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Research agendas for profitable invasive species

Melina Kourantidou and Brooks A. Kaiser

Management & Economics of Resources & Environment Research Group, Department of Sociology, Environmental and Business Economics, University of Southern Denmark, Esbjerg, Denmark

ABSTRACT

Management of natural resources with uncertain net benefits presents an interdisciplinary challenge; economists often must rely on other disciplines to advise and evaluate policies. Net benefits may be uncertain due to absent, inconclusive or contradictory scientific findings. Economics must interpret uncertainties and ground policy recommendations in this context. Understanding biases in primary research agendas and the roles of vertical and horizontal integration in knowledge production and management are essential to prevent sub-optimal allocations across time and space, including avoiding recommendations of excess or insufficient harvest. We empirically investigate these biases by comparing disparate scientific literature and management decisions across vested interests to uncover how economic incentives systematically vary across research investments. The Barents Sea Red King Crab, a simultaneously profitable and invasive species with different net benefits across stakeholders, provides the empirical evidence. We find that scientific consensus is harder to achieve even for primary research when economic incentives differ across research institutions and that research agendas shift over time in response to changes in relative trade-offs between ecological consequences and financial benefits from the resource's presence. Impacts on management are accentuated by integration of the scientific research programmes and management decisions; broadening research participation and agendas may alleviate bias.

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Invasive species; fisheries research; scientific consensus; horizontal/vertical integration in natural resource research and management; research bias

1. Introduction

Applied economic analysis often relies on evidence from other disciplines. Bioeconomic analyses, for example, depend upon biological and ecological evidence regarding the species and systems in question. This evidence is subject to its own discipline's uncertainties. Additionally, the incentives researchers and research funders face in allocating scarce research resources are likely to influence the timing and direction of research. When evidence from another discipline is introduced into an economic model, these uncertainties, along with potential biases, carry forward into the economic results and can impact empirical results and the policy implications one may draw from them.

We investigate how economic incentives and the industrial structure of research and management may affect research agendas in systematic ways that then affect policy recommendations. The objectives of stakeholders often differ across space and time, but also across public and private enterprises, such as government agencies and industries, respectively. High profile cases where research has been funded directly by vested interests with dramatic effects on policy outcomes are well known (Oreskes and Conway 2010), ranging from health effects of tobacco (Barnes and Bero 1996) and

CONTACT Melina Kourantidou mkour@sdu.dk

sugar (Bes-Rastrollo et al. 2013) to valuation tools in environmental economics (McFadden and Train 2017) and climate change impacts of fossil fuels (Dryzek, Norgaard, and Schlosberg 2011).

We examine the more subtle case of a potentially profitable biological invasion, in which a decision-maker's interests and control over research agendas and outcomes are less clear-cut. Public governance institutions, such as environmental and resource management agencies, are often faced with ambiguity when it comes to assigning weights to different decision-making factors (McFadden 1975; Fernandez 2004). The ambiguity also stems in part from the decision-maker's role as both present and future stakeholder in the existing system's productivity and potential shifts in that productivity. McFadden (1975) points out that decisions from public agencies whose objective is to maximize 'public welfare' can be vulnerable to criticism on grounds of inconsistency or of lack of fidelity to the objective.

Here, we assess the case of a purposeful introduction made by one nation which has spread to its neighbour. We expect that, ceteris paribus, the incentives of the introducing state may favour scientific research that promotes the positive, profitable aspects of the species while the neighbour may be more sceptical. The questions are, is this possible bias borne out in comparisons of ecological research by the neighbouring countries, and how do research patterns evolve over time with the invasion's progress?

The questions identify challenges embedded in the decision-making process for invasive species management in cases where there is limited consensus among scientists looking at the externalities of the invasion. Economics is key for decomposing and building a better understanding of invasion processes, impacts and decision-making (Epanchin-Niell 2017). As Epanchin-Niell (2017), Kaiser and Burnett (2010), Kovacs et al. (2010) and many others point out, biological invasions are driven by and affect economic activities at multiple scales and stages of an invasion. This is why evaluating potential management strategies demands integration of bioeconomic factors. In practice, though, it is often the case that resource managers trained in biological and ecological sciences become primary policy advisors, so that policies often rely heavily on biological research while lacking economic underpinnings (Karpoff 1987). This creates vertical integration in the production of the resource that may close off, in particular, informational input that can improve management outcomes. This is also one reason why Maximum Sustainable Yield might dominate Maximum Economic Yield in renewable resource harvesting rules.

Learning over time may also affect the research agenda. This learning includes not only the potential ecological effects of the invasion, but also the economic ones. One might anticipate that the trend in research and its findings over time may reflect the more defined economic expectations of the stakeholders in the fishing industry as much or more than pure scientific knowledge. Greater interaction with researchers that have different interests may reduce potential biases in research output by increasing the access to information. This could happen through increased horizontal integration of research that connects research insights across disciplinary and stakeholder lines. On the other hand, if horizontal integration is limited to science focusing on the same potential effects and interests, then horizontal integration may reinforce biases.

Answers to these questions also inform more broadly on the cautions needed in adapting scientific research from other disciplines into economic analyses. Our study highlights that economic incentives affect policy and outcomes well before any official discussions or debates occur, and that they delimit the scope of the final stages of resource management. This is in keeping with findings such as those in Ando (1999), Lueck and Michael (2003) and List, Margolis, Osgood (2006) that show how economic forces shape the process of becoming listed as an endangered species under the US Endangered Species Act in spite of explicit requirements that only ecological considerations factor into decision-making.

Scientists are aware of potential biases in invasion biology research that stem from language use as well. Warren et al. (2017) test whether the negative language used to portray invasive species creates bias in results when comparing the competitive dominance of invasive versus native species. They find that some bias has been introduced over the years of research in the field, so that texts with boilerplate negative introductions of invasions find higher rates of competitiveness on average. This bias seems to be in the process of self-correcting when tested empirically (Warren et al. 2017). The primary science, in other words, cannot entirely sustain a bias based on language for long in the face of empirical evidence and peer-reviewed publication processes. Does this self-correction also exist in research agendas where research outcomes affect stakeholders differently? If the difference in stakes creates increased incentives for vertical integration in scientific research and management that shuts off avenues for contrary information to reach decision-making bodies, such self-correction becomes less likely.

We provide an extensive review of the existing literature on impact studies for the biology and ecology features of an ongoing crab invasion in the Barents Sea and highlight why the observed discrepancies in the literature merit consideration in policy planning as well as their role in driving future research directions. Russia and Norway must each decide how to treat and manage the invasion; these decisions depend on the quality and breadth of scientific input to the resource managers. The literature presents primary evidence, mainly authored by Norwegian and Russian authors from the late 1990s to the present, and includes both grey literature and peer-reviewed publications. We use logistic regression to empirically evaluate this literature in an effort to uncover systematic relationships in research findings as a function of conflicting economic incentives. The conflicting incentives stem from the dual nature of the species introduction as simultaneously a costly invasion and a profitable fishery resource. We find evidence that the research agendas and findings of Norwegian and Russian authors differ. Furthermore, this relationship has changed over time in ways that increase support for the primacy of the fisheries over other uses of the natural capital in the Barents.

2. Overview of research on the red king crab invasion in the Barents

The Red King Crab *(Paralithodes camtschaticus)* invasion (hereafter RKC) in the Barents Sea provides an excellent example for addressing how research develops over time in a context of uncertainties and ambivalent human preferences. Purposefully introduced in the 1960's (Orlov and Ivanov 1978), the RKC population has evolved into separately managed, lucrative fisheries for both Norway and Russia over the last 15 years. After Soviet Union scientists introduced the crab in Murmansk, the RKC spread west to Norway beginning in the late 1970s and established a self-reproductive population in the southern Barents Sea (Jørgensen et al. 2005). Current management of the species and the structure of the industry differ across national lines. These differences result directly from different consequences of, and responses to, the ongoing biological invasion. In Russia, the fishery is mainly offshore, controlled by a monopolized fleet (FAS 2016). In Norway, the fishery is coastal, with the aim of enhancing fishing profits to local residents. Management policy within Norway is further split, in direct response to ecological research (Sundet and Hoel 2016); since 2008, there has been an open-access fishery on the western frontier of the invasion that is intended to stop its further spread (Fiskeri-og Kystdepartement 2007).

This heterogeneity in the management and fleet organization for the crab may impact the way future research agendas of integrated research and management agencies, such as the ones governing RKC fisheries in Norway and Russia, are being set. In particular, research agendas might focus on direct impacts to other commercial species, or on indirect impacts of the crab as a disease vector or a disruptor of the benthic habitat. Answers to these research questions will, in turn, influence regulation of the fisheries in potentially disparate ways. The confirmation of damages to other commercial species introduces a clear market-measurable, bioeconomic trade-off that recommends harvest of the crab in ways that explicitly recognize the marginal profits of each species. It could make excellent economic sense to allow the crab invasion to supplant a less profitable fishery. On the other hand, indirect effects in which damages occur to the underlying productivity of a difficult-to-value benthos might require harvesting efforts that drive the species' presence to effective extinction in exchange for uncertain and more diffusely beneficial returns. These diffuse returns might include biodiversity conservation. Over time, the progression of the invasion may render opportunities for conservation moot, as ecosystems transform in response to the crab's presence. This is potentially already the case with the Russian fishery, where the invasive crab has been present for more than 40 years.

Studies have sought to identify biological characteristics and ecosystem impacts of the invasion since the crab's successful establishment. From the late 1990's onward, there has been a proliferation of publications in a variety of outlets, in addition to meetings, workshops and symposia held in an effort to identify the magnitude of impacts of the introduced species and provide policy recommendations for its management. This research has been conducted in Norway by the Institute of Marine Research (IMR), and in Russia by the Knipovich Polar Research Institute of Marine Fisheries and Oceanography (PINRO) and the Russian Research Institute of Fisheries and Oceanography (VNIRO), as well as by academics in either Norway or Russia who are closely connected with the aforementioned research and management groups. The large number of studies on the invasive crab can be attributed to its commercial value and the increasing interest for commercial exploitation. Spiridonov and Zalota (2017) view the intensity of research on the RKC, due to its commercial value, as a driver of biases. Such biases are similar to the ones manifested in Conservation and Endangered Species research for charismatic megafauna (see for example Kotchen and Reiling 2000; Swaisgood and Shepherdson 2005; McClenachan et al. 2012).

Despite the great bulk of research on the commercially valuable crab, the impacts identified to date remain incompletely specified. The research often provides inconclusive or even contradictory results, reducing the potential effectiveness of decision-making and complicating the process of identifying the optimal stock. A series of biological and ecological uncertainties regarding the introduced species stands behind this managerial challenge.

Two main categories of uncertainties exist. The first consists of uncertainties about how the crab will fare in the Barents Sea. This includes how the sea's conditions provide favourable or unfavourable habitat with respect to e.g. salinity (Jørgensen et al. 2005) or the crab's adaptation to the natural environment (Daly, Stoner, and Eckert 2012), or more directly for short term fishery management, the population stock estimates (Bakanev and Berenboim 2007; Manushin 2012), the age structure of the population (Bakanev 2009) and estimates of the juvenile crab stock (Oseth 2008). Resolving such uncertainties delineates the potential for the Barents as a source of commercial Red King Crab as well as the potential extent of the invasion.

The second consists of uncertainties about how the ecosystem will respond to the crab's establishment in the Barents Sea. These latter uncertainties are the least well understood. Resolving them delineates the potential for ecological damages to the benthic habitat and its productivity for other economic and ecological purposes. Over the last 20 years, marine biologists, parasitologists and benthic ecologists from both Norway and Russia have been publishing the results of their field and laboratory experiments on both types of uncertainties in an attempt to identify the invasive species' impacts on the ecosystem and provide management suggestions to policy-makers. We focus here on the primary literature pertaining to the second set of uncertainties.

The RKC in the Barents Sea has generally been referred to as an 'invasion', which by definition implies negative ecosystem impacts, although the species has not necessarily been managed as one. As an intentional introduction, the initial Russian plans of developing a commercial fishery are transparent. Longstanding cooperation with Norway in Barents Sea fisheries enabled Russia to persuade Norway to delay any actions that might have stemmed the invasion at the Russian-Norwegian border in the 1970s (see for example Eldorhagen 2008; Broderstad and Eythorsson 2014; Falk-Petersen 2014; Sundet and Hoel 2016). The high potential profitability of the crab may also have influenced Norway's willingness to delay action.

Complaints by Norway's coastal fishers about damages to gear and other commercial losses from RKC bycatch spurred the first active management action in Norway; Russian authorities followed suit, and fisheries-related research activities commenced in the early to mid-1990s. The increasing population of the new species in the early 1990's also triggered the interest of biologists and ecologists who started looking at potential (lab studies) and actual (field studies) environmental degradation from the invasion. Norwegian research led to the policy decision to attempt to curb the spread of the invasion starting officially in 2008 through high harvest levels, as mentioned;[1] At this time formal cooperation with Russia ceased, as the Russians wished to continue conservative management of the RKC as a fishery resource rather than increase current harvests at the expense of future profits.

In recent years some studies from both sides of the border have found either negligible impacts or evidence indicating that the impacts are not as detrimental as previously believed (Dvoretsky and Dvoretsky 2015; Oug, Sundet, and Cochrane 2018). These results suggest that applying a high fishing mortality for the purposes of controlling the population of the invasion may no longer be the preferred policy. In addition, some recent research attributes ecosystem benefits to the introduction of the crab; a prime example is the crab's predation upon sea urchins, a process which helps protect the kelp forests (Norderhaug et al. 2016). Such positive effects are not yet considered certain and remain disputed among experts (Sivertsen 2006) (Knut Sivertsen, UiT, personal communication). Shifts in the focus and results of review studies, scientific reports, and the way the press portray the crab's presence in the Barents all reveal that perceptions have changed broadly over time and that there remains a divergence of scientific opinion regarding the presence or absence of significant ecological impacts from the invasion. A significant concern for the resource economist is that both this evolution in perceptions and the persistent divergence of opinion stem not only from independent scientific progress but potentially from biases built into research agendas and stakeholder preferences.

As resource economists seeking to identify the optimal management of the species and the existing trade-offs, our understanding of the impacts from the invasion is frequently limited to exogenously produced biological studies; if the divergence in study results is driven by systematic economic factors rather than ecological complexities, the uncertainty in the ecological literature must be explicitly addressed as an economic phenomenon in order to properly advise policy decisions on the management of the fishery/invasion. For example, currently there are growing stakeholder pressures to move the line that delineates Norway's limited entry long-term fishery from its open-access fishery so that more area is dedicated to the long-term fishery (Bakke-Jensen and Grimstad 2016; Berg 2017; Forland 2017).

If there really are few negative impacts from the crab, failure to move the line west will be costly to crab fishers and the communities in which they live. On the other hand, if there are significant negative impacts from the crab, moving the line west threatens the productivity of the ecosystem across a wide range of commercial and non-commercial benefits. The irreversible losses that the expansion of the commercial crab fishery would trigger should be delayed until clearer understanding of the ecological impacts is available; such understanding must include interpretation of the economic incentives inherent in the research agendas.

Searches were made from 2014 til 2017 in the following databases and research repositories: Scopus, ScienceDirect, Google Scholar, IMR's archive publications (Books, Chronicles, Scientific Publication Series, IMR-PINRO reports, Survey Reports), archives of PINRO and VNIRO, as well as ResearchGate profiles of individual researchers. The search terms that were used included all types of impacts in all three relevant languages (English, Norwegian and Russian).

The studies highlight how research has evolved over time, possibly impacting policy making. To limit the potential for overweighting some research findings over others, while we collected all studies on the RKC's impacts in the Barents Sea, we have limited our quantitative analysis to include only research studies that report original results from either laboratory experiments or field surveys in the area. We further reduce the task of evaluating the quality of the research by including only papers or reports from the study area (Barents Sea) that have already been published, though the extent of peer review in some cases is uncertain.

To the best of our knowledge, we have included virtually all studies that cover the impact literature on the invasive crab in the Barents Sea. As only studies available and accessible to the academic public have been included in the analysis, it is likely that some reports or papers that have not been distributed outside the immediate study environment or research facility are omitted (see Appendix C for a list non-publicly available studies, identified in our search, which we expect that they document impacts from the invasion). This is likely to be especially the case for research from Russian research institutes. Russian biodiversity data are often fragmented and inaccessible; most of the Russian biodiversity databases lack web interfaces and are accessible to only a limited number of researchers (Ivanova and Shashkov 2016). Our sampling procedure may therefore suffer from some absent information with respect to the work of either 'secondary-nature' studies or studies which are not publicly available/accessible.[2] The missing information is expected, if anything, to reinforce any biases identified due to the fact that language and open-access are the most likely barriers to their inclusion.

3. The data: uncovering economic influences in ecological research findings

One tool economics can use to identify estimates of ecological impacts and the uncertainty surrounding them from a range of disparate research sources is meta-analysis. When research classifies impacts and their sources in consistent, comparable measurements, a meta-analysis can, for example, provide a point estimate and variance characteristics for an ecological impact given a particular source of change. The results of such a meta-analysis can ground-truth the body of research with respect to its findings and uncover economic biases in the research and its findings. Kaiser (2006) identifies, for example, a strategic gap between US Forest Services' stated preferences for timber harvest externalities and revealed preferences elicited by analysis of expected impacts of different timber harvest actions across multiple proposed timber sales. Further, she identifies agency incentives and ecological conditions that changed the gap when new requirements of the National Environmental Policy Act (1970) for documentation and public review interacted with other changes in environmental legislation.

In the case of the RKC in the Barents, one might imagine a series of studies that investigate the predation of the crab on another species that return an expected percentage loss that is conditional on crab densities or other ecological and economic conditions, for example. Then such studies could be examined to identify systematic biases in research conditions that minimize or accentuate the findings of impact relative to the mean impacts. Such directly comparable studies do not exist, however, so formal meta-analysis cannot assist us in uncovering economic influences in expected impacts.

Instead, we consider that the probability that a study finds non-negligible negative impacts from the crab is a function of the presence of actual negative impacts and the economic incentives inherent in the research. Thus:

$$\Pr(\textit{Negative Impact}) = f(R,P,T,S),$$

where $\Pr(\textit{NegativeImpact})$ is defined as the Probability that the study finds negative impacts of the crab on any number of possible outcomes, R is the Research Environment, P is the Study Purpose or the type of expected impact, T is the Timing of the study and S is the Scope of Research.

We discuss the explanatory variables identified from the studies and their expected role in influencing the probability of finding negative impacts below.

To determine the effect of these components of the research on their findings, we identify a total of 89 observations of relations between crabs and their new environment studied for potential impacts from 42 published impact studies,[3] which include both papers in peer-reviewed journals and reports from either IMR or PINRO.

3.1. Research environment

As discussed, Russian and Norwegian research and management agency incentives may differ from one another. The authorship of the research may reflect the economic parameters of the research environment, so that Russian results may favour findings of no significant impacts as compared to Norwegian research. This is particularly the case for the RKC because much of the primary research takes place within the same institutions that make policy recommendations for the fisheries – they are in fact vertically integrated. Connections between these institutions and academic researchers in the field are also strong. We note that only two studies are co-authored by researchers from institutes other than the main Norwegian and Russian ones. We include those two studies among the ones authored in Norway, since the primary authors are from Norwegian research institutes and Norwegian universities in both cases. All of the research results thus stem primarily from one of the two nations. This fact highlights that while the invasion may have broader regional or global consequences if it continues to spread or if it threatens global assets including biodiversity, control over research access in the area results in consistent involvement of the local stakeholders (and potential exclusion of others).

While there exist joint Russian-Norwegian research activities, including annual trawl surveys, co-writing and publication with Russian co-authors continues to face significant barriers – indeed, barriers are significant enough to have instigated a formal agreement through the Arctic Council in 2017 (U.S. Department of State 2017). The difficulties extend to publication language. All the Norwegian studies have been published in English, with the exception of the (generally early) studies on bycatches which are in Norwegian. On the other hand, almost half of the studies by Russian authors have been published only in Russian.

Fewer than half of the studies (19) have been published in international peer-reviewed journals. Figure 1 shows the number of peer-reviewed studies per category of impact (described further below) studied from 1998 until today. We include in our analysis grey literature as well, because we consider it to be valuable source of information that influences management decisions in both the Russian and the Norwegian jurisdiction.[4] The majority of studies from Russian institutes in this field are published in grey literature, an observation also confirmed by Spiridonov and Zalota (2017).

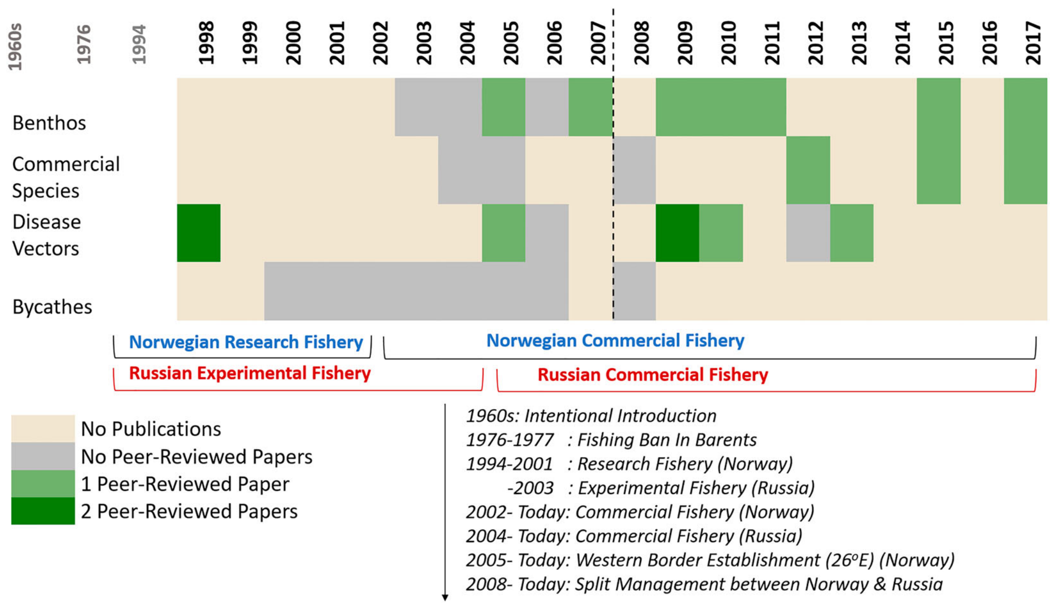

Figure 1. Studies published in international peer-reviewed journals across the research and commercial RKC fisheries in Norway and Russia.

In Figure 1, years with no publications are shown in the palest shading; years where only grey literature was published are shown in grey colour, and years with one or two peer-reviewed papers are shown in graded green colour scale. The distinction between these three latter categories helps visualize how, for benthic and commercial species, publications have moved from non-peer reviewed publications to peer-reviewed publications over the years, whereas this is not the case for bycatch, and the relationship is also less systematic for disease vector research.

Figure 1 also presents a historical timeline of the species' management. The species was originally introduced in Murmansk in the 1960s (Orlov and Ivanov 1978), without prior consent of the Norwegians. In 1976–1977, in negotiations between Norway and the Soviet Union, the two countries agreed to a complete ban in the Barents Sea (Grey Zone Agreement of 1978, see Sundet and Hoel 2016). The first crab was identified in Norwegian waters in 1977[5] and by 1992 the first bycatch issues in traditional fisheries start coming to the surface (Sundet and Hoel 2016). In 1993 the RKC issue appeared for the first time on the agenda of the Russian-Norwegian Fisheries Commission. In 1994, Norway opened a research fishery, and in 2002, a commercial fishery. In Russia the commercial fishery opened in 2004. In 2005, the two countries agreed to establish a western boundary at 26° E, in order to allow for a free-fishing zone to the west of that point. In 2007, the two countries officially agreed to separately set their management goals and to implement harvest control rules within their EEZs independently (Sundet and Hoel 2016).

The above considerations mean that the research home of the primary author identifies with fairly robust certainty whether the invasion impact identified reflects primarily Russian or Norwegian research interests. We use a categorical variable for the country where the research was produced.[6]

3.2. Study purpose

Ideally, the specific impacts from the invasion and their causes could be included as direct influencers on the probability of finding a negative effect. With so few studies, we choose to combine impacts into four different primary types. The types differ in their economic and ecological purviews and so we expect the probability of finding negative effects to vary. The types are: (1) Bycatch in traditional fisheries, (2) Predation upon other commercial species, (3) Introduction of parasites, symbionts and commensals (disease vectors) transported e.g. through the carapace of the crab that are likely to spread infestations, and (4) Degradation of the benthic ecosystem (mostly over the past decade). Figure 2 illustrates the division of these types across authorship lines for the published studies. The pie charts in each country show the distribution of study types, with one chart showing the distribution for negative impacts and the other for limited concerns or no impacts at all. Here one sees that the Norwegians do more frequently find negative impacts across all types of studies.

We exclude from our quantitative analysis the studies on bycatch (eight observations) since they are all Norwegian, and the lack of variation precludes econometric analysis (see summary statistics for the studies included in the analysis, in Table 1). The bycatch studies also focus mainly on direct and visible impacts and there can be little scientific controversy regarding their existence or absence, so we expect little bias in their findings. We discuss below qualitatively what the timing and location of the bycatch studies indicate about economic incentives for research agendas.

We consider the scientific controversy on the impacts to the benthic species to be the most relevant to our questions. Biodiversity losses from the benthos do not have an easily calculable direct or even indirect market value. This reduces their position in any myopic balancing of ecological costs and economic benefits compared to the impacts on other commercial species and the losses from bycatches that do.

The process of classifying the results of the different studies into the impact categories (see Table 1) has not been straightforward. We went through each study in detail and identified not only the

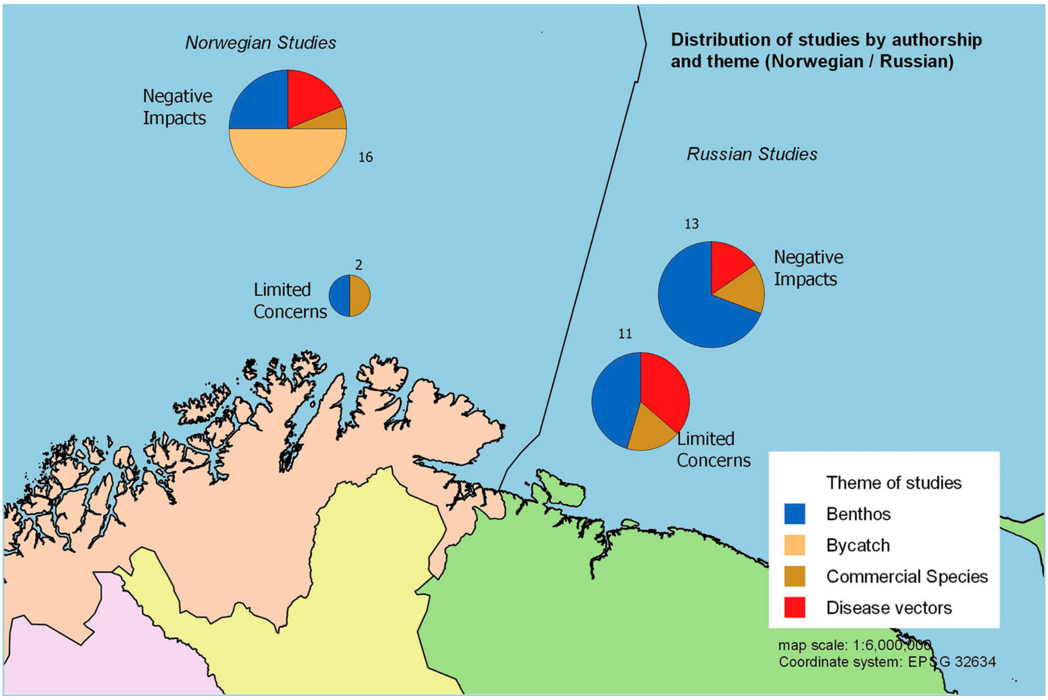

Figure 2. Published studies in Norway and Russia by theme and effect documented.

Table 1. Summary statistics.

	Observations	Mean	Std. Dev.	Min	Max
Effect* (Negative/Limited)	89	0.57303	0.497439	0	1
Authorship* (Norwegian/Russian)	89	0.37078	0.485752	0	1
Language* (English/Russian)	34	0.32352	0.474858	0	1
Number of observations in studies*	89	18.30337	6.823097	1	34
Year (1998–2017)	42	10.07143	4.468823	1	20
Peer review	42	0.45238	0.503760	0	1
Benthic studies	69				
Commercial species studies	11				
Disease vectors studies	9				
Bycatch studies**	8				

* Does not include bycatch studies.
**Not included in the regression analysis.

impact as reported through objective biological results but also the author's interpretation of those results. For example in some studies, although the authors find a certain objective predation rate upon some species, they do not consider that this can put the prey at threat of extinction and therefore argue that the RKC is not an environmental stressor. Other studies looking at benthic habitats have documented declines in some species but recovery in other species throughout time. In capturing the interpretation of impacts by scientists rather than more objective measures, the results speak directly to research biases becoming built into the decision-making.

We treat benthic ecosystem impacts as the base (omitted) categorical variable. Relative to this base, we are agnostic about the potential direction of influence on the probability of finding negative effects of predation on other commercial species or the co-introduction of diseases. We suggest only that they are fixed effects that cover differences in the study theme in order to better isolate impacts of time and authorship.

3.3. Timing of study

We expect that the timing of the publication matters, and the direction in which more recent publications influence the probability of finding effects will provide pertinent information regarding the extent and import of any research biases. Thus we include a yearly index for the year of publication as an explanatory variable (starting in 1998). The studies cover the time period from 1998 to 2017. We expect that over time, as the value of the fishery has become more clear, studies may be less likely to identify negative impacts to ecosystems and commercial species alike. Furthermore, we expect that, because Russian scientists introduced the species for the purposes of developing a commercial fishery, the Norwegians, on the invasion's frontier and not party to the decision to introduce the species, might initially find more negative impacts, but that this may evolve over time. We include an interaction term of Russian authorship and year to examine this possibility.

Figure (3) shows the distribution across time of all 42 of the impact studies for the invasion, classified based on their research foci as described above.

Research increased from the late 1990s to the mid 2000s, but then fell considerably, with two recent years providing no new findings at all. Several aspects of the data shown in Figure 3 bear additional qualitative explanation in addition to the quantitative analysis presented below.[7]

A prominent source of complications from marine invasions in general are related introductions or increases in parasites, the role of which can be pervasive in marine systems (Torchin, Lafferty, and Kuris 2002). Early consideration that new parasites could be introduced via the RKC and might endanger the valuable cod fishery gave rise to parasitological studies as early as the late 1990's (Bakay, Kuzmin, Utevsky 1998; Jansen, Mackenzie, and Hemmingsen 1998). Additional research in this area then did not occur until the mid 2000s, however. In the meantime, RKC bycatch in Northern Finnmark's traditional fisheries started becoming a noticeable nuisance in the 1980s, and problems continued to increase over the years (Fiskeri-og Kystdepartement 2007).

By 1992 there was a sufficiently large amount of crab bycatch by Norwegian fishers (Fiskeri-og Kystdepartement 2007) so that the costly interference with gear and catch of other fisheries had

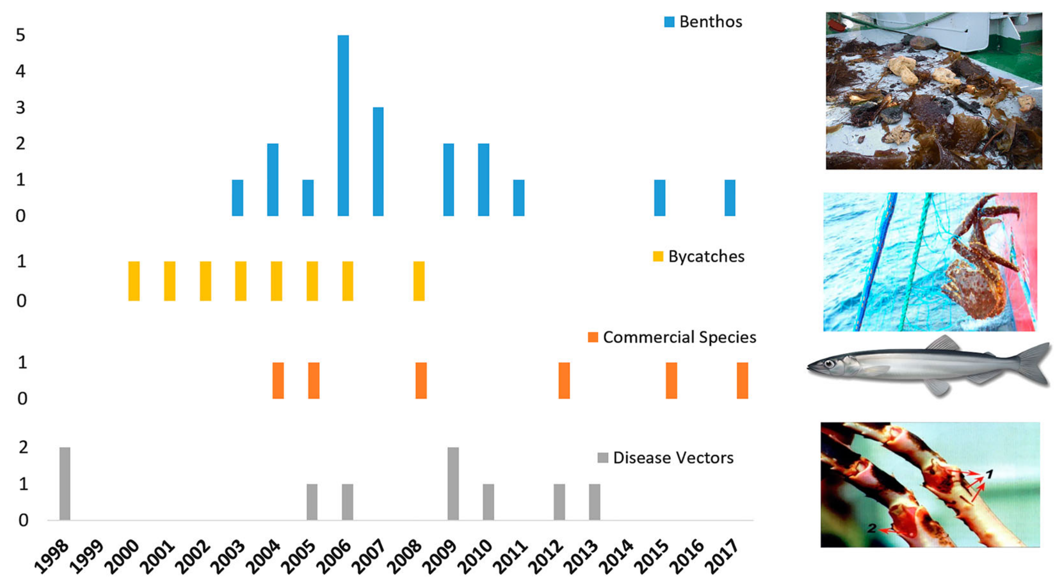

Figure 3. Published impact studies on the invasive RKC in the Barents Sea (1998–2017).

Image Credits for degradated benthos, crab bycatches in nets, Capelin *(Mallotus villosus)* and Johanssonia arctica parasite infections of RKC in: Oug et al. (2011), Endless Ocean Wiki – Fandom, Furevik and Ulvestad (2012), Bakay and Karasev (2006).

grown contentious. These damages to the coastal fishing fleet drove the first bycatch studies. Norwegians conducted studies on bycatch on an almost annual basis up until the implementation of the 2007 White Paper (adopted in 2008) that set up the first formal management regime for the RKC in Norwegian waters (Fiskeri-og Kystdepartement 2007), at which point such studies virtually stopped.[8]

There is less knowledge on the costs of crab bycatch in the Russian jurisdiction for traditional coastal fisheries, but these fisheries are in any case limited in size and scope compared to the Norwegian coastal fleet's economic importance. Coastal fishing for crab in the Russian zone has been banned since 2011 (Zalota 2012).[9] One can see, for example, via inspection of the Russian coast on Global Fishing Watch's map of vessel activity from 2012 to the present,[10] that virtually no fishing is visible directly on the coast of Russia in the Barents Sea; the implication of this, given international requirements for Automatic Identification Systems (AIS) onboard any vessel greater than 15 metres, is that coastal fishing vessels, to the extent that they exist, are quite small. The northern Norwegian coast, on the other hand, shows extensive fishing effort for different types of fisheries, including crab.

Following the identification of impacts for other commercial fisheries through bycatch, concerns started for the first time in the early 2000's on indirect impacts to the benthic ecosystems as well as on indirect effects to other commercial species via food-web links. The pattern in the research objectives of the studies over the years shows that research on impacts did not start as an ecological concern regarding the invasion but rather as an economic concern for the costs to the overlapping fisheries. It is not clear whether the shift from the bycatch studies to more studies on benthic impacts over time can be attributed to increasing ecological concerns or whether it is due to a more lengthy research process in the study of impacted benthic ecosystems compared to the bycatch studies.

As mentioned, Figure 1 shows the timeline for fishery activities in Russia and Norway. Although it is hard to establish a definitive link between the regulatory changes and the dissemination of scientific results over time, we postulate that either the 2007 split in the joint management led to changes in the way the two countries started prioritizing their research on the RKC, or that the diverging results from impact studies before 2007 led to the split in management. The overall number of the impact studies peaked in 2006. Up until 2007, the two countries had agreed to jointly manage the RKC in order to maintain long-term fisheries but also to attempt to limit the spread westwards. They agreed in 2004 to establish an open-access fishery west of 26° E until more knowledge about the ecological impact of this introduced species could be obtained. Norway has unilaterally maintained this delineation after the international agreement ended. Their research, however, tends to occur to the east of the 26° E line; there have been no significant knowledge gains on the invasion frontier (west of 26° E).

We attribute the lack of interest for studying bycatch in the last decade to the allocation of crab quotas as a compensation to the fishers who suffered costs from bycatches in the past. Furthermore it is reasonable to assume that since the landings values from the crab far outweigh the bycatch costs, the social pressure regarding the problem of bycatch has been reduced.[11]

3.4. Scope of research

The unit of observation is a potential impact from the RKC, not the research document per se. Several of the studies in our dataset studied potential impacts for more than one species, so that in cases where those individual effects are distinguishable, the individual impacts have been used as separate observations from the same study. We include a dummy variable (Multiple Impacts) indicating whether there are consequences of grouping the impact studies into one research output. We consider this variable as capturing the scope of the research. If studies that take a broader approach to the potential impacts from the RKC systematically find either more or fewer negative impacts, then this suggests that increased scope may matter directly to policy.

4. The probability of finding negative effects

4.1. Limited dependent variable model

The existing body of research allows us to to think critically about how the research efforts both reflect and impact decisions over the balancing act between commercial profits and uncertain externalities.

Research findings that bias policy in favour of continued expansion of the invasion exchange current profitability for uncertain future ecosystem productivity. In this case, the exchange crosses international borders, so that a divergence in research findings across those borders may increase management tensions for the invading resource. We run a binary logistic regression to establish how the characteristics of the research described above influence whether or not the research finds a negative effect from the crab. Thus the dependent variable, Negative effect, takes the value of 1 if the research finds a negative effect and 0 otherwise. Findings of limited concerns are categorized as no effect.

The regression results are shown in Table 2, Column 1, as odds ratios. For completeness we also include the coefficients from estimating the Logit, Probit and Linear Probability Model (LPM) in columns 2, 3 and 4 respectively. The three regressions yield similar results and concur regarding direction, relative magnitude, and significance of impacts of the explanatory variables; the results are robust to our choice of the functional form.[12] In what follows we discuss and interpret the odds ratio from the logistic regression.

Recall that an odds ratio of 1 indicates that the explanatory variable has no impact on the probability in question – that is, the explanatory variable is an insignificant influence on the dependent variable. Since the explanatory variables in the regression are categorical, an odds ratio less than 1 indicates that if the categorical variable's value is 1, then this decreases the odds that the probability event will happen, i.e. in this regression that a negative impact from the invasion will be found via the research. An odds ratio greater than 1 signifies the opposite. That is, it is more likely than average that the scientific research finds a negative effect from the crab's invasion.

The extremely low and significant odds ratio reported for Russian Authorship (0.0003) is in accordance with the picture presented in Figure 2. That is, Russian authorship is a strong indication

Table 2. Results of logistic/logit, probit and LPM regression.

	Logistic	Logit	Probit	LPM
Effect	Odds ratio	Coef.	Coef.	Coef.
Russian Authorship	0.0003**	−8.2381**	−5.0495**	−0.8271**
	(0.0011)	(4.1605)	(2.5617)	(0.3117)
Year	0.6781**	−0.3884**	−0.2399**	−0.0470**
	(0.1098)	(0.1618)	(0.1003)	(0.0154)
Russian Authorship*Year	1.4322*	0.3592*	0.2181*	0.0368
	(0.2972)	(0.2075)	(0.1277)	(0.0243)
Multiple impacts	0.8966*	−0.1091*	−0.0673*	−0.0092
	(0.0578)	(0.0644)	(0.0394)	(0.0056)
Commercial Species	0.1289**	−2.0485**	−1.2472**	−0.3699**
	(0.1220)	(0.9466)	(0.5511)	(0.1763)
Disease Vectors	0.2412	−1.4222	−0.8750	−0.2848
	(0.2402)	(0.9957)	(0.6063)	(0.1941)
Constant	12541.76**	9.4368**	5.8264**	1.5894***
	(50353.94)	(4.0149)	(2.4758)	(0.2418)
Number of Observations: 89	LR chi2(6) = 16.58		LR chi2(6) = 16.74	F(6,82) = 2.30
	Prob > chi2 = 0.0110		Prob > chi2 = 0.0103	Prob > F = 0.0417
	Pseudo R2 = 0.1365		Pseudo R2 = 0.1378	*R*−squared = 0.1443
	Log likelihood = −52.4467		Log likelihood = −52.3648	Adj *R*−squared = 0.0817
				Root MSE = 0.47669
	(Logistic/Logit)		(Probit)	(OLS)

*,** indicate statistical significance at the 90th and 95th percentiles respectively
Standard errors are reported in parentheses.

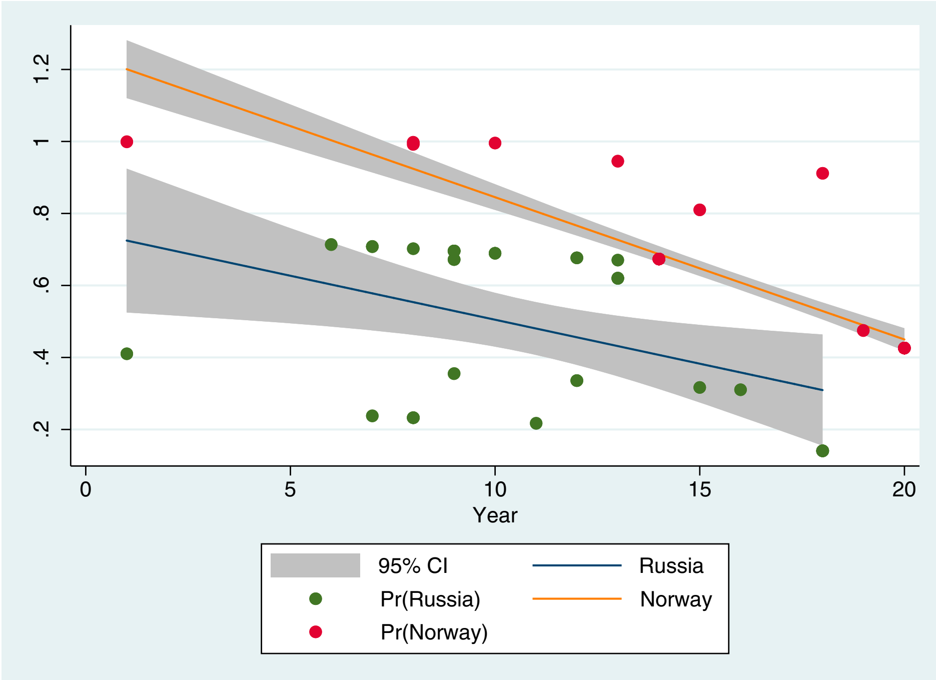

Figure 4. Predicted probabilities of Norwegians and Russians for finding negative impacts over time (confidence interval at 95%).

that the research will find no negative impacts from the invasion. The time trend also indicates that over time, it has become less likely for studies documenting negative impacts from the invasion to be published. More specifically, when we include the interaction term of the time trend with Russian authorship it reveals that this relationship is changing differently for Russian and Norwegian scholarship. The counter-effect of the interaction term on the time trend for Russian authorship nearly negates the effect; the probability that Russian scholarship finds negative results does not change greatly over time. This is in comparison to a strongly decreasing probability that Norwegian scholarship finds negative impacts over the same time period. The gap in influences appears to be closing between Russian and Norwegian scientists throughout time. This is also illustrated in Figure 4 which shows the predicted probability of finding a negative effect from the invasion in either Russian or Norwegian literature with a 95% confidence interval (linear fit).

From the odds ratio on 'Multiple Impacts', we see that more broadly scoped studies generate a small decrease in the probability that a negative effect from the invasion is found. There may be a tendency in larger scale studies to perceive individual impacts as less consequential.

Finally, disease vector studies are not significantly different from benthic studies, while commercial species studies appear much less likely to find negative impacts.

4.2. Selection bias concerns

Our results show fewer negative impacts documented over time in the Norwegian literature. This observation sheds light on the question of how the research foci and the resources for biological and ecological research should be prioritized. Whilst the knowledge gaps on the invasion impacts persist, the evidence from the literature for fewer or not significant impacts is likely to shift the research interests towards other stressors of the marine ecosystem. We expect that the weaker support of adverse effects of the invasion, reinforced by the 'publish or perish' culture in academia, might demotivate scientists in the future from initiating research on this topic. This is because scientists are usually more likely to engage in research where they expect that they can support their experimental hypothesis (e.g. the negative impacts of the invasion) against a 'null' hypothesis of no effect. This creates a scientific bias attributed to the pressure to publish within academia (see Fanelli 2010) while it may limit access to important data and therefore skew the results of reviews (Misakian and Bero 1998).

Arguably the cause–effect relationship could be reversed: The 'file-drawer effect' is the publication bias which arises when the probability of a study getting published depends on whether it can support the testable hypothesis and/or the statistical significance of its results (Rosenthal 1979); this might imply that the studies documenting limited impacts of the invasion might perish, therefore creating a bias in the published research. However we view the risk of a lower interest in further study of the invasion impacts as more critical than the 'file-drawer effect'. The impact studies affect regulators' decisions on fishing mortality. The uncertainties about the invasion impacts are still high; the crab may still be adapting to the ecosystem and continue to change its predatory behaviour. It is common for newly introduced species to change their behaviour once they find their niche in a new ecosystem (Shea and Chesson 2002).

The dataset used for the regression analysis includes both studies which are peer-reviewed and studies that belong to the grey literature. In order to control for selection biases within the literature and detect any endogenous regressors associated with this feature of the studies (peer review process), we performed a Hausman specification test. As expected, the model fitted on this small dataset fails to meet the asympotic assumptions of the Hausman test.

However, the observations in our dataset (see Table 3) do not indicate that the negative results of the studies are what drives publication. Further, the time trends in refereed studies and the probability of finding negative impacts are counter to each other. We therefore do not consider those type of publication biases as relevant for the case of the RKC. We also confirm this using the fact that over time, more studies that find no negative impact are being published.

5. Discussion

Through our analysis we address the challenges embedded in the process of translating existing research findings into policy-relevant guidance for resource management. Policy-makers whose short-run and long-run management options rely on the available knowledge as reflected in the literature face a major political roadblock. Our results demonstrate a clear divergence among research being conducted in Norway and in Russia. This divergence is susceptible to various interpretations. Given that the introduction was purposeful and originated from the Soviet Union, one possible explanation is that there is a limited interest and/or resources for exploring negative externalities of the invasion in Russia. Russian institutes may choose not to study certain types of impacts and/or may be more likely to find no negative impacts either because they are not perceived to be consequential or because the results might affect management in costly ways.

As an example of the first rationale, there are no Russian bycatch studies because there are only limited Russian coastal fisheries; the research is of less interest than it is to the Norwegians.

The latter rationale is more complex to disentangle. A different explanation rests on the assumption that there is considerable spatial heterogeneity among the areas of RKC distribution in the

Table 3. Effects of study observations within the Grey and the peer-reviewed literature.

	Grey literature (%)	Peer-reviewed studies (%)
Limited effect	23.7	76.3
Negative effect	33.9	66.1
Benthos	19.1	80.9
Disease vectors	22.2	77.8
Commercial species	50	50
Bycatches	100	0

Russian and the Norwegian jurisdiction respectively, in terms of habitat and prey species distributions. Indeed, there is now evidence that the populations are diverging genetically (Zelenina et al. 2008). This could, theoretically, be due to differences in feedback mechanisms from differences in feeding and/or behaviour that generate different findings for ecological impacts. However, even when it comes to results that should not depend significantly on the spatial heterogeneity, such as the increase in parasites due to the introduction of the RKC, there is a divergence in opinions among Norwegian and Russian scientists (IMR/PINRO 2009) (see Figure 2).

An additional parameter that needs to be factored in is that the crab was already well established in Russian waters before it started spreading over towards Norway. Therefore, by the time the studies on the impacts started in Russia, the ecosystem may have already been altered by the introduction of the opportunistic crab predator, therefore leaving limited possibilities for baseline research.

Norway on the other hand has been the recipient of the invasion externality; the introduction was made without consent. Benefits started accruing only after the beginning of the commercial fishery in 2002. Up until that point most of the focus was put on the direct impacts of the newly introduced species on traditional fisheries that were suffering from bycatches. Had the commercial crab fishery not opened at this point, it is likely that the research agenda would have been formed in a different way. As the commercial RKC fishery started growing larger in Finnmark with increasing investments in gear and onshore crab landing facilities, stock assessments moved up in importance in the research agenda. Decision-makers in Norway, in response to myopic economic incentives, seem to have prioritized the need for accurate information on the size of the commercial stock so as to be able to set harvest control rules that can ensure a long-term crab fishery. This is reflected through a) the prevalence of related studies with a focus on the management and the biological features of the crab in response to the RKC industry's needs (fishers and processing plants) and b) the allocation of research resources within IMR, which is disproportionately higher for research geared towards commercial exploitation compared to research for exploring the ecosystem impacts from the invasion. Specifically, analysis on the expenditures within IMR for different research projects on the RKC (from 2004 to 2016) has shown that investments in research for developing the commercial potential of the fishery have significantly exceeded investments for exploring ecosystem impacts and risks at the frontier of the invasion (beyond the quota-regulated area) (Kourantidou and Kaiser 2017).

These days, Norway tacitly acknowledges the negative ecosystem impacts of the invasion by allowing for an open-access fishery west of 26° E, a management policy which is particularly controversial among different stakeholders (see for example WWF-Norge 2002). In addition to those controversies, although the Ministry of Fisheries and Coastal Affairs has endeavoured to make clear that the RKC is an unwanted invasion that should not spread further west along the coast (Fiskeri-og Kystdepartement 2007), the management in practice often contrasts sharply the stated management goals. Examples include the Fisheries Directorate's rejection of 2 proposals in the open-access area (west of 26° E) for big-sized vessels that targeted large-scale crab harvesting (Nilsen 2008). More recently, due to the social pressure exerted on regulators for broader participation in the quota-regulated fishery, discussions have started for moving the 26° E further to the west, among various stakeholders (e.g. Norges Kystfiskarlag) (Berg 2017). A decision to do this would possibly shift future discussions further to the west, where the debate will reignite with new stakeholders on the new frontier desiring to be included in the windfall.

Meanwhile, the last decade's bonanza of the commercial fishery east of 26° E engenders pressure on behalf of both the fishers and the processing industry to maintain a long-term fishery without stock fluctuations (see for example Sved 2010; Norum and Sandmo 2010). The intent is to sustain livelihoods in Northern Finnmark (Sundet and Hoel 2016). We consider this social pressure likely to shift the focus of the research agenda towards exploring further the viability of the crab fishery rather than the crab's interaction with the ecosystem.

In a decision-making framework, we consider two types of possible errors that may arise from misinformation on the impacts: Type I error refers to incorrectly rejecting the hypothesis that there are negative impacts and therefore managing the stock as a long-term fishery; Type II error refers to retaining a false hypothesis that there are negative impacts and therefore eradicating. As the resource economists utilizing this research, we view a Type I error to be more costly in terms of social welfare than a Type II error. This is because a Type I error comes at an unknown cost through ecosystem losses that might be irreversible, while a Type II error comes at the cost of the rents from the RKC fishery plus the costs of rebuilding the stock, if it turns out that there are no negative impacts.

The exacerbation of the impacts of such errors can be understood by considering the industrial structure of research and management of the crab populations by the two countries.

Research and Management advice comprise early inputs to determination of RKC harvests. It is useful to consider them in the context of industrial structure to illustrate potential avenues of research bias and its amplification. We consider four stages of research and management: primary research, publication and dissemination of research results, research result advice to management, and management decisions over harvest. In Figure 5, the green shaded path represents a comprehensively integrated information and production system in the Barents. There is horizontal integration at each output stage of research and management, as well as vertically integrated management through joint cooperation. The blue inverted-V-shaped path, on the other hand, shows the split of research and management that has developed over time in the Barents Sea RKC fisheries. This split reduces information to Russian management from Norwegian information and vice versa; and increases the likelihood of cross-border externalities from over- or under-harvest. What cooperation does continue is focused on the fishery rather than the broader ecosystem, limiting potential benefits of any horizontal integration.

At the same time, vertical integration along either the jointly determined or the individual country's information production line increases the possibility of self-reinforcing bias. The likelihood of bias, and negative impacts from that bias, are increased when the countries diverge in their research

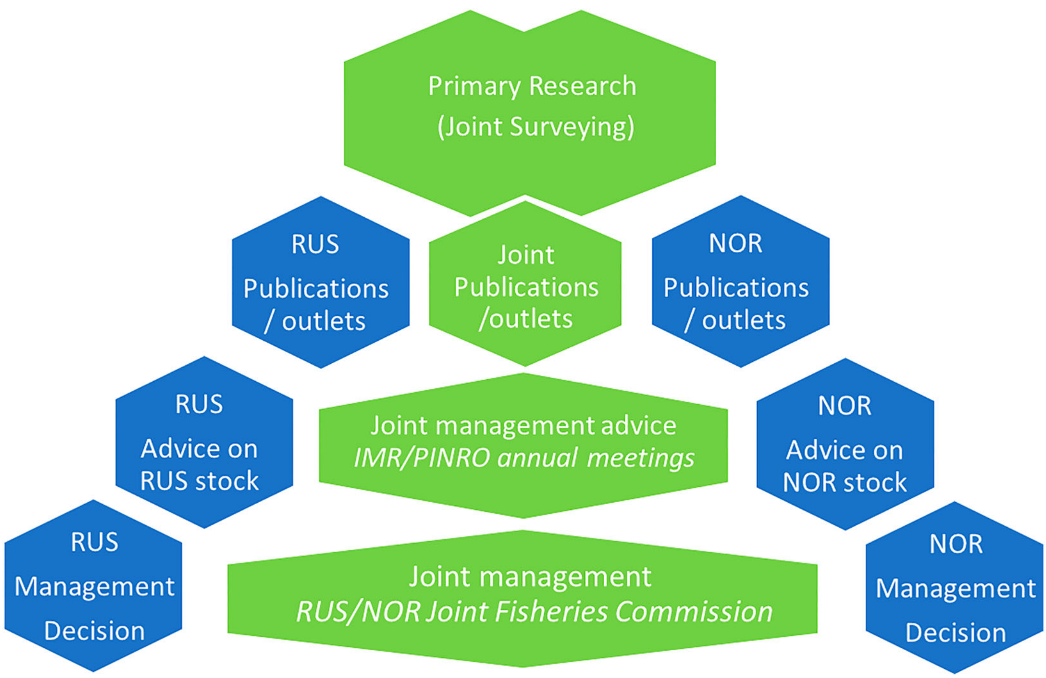

Figure 5. Conceptual illustration of horizontal and vertical integration in production of Barents Sea Red King Crab *(Russia-RUS & Norway-NOR)*.

and management paths. The vertical integration stems from the in-house nature of research and management advice. With little or no input from scientific research of a greater scope, the profits of the commercial fishery may push more research toward the commercial fisheries than is optimal. When there is little scientific cooperation post-initial data collection, this bias is likely to be stronger. Greater access by independent researchers to primary research data and greater inclusion of external research findings in management, whether joint or individual, is likely to improve fully specified economic outcomes based on maximization of social welfare.

Note that other shared fish stocks in the Barents Sea, such as the North-East Arctic cod, the haddock, the capelin and the Greenland halibut are successfully managed by Russia and Norway along the green path shown in Figure 5. The observed differences between those jointly managed fisheries and the decision-making processes followed for the RKC management highlight the asymmetric incentives of the two countries attributable to the invasive aspects of the crab. While horizontal and vertical integration exist and generate mutual benefits for research and management for all other shared stocks in the Barents, the RKC's high economic profits, and spatially distinct and uncertain damages, create a sufficient wedge in otherwise aligned interests to reduce, in particular, horizontal integration in research and management. The remaining 'siloed' vertical integration then fails to take in information from outside the institutionalized research agendas and their potential biases. This exacerbates the potential impact of the bias on research outcomes and subsequent management decisions.

6. Conclusions

In this paper we show that scientific consensus may be more difficult to achieve when economic incentives differ across the participating researchers. In the case of a purposefully introduced commercial species with invasive characteristics, the introducing country and the neighbouring invasion recipient may have different interests at stake that are translated into both the research agenda and the findings of the research agenda. The resulting lack of scientific consensus creates challenges for designing policy instruments.

The RKC is an excellent example of a controversial invasion that demonstrates how economic incentives supplement an inconclusive biological and ecological literature and feed into research agendas. However, our key conclusion is applicable more generally: uncertainties and biases in the literature are likely to affect management objectives and determine which research avenues are worth pursuing in the future. These in turn may shift decision-making that makes more costly Type I errors, with irreversible outcomes for society.

Our analysis can contribute to interdisciplinary efforts on any situation where foundational research can become biased in favour of one aspect of an uncertain cost or benefit over another uncertain and conflicting aspect, due to e.g. the distribution, timing, and/or certainty of the net benefits of the new knowledge produced. We show how integration of the production of scientific knowledge and management can in fact result in biased policies and strategies for long-term management, even in subtle cases such as the red king crab introduction in the Barents Sea. Additionally we illustrate how the levels of vertical and horizontal integration may impact cooperation (or non-cooperation) among neighbouring states when the spatial distribution of an uncertain cost or benefit is shared across borders. In doing so, this paper particularly cautions that unresolved scientific questions in foundational research needed for management should be approached with concern for the incentives and with the industrial framework of the knowledge production clearly in mind. Furthermore, through increased understanding of such biases, it may become more systematically feasible to assess how one should use the foundational scientific literature from fields outside of economics and its uncertainties in more effective ways when assessing or advising policy options.

Other occurrences of such structural concerns may be quite similar to the Red King Crab case, or extend far beyond. In similar examples, we see commercial harvesting increasingly used as an invasion control mechanism for invasive species that hold a value in the market. In several cases this harvesting has evolved into an important source of income for local communities, supporting livelihoods as well as a wide range of industries and activities critical for the survival of the community. Examples of these locally important industries include the invasive Australian Red Claw crayfish *(Cherax quadricarinatus)* in Jamaica (Pienkowski et al. 2015), exotic salmonids in Patagonia (Pascual et al. 2009), wattle species (*Acacia mearnsii* and *Acacia dealbata*) and Prickly pear (*Opuntia ficus-indica*) in South Africa (de Neergaard et al. 2005) and Prosopis *(Prosopis juliflora)* in Sudan, Kenya and other places in Africa (Geesing, Al-Khawlani, and Abba 2004; Mwangi and Swallow 2005; Laxén 2007; Bokrezion 2008). The management of such species creates complex trade-offs between ecosystem conservation and the economic development of local communities, and it may be a valuable exercise to examine remaining scientific uncertainties in light of the incentive issues presented here in order to ascertain whether management options, and investments into research and its levels of collaboration across interests, are sub-optimal.

Further afield, agencies charged with multiple use management such as the US Forest Service or Bureau of Land Management, or with management of a multiplicity of species each having different values and scientific uncertainties, such as US Fish and Wildlife Service management of the Endangered Species Act; 16 U.S.C. § 1531 et seq may face similar challenges. This is likely to be especially the case when relevant knowledge is produced across rather than within such agencies. Fostering cooperation before, e.g. Consultations mandated under the National Environmental Policy Act (1970) or through moving forest service personnel across regions is likely to be highly valuable for reducing bias (Kaiser 2006).

The issue is not limited to biological resources. Transboundary water pollution, and even water quantity allocations amongst stakeholders that depend on scientific understanding of the hydrological cycle may face similar management dynamics. Current water allocation shortfalls under the Colorado River Compact stem in part from incomplete scientific assessment of average precipitations at the time of the agreement that took unusually high years of precipitation and flow as average years. Now, it is hard to change the upstream allocations, in spite of better estimates of long-run flows that started appearing in the literature in the 1970s (Woodhouse et al. 2016).

The application of our approach remains limited by the availability of data as well as the deficiency of biological knowledge in general. Given the limited number of impact studies available, precise estimates are beyond the scope of this paper, which conducts stylized coarse-scale analysis for the purposes of reflecting upon the trends in biological research for the invasive crab. Establishing causality with fishery management policies is particularly challenging due to feedback effects between research and decision-making that creates the endogeneity of research and policy that concerns us. This partly explains why the management of the crab has shifted multiple times: in Norway the RKC is both viewed as an unwanted invasion and at the same time it is being managed as a long-term sustainable fishery.

Informational asymmetries in impacts research are likely to have important consequences. Priorities in allocating resources for research are often determined based on policy-makers' perceptions of the expected ecosystem losses. This stresses the importance of identifying the patterns of research across time and nations especially for a controversial invasion such as the RKC. More studies on the invasion can only promote a deeper understanding of the crab's interaction with the ecosystem. This implicitly builds on the expectation that scientific views will start converging before the allocation of research resources is shifted away from impact studies.

Overall, despite the joint research initiatives between the two countries that share the stock, very limited studies are a result of co-authorship between Norwegian and Russian researchers, with the exception of joint workshops and the joint report series between IMR and PINRO. Despite the cross-citations among Russian and Norwegian studies, we generally observed a lack of critical assessment in specific methods, concepts or assumptions, as well as a lack of strong links with past studies and also with cross-national studies. The lack of such assessments along with the fundamental differences in the results of the impact studies, underline the critical importance of how empirical work needs to be framed, with respect to providing useful policy recommendations for management.

An additional caveat that applies to our results is the fact that we have not included in our analysis the bibliometric networks in order to control for co-citations, co-authorship relations and bibliographic coupling for establishing similarity relationships between papers and reports. The analysis of citation networks of the publications on the impacts of the invasion could arguably facilitate the analysis of the development in the field over time. A critical barrier in performing such analysis has been the fact that most of the studies are not included in commonly used databases such as Scopus, Web of Science, and Google Scholar. Future work should integrate such analysis as it is needed to better translate existing research findings into policy-relevant guidance and pave the way for future research directions. For that to be achieved and enable more informed and responsive policy-making, the governance model in place needs to broaden its scope by promoting greater scientific cooperation at all levels across borders.

The study of economic incentives and publication biases in the primary research fields needs to receive more attention when designing policy interventions for resource management. The value added from such research is that it can inform ongoing policy debates by revealing how diverging viewpoints among different stakeholders influence research agendas. These benefits are not limited to resource management but extend to any decision-making that relies on cross-disciplinary information.

Notes

1. The western frontier boundary at 26° E was originally agreed between Russia and Norway in 2005. The Norwegian open-access management came into place with a report (white paper) to the Parliament in 2007 (Fiskeri-og Kystdepartement 2007).
2. Secondary-nature studies are those which do not report original results, but instead process results of other field surveys/lab experiments.
3. See Appendix A for a full list of the studies included in the analysis.
4. The studies we refer to as 'grey literature' are the ones that have not been published in international peer-reviewed journals or they do no explicitly mention that there has been some peer-review process, although they might be part of some edited volume.
5. According to Kuzmin and Olsen (1994) the first reported crab in Norway was caught in 1976. Orlov and Ivanov (1978) refer to 1977 as the year of the first crab occurrence in Norway, based on Norwegian press releases.
6. We have coded Russian authorship as 1 and Norwegian authorship as 0. As such we label the categorical variable 'Russian authorship' for expository clarity.
7. While interaction terms of year and study theme could be expected to capture such effects, they are directly visible in the data and the degrees of freedom lost by including them do not compensate sufficiently for their inclusion. Similarly, structural breaks were estimated in correspondence with the timing evidence elaborated on here, but they do not offer improved explanatory power compared to the annual trend.
8. We have excluded from our analysis bycatch studies that do not directly address impacts but instead discuss ways to reduce bycatches or explore the drivers behind those (see for example Godøy, Furevik, and Løkkeborg 2003; Furevik et al. 2007, 2008; Furevik and Ulvestad 2012 in the Norwegian literature and Stes 2016 respectively in the Russian literature).
9. The initial ban in the Russian coastal zone was introduced in 2009 but was lifted for 2010 and was introduced again in 2011 (Anonymous 2013).
10. Online platform available at globalfishingwatch.org/map/
11. According to the latest estimates available for Norway, the annual RKC landings value in 2016 was more than 332 mil. NOK, with 796 vessels having participated in the fishery (Norges Råfisklag n.d.). The bycatch costs as reported in the literature (Falk-Petersen and Armstrong 2013), were estimated (for 1999) at 3 and and 10% for increased gear replacement costs and increased fuel expenses respectively. Those are likely to have decreased over time due to gear improvements and advanced knowledge about the 'crab-free areas'.
12. For the LPM model we use heteroskedasticity-consistent robust standard error estimates but the predicted probabilities are expected to be biased and inconsistent (Horrace and Oaxaca 2006). This is in part because LPM estimates are not constrained to the unit interval.

Disclosure statement

No potential conflict of interest was reported by the authors.

ORCID

Melina Kourantidou http://orcid.org/0000-0001-9595-3354
Brooks A. Kaiser http://orcid.org/0000-0002-7012-1663

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