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Research article

A case for the commons: The Snow Crab in the Barents

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ABSTRACT

Closing of the marine commons increases economic returns and slows depletion of valuable ocean resources. Rights-based management is widely used for fisheries rationalization. Regulators with sound biological and economic information can in theory set overall harvest control rules that protect the fish stocks, and manage for external costs and benefits from harvest. These may include ecosystem damages, overcapitalization in the fishery, and/or equity concerns. Regulatory efforts and related rights-based management instruments may increase the returns to fishery stakeholders but miss important challenges that are increasing under climate change. These include transboundary resource management and tradeoffs between local economic returns and Total Economic Value. The case of the valuable, yet invasive, crab species, *Chionoecetes Opilio* (Snow Crab) in the Barents Sea illustrates the concerns. The spread of the crab has known and unknown ecosystem and commercial fishery risks, particularly to uncertain ecosystem values. We show how the progression of the biological invasion interacts with human strategic behavior to identify limitations of management options. Open access harvesting of the species in international waters has generated a positive spillover effect by slowing the westward spread of the species to sensitive benthic ecosystems. This benefit is threatened by reclassification of the crab as a "sedentary species" (one which is not capable of leaving the seabed when harvestable (UNCLOS, 1982, article 77, part VI)). This shifts the regulatory environment for the crab in ways that exacerbate the invasion in exchange for protection of local gains. Such problems will increase in magnitude and impact as climate changes increasingly affect species' ranges. Optimal decision-making regarding profitable species in new ecosystems must incorporate how strategic institutional shifts occurring in response to the economic incentives asymmetrically affect local and global stakeholders in addition to standard concerns over ecological and economic damages.

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1. Introduction

The global fishing commons has shrunk and become increasingly overtaxed in the past half century (Jasper, 2010). This general trend has led to recommendations and actions that promote limited access through sovereign claims in the world's fisheries. It is well established in the fisheries economics literature that closing the commons produces a clear economic boon (Birkenbach et al., 2017; Munro and Scott, 1985), when utilized with private, decentralized, or common property management regimes (Ostrom et al., 1999). When concerns have been raised in the literature, they have generally focused on shifts in equality and distribution of benefits rather than overall benefit levels (Da-Rocha and Sempere, 2015). Here, we argue that the details of the ecological process matter significantly in determining the net benefits, further mitigating the realized economic gains. This is particularly true in cases of invasive species and species range expansions, which will continue to increase in frequency and extent under current climate change projections (Perry et al., 2005). We examine this complex story through the case of the Snow Crab (*Chionoecetes opilio*) invasion in the Barents Sea in order to bring awareness to important dimensions of commons management that the literature has missed.

The Snow Crab's recent introduction and spread in the Barents Sea is a harbinger of expected marine impacts from climate change. The biological invasion of this profitable species reflects the limitations of political, economic and ecological management of fisheries and transboundary marine resources that become more salient as climate change shifts habitat ranges for commercial

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species. We provide a framework for understanding how the shifts in incentives initiated by such species movements may be integrated with biological factors, climate factors, and economics to inform policy analyses and decisions for improved outcomes. Multiple spatially differentiated property rights regimes affect the Barents' Snow Crab fishery. These provide comparative evidence from which we draw to illustrate the limitations of applying conventional wisdom regarding how to maximize benefits of marine resources, particularly in the case of invasive species.

The expanding presence of the Snow Crab in the Barents Sea has become a topic of growing interest for political analysts and scientific experts. The biological invasion has political, economic and ecological ramifications that extend far beyond the typical case of an introduced species. Political scientists have pointed out some of the existing challenges. These include the applicability of international invasive species agreements to a case with significant potential economic benefits, behavior of different stakeholders in international waters in the Barents, and the complex and disputed property rights surrounding Svalbard, into which waters the invasion is heading (Hansen, 2016; Tiller and Nyman, 2017). They rightly surmise that the stakes for Norway are higher than the value of the fishery alone. Norway is acting as though the Snow Crab's classification as a sedentary species creates a test case for cementing property rights to the Svalbard Continental Shelf (CS).

What the approaches of these papers have missed are the connected shifts in incentives that illustrate the importance of fully integrating biology, climate factors, and economics into policy analyses and decisions. Two property rights issues are at play in the Barents that affect the overall net benefit of the crabs' presence in the region. We examine economic incentives under these rights, and their biologically imposed constraints and spillovers, to explain how strategic regional decisions to conserve the crab stocks in the Barents may reduce global social welfare outcomes, and how maintaining uncertainty about these reductions increases the ability of local stakeholders to benefit at global expense.

The first property rights issue is the contention and uncertainty surrounding the extent of Norway's sovereignty over the Svalbard CS. Both the water column and the continental shelf of the Svalbard Fisheries Protection Zone (FPZ) have provided controversy for years. While Norway asserts the Svalbard CS and the Svalbard FPZ are theirs to manage and benefit from (Ministry of Foreign Affairs, 2009), Russia and others contest this view through the 1920 Svalbard Treaty, with the unique *terra nullius* arrangement on land extending to the continental shelf (Rossi, 2016; Thomassen, 2013). The Treaty recognizes Norwegian sovereignty over the area, while it simultaneously assures equal access and treatment of the signatory parties for commercial activities and natural resource extraction. The intensity of this controversy is increasing as resource pressures mount around the world.

The second property rights issue stems from changes involving the international waters of the Loophole between Russia and Norway. Fishing activity in the international waters of the Loophole, which is outside the Russian and Norwegian Exclusive Economic Zones (EEZs), is formally under the jurisdiction of the North-East Atlantic Fisheries Commission (Ebbin et al., 2005), but the new Snow Crab fishery there began with open access harvesting in 2012. At that time, both Norway and Russia had been studying the Snow Crab invasion and had yet to open fisheries inside their EEZs. In Norway, this is because there is little Snow Crab population in the EEZ; in Russia, this is because they wish the stock to support a long-term fishery.

During the 20th North Atlantic Fisheries Ministers' Conference (Valletta, Malta, 16–17 July 2015), Norway and Russia agreed on the designation of the crab as a sedentary species. This decision transferred its status from a water column species to a continental shelf resource (Joint Norwegian Russian Fisheries Commission, 2015). Tiller and Nyman (2017) point out that there is a general disagreement among states on whether the Snow Crab is sedentary or not, but Hansen (2016) notes that no countries have directly questioned its sedentary status in the Barents and therefore it falls under full sovereignty of Russia and Norway. Formal EU recognition of this designation remains part of the currently-defunct negotiations between Norway and the EU, with a proposed July 2017 statement confirming such recognition going unsigned (Council of the European Union, 2017). In the meantime, its designation as a sedentary species has shifted the crab from being a fishery resource in the international waters of the Loophole to a shelf resource that is Russian and Norwegian property on their respective portions of the continental shelf. These rights extend beyond the 200 nautical miles of both the Russian and the Norwegian EEZ. This closes the Loophole, placing about 85% of it on Russian CS and the rest on Norwegian CS.

The provisions of the United Nations Convention on the Law of the Sea (UNCLOS) allow the two countries to exercise sovereign rights over their extended continental shelves and therefore to explore and to exploit the natural resources lying on the shelf, one of which is now the Snow Crab. Furthermore, the designation of the species as sedentary implies that there is also no requirement by the UN Fish Stocks Agreement for managing the species in cooperation. This is not undisputed. The North-East Atlantic Fisheries Commission (NEAFC) has the responsibility to "ensure the long-term conservation and optimum utilization of the fishery resources in its Convention Area, providing sustainable economic, environmental and social benefits," within the international waters of the NEAFC Convention, which includes the Barents Sea Loophole (NEAFC, 2017). This organization tracks licenses issued by the European Commission to vessels for Snow Crab fishing in the Loophole. In fact, NEAFC's authority to track European Commission licenses in the Loophole stems from earlier disagreements over cod fishing that began when climatic changes increased cod in the Loophole (Stokke, 2001), serving as another precedent for the challenges ahead.

The sedentary species designation increases the potential Russian stake in the Barents Snow Crab by increasing their control of the fishery asset. The extent to which they exercise control over this area will be a function of the incentives to spend on enforcement of their fishery regulations. Russian and Norwegian incentives and management of the crab before and since the designation mean that the positive externality generated by the open access harvesting in the Loophole (67,100 km^2 on the invasion's frontier) is disappearing as the Russians extend enforcement outside their EEZ. We argue that, as the Russians have so far maintained a closed and limited experimental, and now TAC controlled commercial, fishery for *C. Opilio* in the Barents, such extension of the enforcement is expected to continue. Russian enforcement may also help Norway more than it helps Russia itself; Russian closures increase the probability of more and longer term crab stock in Norwegian waters. Thus Norway may have more incentive to close their portion of the commons and to encourage the Russians to do the same.

Should both Russia and Norway successfully close the commons and manage the areas for maximum economic yield, the question of whether the capture of these resource rents is greater than global losses from the spread of the invasion westward is still an open one. Concerns about uncertain damages remain unalleviated. Potential externalities from a spread of the crab beyond Norwegian and Russian jurisdictions present additional, though uncertain, costs.

Finally, lessons from dynamics of Snow Crab populations in Canada, Greenland and the Pacific may be pertinent to the management in the Barents. Evolving climatic conditions may have

dramatic impacts on the global supply of Snow Crab in ways that promote the rise of Barents Snow Crab (Mullowney, 2015; Mullowney et al., 2014). Furthermore, within the Barents, variations in climatic shifts to warmer temperatures (Degen et al., 2016) may push the crab expansion in ways that favor growth more in Russian territory than Norwegian territory. This will influence the asymmetry of incentives for Russia and Norway, and potentially affect the net benefits of the level of cooperation between Russia and Norway in particular, as well as with the rest of the world.

The dual nature of the Snow Crab as invader and profitable resource and the recent sedentary species designation reduce the potential net benefits from the crab under its current fragmented management as a fishery resource. Bio-economic complexities similar to those of the crab are likely to become more common under climate change shifts in marine resources, so that traditional assumptions about property rights in fisheries need refinements that integrate ecological and economic concerns. We show that the inherent tradeoffs and uncertainties from the bio-economic conditions place management in a second-best framework. We conclude that the difference in second-best outcomes from socially optimal management of the Snow Crab may be significant; open access fishing of crab in the international Loophole and the Svalbard FPZ may be second-best optimal compared to other property rights arrangements.

2. Conceptual model of management of a profitable invader in international space

Standard fisheries and invasion bio-economic models capture economic and ecological parameters of change and can present first-best management solutions in comparison to less optimal spatio-temporal harvest and effort levels. The contrasting combination of profitable resource and costly invader can similarly weigh the marginal benefits and costs against one another under different harvest schemes, if the costs can be accurately measured, which is not the case here. These standard models cannot, however, incorporate strategic influences that stem from the potential ability to re-define the legal framework for rights to the crab nor the interplay of climate changes on the progression of the invasion in the context of this shifting legal framework, outside the location of sovereign claims to the fishery and its habitat. The problem is thus necessarily relegated to contemplation under the theory of the second-best (Lipsey and Lancaster, 1956).

Our conceptual framework distills the multiple constraints across legal, ecological, and climatic limits to achieving a first-best unconstrained objective for fisheries management. By synthesizing these various components we characterize the second-best fisheries management options taking into account the reality of continuous change in the time and space of the Snow Crab.

3. Background of the invasion

3.1. The Snow Crab as a profitable biological invader

The Snow Crab is a benthic predator that feeds mostly on crustaceans, polychaetes and fish (Jørgensen & Spiridonov, 2013). Its predatory behavior might cause competition with other bottom feeding fish and benthic species (Haug et al., 2017). Impacts of the Snow Crab's presence in the new ecosystem are however particularly hard to identify, especially those occurring through indirect food web links. This also makes negative impacts easier for policy makers to ignore in return for immediate and tangible fisheries gains.

The Snow Crab is distributed in the North Pacific (eastern Bering Sea) and the North West Atlantic, including Canada and Greenland (Agnalt and Jørstad, 2010). The crab has recently established in the North East Atlantic and more specifically in the Barents Sea where it is considered invasive. Other related, commercially harvested Snow Crab species such as *C. bairdi* are not present in the Barents. In 1996 the first five specimens of Snow Crab were identified in the southeastern part of the Barents Sea, in the net of a trawler fishing for cold water prawn on Gåsbanken (Goose Bank) west of Novaya Zemlya (Sundet, 2015). The crab was mostly likely transferred to the Barents accidentally via ballast water rather than through direct range expansion (Jorstad and Jelmert, 1997).

The species has successfully established in its new environment in the Barents Sea and has expanded its geographical range and abundance (see Fig. 1). The Snow Crab's main habitat is currently located in the northern parts of the Russian EEZ as well as in international waters of the Barents Sea (Loophole). The crab is presently expanding into the Svalbard FPZ adjacent to the Loophole. The overall area of distribution covers more than 34% of the Barents Sea (618,000 km^2). Higher densities are found in the eastern part of the Barents Sea, with juveniles mostly in the south east (Pechora Sea) and north east off the coast of Novaya Zemlya, and adults in the central and central-eastern part of the Barents (Novozemelskaya) (Bakanev, 2015).

In addition to the economic benefits that may accrue from the crab, there exist potential ecological benefits from the development of the Snow Crab fishery. IMR's modeling of the Barents suggests that the Snow Crab may potentially have beneficial effects on stocks like cod, haddock and capelin. There is evidence that the crab is digging up biomass that goes up through the ecosystem, and is thus contributing to food resources for those species (Hvingel, 2015, 2016; Hvingel et al., 2015). Despite the scarce biological and ecological data, the projections of IMR models suggest that the Snow Crab may help exploit the lost biological energy from the bottom fauna that otherwise becomes dead organic material. The nutrients from the bottom fauna disappear as a part of the geological process (e.g. oil formation) but the Snow Crab serves a biomass-recycling role and makes the nutrients readily available to fish or other predators above or on top of the bottom sediments. This process is therefore likely to increase nutrient production in the ecosystem (Hvingel et al., 2015), increasing overall biomass production possibilities.

The reduction in benthic biomass attributed to the presence of the Snow Crab in the ecosystem as estimated by NoBa-Atlantis (Hansen et al., 2016), a marine ecosystem model employed in the Barents Sea,[1] ranges from 10 to 30% (Hvingel et al., 2015). The role of the crab in the ecosystem is highly uncertain and based on extremely limited data that have been used for the purpose of calibrating an equilibrium for the model. Additional efforts to refine the model and expand its usefulness for Snow Crab dynamics are underway (Cecilie Hansen, IMR, personal communication 2017). Although it is unclear whether such a biomass reduction can have negative side effects on other species, preliminary analysis indicates that it will not (Hvingel et al., 2015). ICES (2017a) suggests that the overlapping distribution of cod and Snow Crab has resulted in increased cod predation upon Snow Crab as their population grows, and this could have a top-down effect that limits the spread of the invasion.

3.1.1. Fishery gains

The fishery has the potential to become quite valuable. In the US,

[1] The Atlantis model aims at representing the key species and processes in the Nordic and Barents Seas (NoBa), where the main objective is to explore combined climate and fisheries scenarios. The model has previously been employed for other areas including Australia, U.S. and European waters (Hansen et al., 2016).

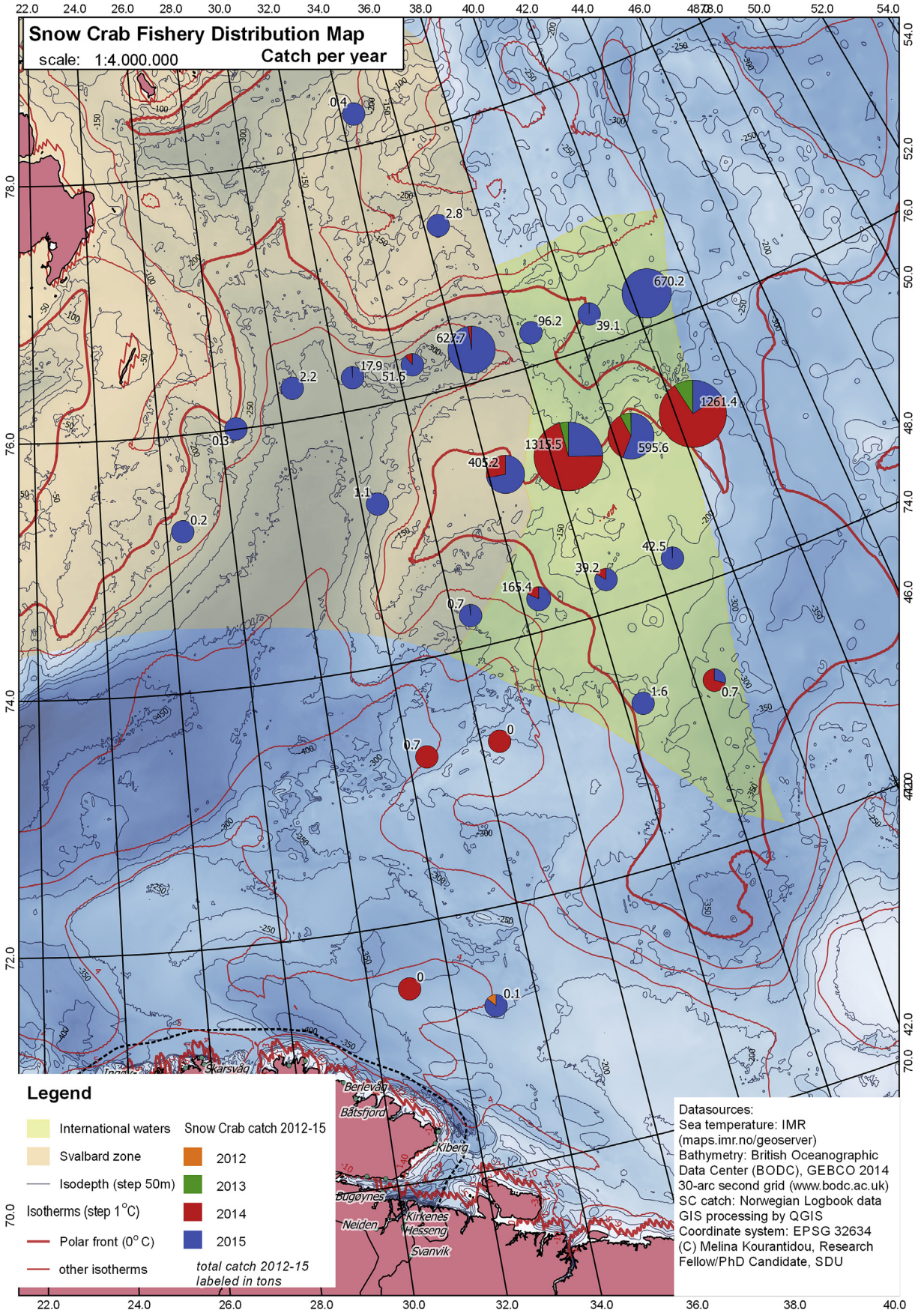

Fig. 1. Commercial Fishery Activity (Norwegian Logbook data).
Sources: IMR, 2017a; Natural Environment Research Council, 2017.

Russia, and Canada, the crab is a highly valuable harvested species (Hardy et al., 2011; Pinfold, 2006; Simon, 2015). The Barents' harvest is growing at a very quick pace: Norwegian landings of Snow Crab have increased over 2,000 times in magnitude from a total roundweight of 2,478 kg in 2012 to 5,405,764.2 kg in 2016 (Norges Råfisklag, 2017). According to the Institute of Marine Research in Norway (IMR) the value of the Snow Crab fishery might reach up to 2.5 billion NOK, based on how landings have evolved to date. Most of the commercial harvesting of the species has occurred in the international waters of the Barents Sea Loophole. This harvesting is a control measure on the invasion by reducing the stock, particularly on its western frontier. Norwegian and Russian vessels joined the fishery first in the Loophole, while Spanish, Latvian and Lithuanian vessels joined in subsequent years (see Table 1 for a recent description of the fishing activity in the Loophole).

Despite existing uncertainties in the stock estimates and the difficulties in biomass simulations (Hansen et al., 2016), there are expectations for sustainable landings of 50,000 tons within a 10 year horizon and for 75,000 tons within the next 20 years (Fenstad, 2015a; Hvingel, 2015). If these expectations are met, then the Snow Crab fishery will be of much greater commercial value than the mackerel, herring and saithe (~830 m NOK) fishery, and possibly greater than the value of the important cod fishery (~6.788 m NOK) (Norges Råfisklag, 2016).

The map in Fig. 1 shows the open access commercial fishery activity of the Norwegian fleet from its beginning in 2012 until 2015, when a change in property rights regimes from open access international waters to protected sedentary species began (IMR, 2016). This shows a minimum of the fishing effort as it does not include foreign vessels for which comparable data is not available. High levels of activity are present in the Loophole (center, shaded green). We overlay the fishery information on thermal and bathymetric data to identify how anticipated spread may occur to the North and West. Generally, depth range varies according to season and size. On the map, one sees the significant and rapid growth in fishing intensity in the Loophole and in the Svalbard FPZ (beige shaded area between Svalbard and the Loophole) along the depth-temperature combination where the water temperature drops and the depths increase. The Snow Crab is a stenothermic species found in greatest numbers at bottom water temperatures between −1 and 4 °C (Chabot et al., 2008). In the Barents Sea the Snow Crab is widely distributed in areas with bottom temperatures ranging from −0.7 °C to 3.4 °C (Alvsvåg et al., 2009), with most crabs found in waters below 2 °C (Jørgensen & Spiridonov, 2013). In the central region of the Barents Sea a significant number of crabs have been found in waters from 180 to 350 m (Alvsvåg et al., 2009).

3.1.2. Ecosystem and climate losses, and uncertainties

In its native range, the Snow Crab population is characterized by large inter-annual variation as reflected in both numbers and landings. Reasons for these large fluctuations include density-dependent mechanisms as well as changes in water temperatures that may result in changes in crab abundance and habitat range (Chabot et al., 2008). Evolving climatic conditions may have dramatic impacts on the global supply of Snow Crab in ways that promote the rise of Barents Snow Crab, though with similar fluctuations (Mullowney, 2015; Mullowney et al., 2014), as the invasion fills in the habitat capacity. Quantitative parameters indicate that in 2015 there was an overall reduction of the measured Snow Crab population by half compared to previous years, despite the increase in the distribution (Anisimova and Jørgensen, 2015). This adds a significant degree of uncertainty at attempts to predict the future biomass and spread.

Biomass shifts may also affect the distribution of crab between Russia and Norway, complicating the management for both nations. Projections indicate that the Barents will warm faster than other Arctic waters and will do so from west to east (Degen et al., 2016). Norway's position on the frontier of the invasion makes its investments in enforcement and management less certain. If these projections are accurate and generate population shifts that move the continuing invasion more to the north than to the west, its curtailment of current harvests in the hopes of future returns will result only in lost revenue. The effects of this uncertainty are already affecting international negotiations over quota sharing for other species, such as the North-East Atlantic mackerel fishery negotiations to accommodate what may either be a temporary or permanent shift of population into Icelandic waters (Ellefsen et al., 2017).

Shared, straddling and highly migratory fish stocks create situations where EEZ delimitations for fisheries management need supporting international regulatory investment (e.g. see Bjørndal and Munro, 2012; Hannesson, 2004; Lauck et al., 1998). The continued expansion of EEZs to the 200 nm limit formalized under UNCLOS in 1982 has resulted in a legal framework that allows for nation states sharing fish stocks to limit others' access to those stocks (Hannesson, 2004). This formalized a longstanding and well-studied transboundary externality problem in fisheries management and conflict that intertwines strategic human behavior and underlying population dynamics of the fish stock (Levhari and Mirman, 1980). In the case of the Snow Crab, there is a third aspect that factors into the problem: The local management strategies of the two countries fail to account for the uncertain consequences of the invasion and therefore risk imposing this externality upon other countries.

As Hannesson (2004) points out, the fact that the 200-mile zone does not establish complete property rights over fish stocks is a significant weakness. The EEZs only determine access, unless the stock is entirely enclosed within the zone. When fish stocks do cross national boundaries (out of the 200-mile zone into the high seas) there is no generalized institutional mechanism in place for their management; Regional Fisheries Management Organizations (RFMOs), established by bi-lateral or multi-lateral international agreements or treaties, each have their own decision-making structures and aims that differ in terms of the balance between fish stock use and marine ecosystem conservation. They provide incomplete spatial, species, and ecosystem coverage of the world's international waters. Of the 17 existing RFMOs today, just two are actively managing ecosystem interests more broadly.[2]

Table 1
Fishing Activity in the Loophole for 2015 and Jan–Sept 2016.

	2015		2016	
	Fishing Activity	No. Vessels	Fishing Activity	No. Vessels
Norway	21.59%	11	47.37%	11
Russia	42.68%	6	13.41%	7
Latvia	19.00%	12	32.31%	10
Lithuania	9.36%	3	5.29%	2
Spain	7.37%	1	1.62%	1

Source: Ripman, 2016.

[2] The Western and Central Pacific Fisheries Commission (WCPFC; https://www.wcpfc.int/) and the Inter-American Tropical Tuna Commission (IATTC; https://www.iattc.org/HomeENG.htm) both include ecosystem components in their formal management agreements. FAO Guidelines for ecosystem-based management of deep-sea fisheries in the high seas exist but remain voluntary (https://doi.org/10.1139/f57-025).

3.1.3. Uncertain ecosystem interactions amplify asymmetries

A projected expansion towards Svalbard raises additional concerns among scientists given the vulnerability of Arctic food webs that stems from the limited numbers of species at each trophic level (Sundet, 2015). Potential elimination of some species caused by Snow Crab predation is therefore particularly worrisome for Arctic ecosystems, due to potential severe effects both upwards and downwards in the food web, as opposed to other more resilient ecosystems where more diversity means some species' roles have more substitutability.

Echinoderms for example, which are known to play an important role in redistribution and remineralization of organic carbon on Arctic shelves (Bluhm et al., 2009), are among the most common prey items for the Snow Crab (Jørgensen & Spiridonov, 2013). Foraminifera, another dominant category of prey species found in stomach contents of the Snow Crab (Jørgensen & Spiridonov, 2013), represent an important link between lower and higher levels of the food web (Gooday et al., 1992; Hansen, 2015). Changes in the abundance and composition of echinoderms may lead to large structural ecosystem changes and so do potential changes in foraminifera (Hansen, 2015). Manushin (2016) finds that the Snow Crab has led to a decline in the biomass of benthic species, especially in the eastern parts of the Barents Sea where the crab abundance is high (Frantzen et al., 2017). In measurements of the benthos biomass for the Barents Sea, the decline observed after 2013 has been found to overlap with the maximum distribution of Snow Crab and the period of maximum benthos consumption (ICES, 2017b). However, the area of reduced benthos also overlaps with an increase in bottom temperature (since 2007) and therefore the decline in benthos biomass is attributed to multiple impact factors (ICES, 2017b), which makes it hard to disentangle the effects of the Snow Crab alone.

Direct and indirect threats to other commercial fisheries are also possible. In Newfoundland, the Snow Crab has been observed to feed on capelin (Squires and Dawe, 2003) and thus there might be a possibility of the crab representing a threat for post-spawn capelin (Mikkelsen, 2013). Other concerns include the food competition the crab might create with other commercially valuable species, through its predation on the Polychaeta community. The northern shrimp is an example of a commercially exploited species whose distribution is partly overlapping with the Snow Crab distribution, mainly in Norwegian waters of the Barents. Dvoretsky and Dvoretsky (2015) find a negative correlation between biomass of Snow Crabs and shrimp, which they attribute to prey-predator interactions. The authors consider the Snow Crab's impact on shrimp negligible, however, due to the relatively small fraction of shrimps found in stomach analyses of the crab.

The small spatial and dietary overlap between shrimp and Snow Crab, and the limited negative impacts observed so far, shrink the concerns for dramatic ecological effects from the invasion (Anisimova et al., 2016 in ICES, 2016). However, the lack of long-term predictions adds a significant degree of uncertainty to the potential consequences (ICES, 2016). Furthermore, fishing behavior of the Snow Crab fleet does seem to impact the northern shrimp fishery's costs and productivity due to spatial overlap of crab pots and shrimp trawls (Fiskeridirektoratet, 2016).

Dvoretsky and Dvoretsky (2015) do not exclude potential spatially differentiated negative ecosystem impacts from the Snow Crab, while they also highlight the fact that the ecosystem may not have adapted yet to the new species whose biomass is still increasing at exponential rates. Norwegian shrimp fleets reported numerous incidents to the Coast Guard of costly damages (e.g. broken trawls) caused by Snow Crab gear left behind on the sea bottom. Snow Crab Vessels are fishing with up to 2,500 traps each one of them which are strung together in chains up to several kilometers long (Sundet, 2015). Degradable excluder devices on crab pots, which are mandatory for a Snow Crab license in Alaska, Newfoundland and Labrador, are not common in the Barents Sea. Despite the numerous complaints the Norwegian Coast Guard has received, the agency has not been authorized to intervene in any way (Fenstad, 2015b; Jensen, 2015).

The distribution of the external costs and benefits from the establishment and spread of the invasive crab is likely to vary between Norway and Russia. The natural capital assets imperiled by the invasion vary both across space and time. In the Norwegian part of the Barents Sea the impact of the invasion is currently expected to be lower than in the Russian part (Frantzen et al., 2017; Manushin, 2016). An adequate understanding of what ecosystem values are at stake is currently lacking for both the Russian and the Norwegian part of the Snow Crab distribution. Joint surveying of the Barents by IMR and the Russian Nikolai M. Knipovich Polar Research Institute of Marine Fisheries and Oceanography (PINRO) over the past two decades is beginning to quantify the ecological stakes (IMR, 2017b). Until entry by commercial vessels in 2012, these surveys were assessing both potential ecosystem changes and the potential for fishery development at a measured pace. While this has increased knowledge about the population, it did little to control the invasion.

Russia has experienced the ecological brunt of the invasion so far, since the invasion has mainly existed in Russian waters. The introduction of international fishing vessels in the Loophole and Svalbard FPZ has acted to slow the invasion into Norway (Fig. 1). Uncertainties about the future path of the invasion and how climate may affect this path matter for how countries will feel future impacts, and their incentives to respond. In addition to shifting current economic benefits from international vessels to Russia and Norway, the increasing restriction of vessels and fishing in these areas may now increase the rate of invasion and its impacts in Norway as well as on the Russian CS in the Loophole. The extent to which the invasion will move permanently into Norwegian waters affects their long run incentives on both the ecological and economic fronts. If climate shifts push the invasion more north than west, the imbalance toward Russian impacts, in both dimensions, will continue to grow.

4. Interpretation and analysis

4.1. Property rights dynamics of the Snow Crab fishery have widespread impact

The efforts by Norway and Russia to limit participation of EU vessels in the Loophole and more generally control Snow Crab harvests in the Barents include the establishment of quotas and/or limited vessel entry. The Russian enforcement of continental shelf property rights to the crab was initiated in September 2016, while the similar Norwegian enforcement was initiated in January 2016 (JCS Arctic Fishing, n.d.).

In the Russian EEZ the commercial fishery started in 2016 for the first time with a relatively small catch (1,500 tons), while for 2017 the TAC for the Russian EEZ has been set at 7,870 tons and the Russian portion of the Loophole is effectively closed to commercial fishing (Sergey Bakanev, PINRO, personal communication, 2017). Norway introduced a TAC for the first time in 2017. It was set at 4,000 tons, with 500 tons reserved for foreign vessels (Regjeringen, 2017a); the country has previously licensed Norwegian vessels (20 vessels in 2016 and 50 vessels in 2017).

The Norwegian authorities have arrested and fined two vessels for Snow Crab fishing on the Norwegian CS in the past year. In December 2016, Norway prosecuted a Lithuanian vessel *Juros Vilkas* that had been arrested the previous July for harvesting Snow Crab

on the Norwegian portion of the continental shelf in the Loophole (Øst-Finnmark Tingrett, 2017). The captain and owners were prosecuted for illegal harvesting of Snow Crab on the Norwegian CS within the Loophole. The defendants were acquitted by a lower court on January 24, 2017. This case has continued up to the Norwegian Supreme Court through the appeals system, which reversed the decision in favor of Norway on November 29, 2017. (Norwegian Supreme Court, 2017).

A week prior to the initial acquittal of the *Juros Vilkas*, a second, Latvian flagged vessel, the *Senator*, was arrested for laying 2,600 Snow Crab pots in the Svalbard Fisheries Zone (Jeffries, 2017), despite holding an EU-issued Snow Crab license for the area. This case is currently working its way through the European courts, and also may be taken up by the international court in The Hague at Latvia's request.

The first case rests mainly on whether the sedentary species classification in the Loophole gives Norway the right to exclude other countries from fishing the resource, as suggested by UNCLOS. The alternative is that the NEAFC Convention (1980) supersedes this exclusivity and gives the regional authority the ability to regulate sedentary species, including Snow Crab, in the Loophole (PECH secretariat, 2016; Regjeringen, 2017b). The second case adds to the complexity because of the additional requirements of the Svalbard Treaty for equal treatment.

Norwegian enforcement accommodated EU fishing vessels through most of 2016 in the Loophole in pursuit of the crab. Since the end of 2016, however, Norwegian enforcement has targeted EU vessels as described. This has been presented as stemming from fears brought about by the lower Norwegian catch experienced in 2016 due to lack of access to the Loophole (Martinussen, 2017). Additionally, engaging in lengthy and expensive legal cases creates delays, reductions in harvest, and uncertainty about any capital investments undertaken by international participants. This must also be considered a strategic action. So far, the EU is not backing down; on December 13, 2017, the EU Fisheries Ministers determined to issue 20 new Snow Crab fishing permits for the Svalbard Fisheries Zone for 2018 (EU Fisheries Minister, 2018). This has halted current negotiations on the Snow Crab between Norway and the EU and can be expected to bring about further arrests and subsequent court action if EU-licensed vessels fish for crab in Svalbard Fisheries Zone waters.

4.2. The Snow Crab as a sedentary species

The de facto closing of the commons through the sedentary species designation at the North Atlantic Fisheries Ministers' Conference removes the fishery from an open access case where theory and practice suggest harvesting at levels that exceed those for highest profitability and that could stop the commercial viability of the fishery (Bjørndal and Conrad, 1987; Gordon, 1954; Schaefer, 1957). Instead, Russian and Norwegian authorities now have sovereignty over their continental shelves and have recently chosen to close the commons. Continued crab migration in the Barents between Russian and Norwegian waters is expected (Degen et al., 2016; Jørgensen et al., 2015). The joint Norwegian-Russian Fisheries Commission has to date handled transboundary fish stocks, but there are complications in this case. The first is the differing legal status of the Snow Crab, in that it is a sedentary species and therefore does not have to be regulated as a fishery by the Commission. The second is precedent: the only species for which the Commission has failed to agree on management is the Red King Crab, with a similar history beginning a few decades earlier (Kourantidou et al., 2015).

Thus we might expect that the Norwegians and Russians will develop different harvest control strategies – and different levels of enforcement of property rights, once secured = for the species on their own Continental Shelves, much as they have with respect to the Red King Crab. Economic factors for the difference between the two countries include the diversified supply Russia has for Snow Crab that includes its Far East EEZ. This fishery is closer to market demand and allows for cheaper crab delivery to Asian markets by sea. Norway lacks such diversified supply. Biological factors for the difference between the two countries are linked to the shifting climatic conditions. These may be leading to movement of Snow Crab to deeper, cooler depths such as are provided in Northern Russian waters (Degen et al., 2016) in order to avoid increased water temperatures in shallower Norwegian and Svalbard FPZ waters (Mullowney, 2015; Mullowney et al., 2014). Studies on temperature tolerance of the Snow Crab and its current geographical distribution do project that the crab will most likely invade the Euro-Arctic shelves rather than spread southwards (Siikavuopio et al., 2017). A large expansion of Snow Crab is currently expected in the northwestern (Norwegian and Svalbard Zone) part of the Barents Sea (see Fig. 4 in Siikavuopio et al., 2017). In September 2017, the Snow Crab was found for the first time northwest of Svalbard (Ingvaldsen, 2017). Recent findings in areas of high abundance generate estimates of 4,000–9,000 crabs per km^2, including a large number of juvenile crabs (Buhl-Mortensen et al., 2017).

Failure to halt the spread of the invasion within the Barents will move the strategic interactions between nations to the next consecutive parties; the stakes will depend on climatic variations and economic decisions in a pattern similar to the discussion here. The current legal actions underway to extend the continental shelves in the Central Arctic Ocean mean that any northward expansion will also remain a limited entry fishery for the sedentary species rather than one open through international waters. Access to the shelves remains limited, however. It remains unclear whether the ongoing negotiations between the five Arctic coastal states, Iceland, China, Korea, Japan, and the European Union to refrain from fishing in the Central Arctic Ocean pertain only to the high seas, or whether a sedentary species like the Snow Crab, under individual state jurisdictions, would be exception-worthy (Rayfuse, 2018). If so, this would reduce the effectiveness of the proposed ban in maintaining healthy and pristine marine benthic habitats.

With many uncertainties reducing the expected payoffs from enclosing the commons, we argue this enforcement has more to do with creating increased certainty by establishing rights to the crab as a sedentary species on the continental shelf, and the right to control the Norwegian CS in the Svalbard FPZ, than to the Snow Crab fishery alone.

4.3. The Snow Crab as a test case for Svalbard Treaty rights to the Norwegian Continental Shelf

Sedentary species include other valuable resources such as oil and gas in the Svalbard FPZ. International law under the Svalbard Treaty of 1920 (Molenaar, 2012) clearly indicates Svalbard's land resources are open to all, and precedent has established that the pelagic zone is international waters. The question of the continental shelf, however, remains disputed by Norway. Norway believes it has sovereignty over the continental shelf and a right to govern the Snow Crab, as well as any other "sedentary species" (Regjeringen, 2017b) in the 12–200 mile nautical zone surrounding Svalbard.

This has recently become a much bigger concern to both Norway and other stakeholders in the Barents fisheries, as well as the global oil and gas industry. The finalization of the Norwegian-Russian maritime border in 2010 (Office of the Prime Minister, 2010) resolves uncertainties over hydrocarbon rights in the Barents Sea. It defines the border and the requirements to unitize any resources

that cross this border. Norway possesses the technology and capital to begin exploration, and has done so rapidly. Indeed, the 23rd round of oil licensing, concluded in 2016, gave licenses to Statoil north of the 74° line, in the Svalbard Zone (Production licenses 615B and 859, Norwegian Petroleum Directorate, 2017). These have been protested by Russia, and the 24th round promises to instigate similar clashes (Staalesen, 2017).

The recent quota negotiations, now abandoned, confirm the importance of the Snow Crab in establishing property rights. The EU rejected Norway's offer to set aside 500 tons, out of the 4,000 Snow Crab TAC, for EU vessels (Council of the European Union, 2017). This rejection prevents Norway from using the deal to defend its claims to the shelf (SCMP, 2017).

Even with reduced oil prices and high crab prices, the importance of oil and gas in the economies of both countries dominates these dynamics. The lower costs of participating in, and in litigating controversy over, the crab fishery make the industry an excellent proxy for determining the applicability of the Svalbard Treaty to continental shelf resource extraction.

4.4. Spatial asymmetries in economic incentives: Russia's Far East Snow Crab fishery

Fig. 2 shows the global distribution of Snow Crab. The Russian Federation has Snow Crab stocks in the Far East as well as in the Barents Sea; diversification of supply increases their flexibility in the timing of development of the new fishery resource, including enforcement of property rights for conservation of the commercial stock. Because the main markets for Snow Crab, particularly for live Snow Crab, are located in neighboring Korea and Japan, the Far East Russian fishery has much lower costs in delivering product to market. The stocks of Snow Crab and market linkages are also better established in the Far East; the Russians have been providing live crab for decades (Nofima, 2017). Russian incentives to invest in Snow Crab production in the Barents are lower than those of the Norwegians, who envision the crab as a boon development for northern communities facing economic difficulties. As global prices have risen for Snow Crab, the benefits to Russia of managing the Barents' stock in addition to the Far East stock are increasing. The diversified portfolio creates greater incentives to conserve the stock in the Barents, particularly as a reserve stock. This enables continued capitalization on the higher prices with little risk to overall supply by harvesting in the Far East. That is, the higher price induces greater interest in conservation of the Barents stock by transferring the use of the stock from open access EU fishing to exclusive Russian fishing. This conservation fosters the continued expansion of the invasion and reduces incentives to research and identify the costs of ecosystem damages.

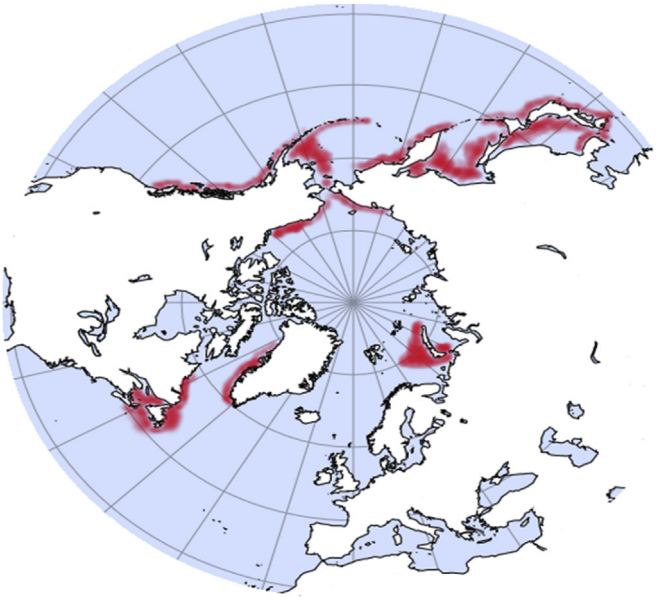

Fig. 2. Global distribution of *C. Opilio.*
Source: (Sokolov and Pavlov, 2016)

4.5. International environmental agreements have loopholes

Russia and Norway became parties of the UN Convention on Biological Diversity long before Snow Crab in the Barents Sea, which can require parties to take remedial actions when an invasive species becomes established. However in this case the CBD COP6 Decision VI/23 on ''Alien species that threaten ecosystems, habitats or species'' has been ignored by both countries and fails to drive ongoing policy on the management of the invasive crab because the introduction of the crab has not been classified as intentional. This is not the first time the two countries have taken a dissenting stance towards a commercially valuable invasion; the aforementioned disagreement regarding the Red King Crab has its basis in the invasive aspects of the population spread. The Red King Crab, for which scientific observations on ecosystem losses are better documented, is an additional case of violation of the CBD (Miljøvernforbund, 2010; WWF-Norge, 2002). The Red King Crab's more southerly and more coastal habitat range does not present the additional property rights issues of the Snow Crab, however.

4.6. Price shifts change incentives for institutions as well as enforcement levels

The crabs may even increase biodiversity in the Barents Sea (Sundet and Hoel, 2016). As profitability of an introduction increases, incentives to capture the profits increase as well. Minimum prices for Canadian Snow Crab jumped 46% in the last year (Navigator, 2017); overall, North American wholesale prices have hit $8 per pound, a rise of 25–50% over most years (McDowell Group, 2016). These trends are expected to continue as Alaskan and Canadian quotas decline. With low levels of regulation and enforcement, higher prices should drive up open access harvesting and stem growth and spread of the invasion. Stakeholders with the ability to adjust institutional mechanisms that can limit this overharvesting will pursue these adjustments; examples include the court cases initiated by Norway's arrests of fishing vessels in both the Loophole and the Svalbard FPZ. Successful implementation of harvest limits increases the profitability for the owners of the resource. In exchange, more tenuous stakeholders' claims, such as those made under the Svalbard Treaty, are reduced. The consolidation of control to the Russian and Norwegian authorities further increases the ability to limit harvest and to stifle concerns about changes to global benefits from e.g. preserving benthic biodiversity.

The expected northwesterly spread of the crab is raising hopes for the opening of a new economic activity in Svalbard (Abelsen and Eftestøl, 2017) that would be open to all parties to the treaty. These economic expectations are generating shifts in the regulatory environment and capital investments to accommodate the crab. Norway's Marine Resources Act was amended in 2016 so that Svalbard fisheries operations now have the same rights and responsibilities as mainland Norway (Nærings- og fiskeridepartementet, 2016). Fish processors are progressing with processing investments on the archipelago; for example, Cape Fish A/S has concrete plans to establish a Snow Crab storage and processing facility, including live export capability, in Longyearbyen

(Engås, 2016).

The payoffs to Norway of excluding others from the Svalbard FPZ are increasing in the increasing prices. This has driven Norwegian efforts to protect the new resource from other international participants through the arrests of vessels in both the Loophole and the Svalbard FPZ as described above.

5. Conclusions and lessons for economic theory and management

We show that assigning unilateral governance rights to economically profitable species with potential and uncertain externalities may be more detrimental than beneficial. We argue that optimal decision-making regarding profitable invasive species must include analysis that extends beyond standard fisheries economics. Importantly, this extension must include not only the consideration of ecosystem risks and damages but also the institutional shifts that may occur in response to the economic incentives presented by the invasion.

The conventional wisdom that property rights improve abilities to solve the externalities fails to hold in the case where the "commons" problem is coupled with a spatial externality. The former open access regime (Barents Sea Loophole) coincided with the invasion frontier and worked to ameliorate damages from the Snow Crab invasion by reducing the externality. The welfare for the two countries, through excluding international participants from the fishery, may increase due to higher fishing rents. This will be at the expense of benthic productivity for Norway and Russia and ecological values to the rest of the world if it turns out that the newly introduced crab is of significant ecological concern. Furthermore, the more long-term the potential economic benefits to those with established property rights on the frontier, the greater likelihood that established, unilateral rights will be enforced for conservation of the resource and increase the potential for ecosystem change.

The cooperation of Russia and Norway is limited at the research front (Korneev et al., 2015). However, the crab invasion might warrant more focused harvest efforts at certain points along the frontier of areas with sensitive benthic habitat. NEAFC's mandate for management of both fisheries and habitat in international waters would support the need for joint management. Currently, there is no plan for joint management on behalf of either side.

The Snow Crab is not the first commercial crustacean invasion shared between Norway and Russia. In the case of the earlier Red King Crab invasion in the southern Barents Sea (Kourantidou et al., 2015), the two countries' cooperation is also limited. This is in spite of the long-standing and well-functioning Joint Russian-Norwegian Fisheries Commission. Initial discussions about management of both species in the Commission led rather to an agreement to act individually; this is clearly a response to economic incentives competing with each other and ecological uncertainties.

Crépin et al. (2017) use the Red King Crab invasion to highlight difficulties from including too few dimensions in management of invasive Barents crab resources, and the benefits of scenario analysis for ecosystem based management. They explore the potential uncertain effects and feedbacks that the complexities of changes brought by the ongoing Red King Crab invasion in the Barents, and remind the reader that "multiple whammies" may overwhelm socio-ecological resiliencies. While superficially similar, the two invasions have considerably different legal frameworks and socio-economic consequences. The newer Snow Crab invasion is a compounding threat rather than a substituting one. Its strategic concerns and required governance interventions are dynamic and uncertain and must involve the multifaceted perspectives we delineate.

The spatial dimension of the externality problem has both ecological and economic complications. The impending range shifts of the Snow Crab indicate that should Norway change to favor control of the invasion over fishery profits, any possible future efforts to prevent the spread further northwest towards Arctic waters are interdependent of management applied in the neighboring Russian jurisdictions. This is a standard concern of invasions that further reduces incentives to identify and include ecological damages in decision-making. Again, joint action is needed between Norway and Russia, but also including any other stakeholders. NEAFC could operationalize this cooperation.

Although both Norway and Russia have recently started enforcing property rights, the question of whether the enforcement benefits are higher than the enforcement costs remains open. If the ecosystem values at stake from the invasion are high enough, enforcement decreases social welfare. We further propose that those enforcement benefits and costs are most likely associated with the continental shelf rights: The rights to the Snow Crab as a continental shelf resource are paving the way for future rights to other valuable resources lying on top or underneath the continental shelf such as oil, gas, minerals etc. On the invasion frontier, one's decisions matter not just for balancing the commercial and ecological benefits of crab harvest in their own waters but also for the spread of the invasion, into other waters west and north.

The Snow Crab presents a useful prism for viewing how multiple ongoing and competing events are identifying conflicts in maritime law that climate change will enhance impacts on species presence and diversity. We identify clearly the economic incentives and asymmetries in this species invasion- turned-fishery in order to explore how climate changes' uncertainties will play out at the international scale. Further, in highlighting these conflicts, we show pathways for reducing social losses from new invasions or species range expansions. These include greater cooperation at all stages, from initial property rights definitions and research through harvest and again in iteration. Additionally, greater dialogue is needed about standard economic recommendations for fisheries management and habitat protection. In this case, we show how an open access fishery may be the most pragmatic second-best option to weigh uncertain outcomes for both economic and environmental gains.

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