species. Research challenges in the Arctic not only make the establishment of such a baseline extremely costly, but also research is limited by the seasonality of what is feasible, and by research foci that stem from prioritizing the gathering of more information on direct resource use rather than broader ecosystem functioning. This all leads to the introduction of research biases that direct both policy and research dollars in inefficient ways. Research efforts that aim to fill in gaps in knowledge about baseline conditions, seasonal ecosystem effects and interactions between trophic levels are likely to produce particularly valuable gains, especially if they are integrated with expectations about changes in human behaviors that will change the likelihoods of both deliberate and accidental introductions. A broader approach that includes frequently overlooked microorganisms is also recommended to capture the greatest returns for protection of ecosystems and the resources they support.

The examples here highlight several important considerations for policy development and governance of invasive species issues. These include both bio-economic and strategic aspects of invasive species problems, and range from difficulties in aligning strategic incentives to fight ecosystem change, as we see in the Barents, to difficulties in adapting lessons from one species and location to another, even if they seem potentially quite similar (Kaiser et al. 2015).

Increased coordination of Arctic marine governance at the international level in the form of the Polar Code has failed to include invasive species management. We anticipate this could prove to be a very costly mistake. Increased research and coordination of preventative measures in particular present opportunities for joint (cost-saving) actions across jurisdictions, resource users, species' threats and ecosystems. The authors of this article and their colleagues are engaged in a long term research project through the Belmont Forum to investigate specifics of viable policy options for the Arctic that address the ecological and economic complications laid out here. It is certain that successful multilateral coordination efforts must address realities of both ecosystem and human behavior, so that in the case of marine invasions in particular, policies that front-load interception and disruption of pathways for introduction and establishment of exotic species rather than delay efforts until a serious problem is identified, are likely to be most cost effective. Furthermore, beyond international agreements, successful policy will require integration to identify, prevent and treat threats within communities with differing marine resource uses and users. The vast scope of these differences in the Arctic creates a particular set of challenges that add to the importance of incorporating ecosystems directly into policy decisions.

Since scientific understanding of existing Arctic ecosystems is relatively incomplete, promoting ecosystem resilience with cooperative actions to slow climate change should be considered valuable investment in prevention. Still, prevention of invasive species is imperfect. We can only reasonably expect to delay changes. We must engage in improved monitoring of invasive species and harness the observational capacity of local resource users to widen the net for detection and subsequent reparative action.

Notes

1. In Part VI, Article 76 of the UN Convention on the Law of the Sea (UNCLOS, 1982) describes the process through which coastal states can determine the outer limits of their extended legal continental shelves beyond the 200 nautical mile limit of their Exclusive Economic Zone (EEZ) and thus gain marine sovereignty rights. Sedentary species (on the continental shelf) are also regulated by Part VI and not Part V that focuses on coastal states' rights and duties in EEZ and includes regulations for living marine resources. For sedentary species occurring beyond the continental shelf, the regime described seems rather unclear as the initial intention was to regulate mining and extraction of other non-living resources, since at the time the economic and commercial interest for those fishery resources had not developed to the extent it has today.

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