10. Bioeconomic Strategies to Address Potential Marine Invasive Species in the Arctic

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10.1 Introduction

The chance to stop non native marine species from threatening and damaging Arctic marine ecosystems still exists. There are economic aspects underlying fundamental efforts to take this existing chance to protect the unique Arctic. Dynamic changes in environmental media conditions (temperature, current shifts, ocean acidification) may widen the range of flora and fauna from outside the Arctic to inside the Arctic to successfully invade through establishing and displacing native Arctic species (Miller, 2014, this issue). Therefore vigilant efforts to address human induced movements of the non native species to the Arctic are needed. This section outlines the manner in which economics and marine biology can work in concert in analysis informing prompt steps towards actual protection from non native marine species before they invade the Arctic. The section includes analysis of existing policies and identification of policy gaps at different scales (international to regional) that can be finetuned and augmented with input from economics to help in steps towards protection of the Arctic marine environment.

Time and space influence not only non native species spread from outside to inside the Arctic but also influence the likelihood of more than one country being involved in decisions that start or stop pathways (vectors) of non native marine species from invading the Arctic. The spatial scale of potential marine species in the Arctic is international. A few remote ports of sovereign countries with Arctic coastline interact economically and ecologically with the rest of the world, with increasingly open access to the Arctic Ocean center.

Much attention has focused on the pathways the ice melt provides for transport in east and west directions within the Arctic to reduce time and fuel in transit compared to equatorial passages. Additionally, there are the north and south directions to address as a basis of discussing economic incentives to foster any action on potentially invasive marine species in the Arctic. This section draws from a large spatial scale starting south of the Arctic, in the Pacific Ocean near Baja California up through the Bering Sea for several analyses with relevance for the Arctic in terms of the realistic spread of southern non native species to the Arctic (Vermeij, 1991). The analyses tackle open access and incompleteness of existing policy for addressing protection against the biological pollution of non native marine species that may successfully invade where many polluters (responsible for vectors of non native species) can damage without the stewardship for protection from ruin resulting from invasion. The vast spatial scale challenges Arctic protection from marine invasive species. Ideally, policies with economic incentives for self enforcing abatement of invasive species are possible in the Arctic given limits to resources to police internationally the open access scale of threats to Arctic protection from marine invasive species.

10.2 Four Analyses with Lessons for the Arctic

Marine invasive species threats of relevance to the Arctic encompass multiple bioeconomic considerations. Four existing analyses that address components of the Arctic challenge across different vectors of non-native marine species with potential for invasion. As these analyses are based on previously presented models, I summarize the elements of each analysis and information necessary to relate results to relevant Arctic marine resource management.

These are: (1) between trading countries (commercial shipping) in and out of the Arctic; (2) between shipping industry and ports with different information on risk and pollution control; (3) across boating industry and recreational boaters in various countries; and (4) in coastal public waters where aquaculture and aquarium trade may take place. These analyses investigate incentives and policies for more than one decisionmaker of the shared biological pollution problem to prevent non native marine species from hitchhiking on boats, aquaculture inputs through investment and management practices related to shipping, ports, aquaculture and aquarium trade vectors of marine invasive species. The analyses share underlying characteristics of: threats of losses due to inadequate policy are imminent and costly; interplay of ecology and economic behavior is clear; knowledge of ecosystems and political economy allows for predictive results; and successful policy integrates remaining risks, uncertainties, ecology, and economic behavior. The bioeconomic analyses rely on applications of game theoretic tools and integrated marine resource management tools for more than one decisionmaker addressing transboundary and potentiall invasive non native marine species with changing risks and uncertainties over space and time affecting long term vigilance for resource protection with and without coordination. All of the analyses can offer guidance for the nascent development of the Polar Code that so far involves the International Maritime Organization (IMO) dealing with the separate sovereign Arctic countries over search and rescue and operation safety without attention yet towards including non native marine species threatening invasion (Deggim, 2013).

Varied motives exist for vigilance against marine invasive species by the decisionmakers in the analyses that can lead to investment choices ranging between pollution prevention and reactive abatement as functions of non native marine species flow and invasive marine species stock, respectively. Some motivators in the Arctic setting include reductions in transportation costs (speed, weight, fuel) that abatement can yield, regulation to avoid potential damages and reciprocity for facing a shared threat. Given this range of motivators, the analyses seek potential international cooperation for matching the scale of management to ecological scale in need of protection.

10.3 Analysis 1: International Maritime Shipping and Strategies between Trading Countries

Maritime shipping around the world can bring potentially invasive marine species to the Arctic through ballast water and biofouling of hull and niche locations (propellers, etc) (Miller, 2014, this issue). A summary of analysis (1) between trading countries relying on commercial maritime shipping offers some lessons for stimulating vigilance against marine invaders through these vectors.

In analysis (1), asymmetric incentives across countries in the Pacific Ocean from Baja California through the Bering Sea are based on different pollution control costs, flow and stock effects, ability to pay, and damages of ecosystem changes, and costs to habitat resiliency. Fernandez (2007) develops and applies an integrated bioeconomic game model with Pacific Ocean countries along North America deciding simultaneously to minimize expected net costs of abatement and damages due to invasive marine species. Each country's objective to minimize costs is constrained by non native marine species dynamics with a transport matrix of invasive species movement (flow) between ports through ballast water and hullfouling vectors with plausible effects on native species (stock) from successful invasion of the non native marine species. These costs are influenced by both the components of the flow of arrival of non native marine species as well as any accumulated stock of successfully invasive marine species. There are choices over which stage to address non native marine species, ranging from prevention if focused on the flow to reaction (rapid response or eradication) if focused on the stock of marine invasive species after successfully established. These choices are investigated in the model that specifies explicitly prevention costs as a function of flow for ballast water and hull biofouling abatement on ships, monitoring and rapid response on shore. Also, the model specifies explicitly reactive costs are a function of stock for eradication of established marine invasive species.

Of prime importance in the analysis is a comparison investigating the economic incentives of coordinated protection versus unilateral action by solving for noncooperative and cooperative game solutions from the applied bioeconomic game modeling. The comparison of game solutions help to articulate ecosystem management strategies at an international scale as the decisions are direct functions of the stock of marine resources. Empirically, there are true asymmetries in costs and damages in the North and South with non native marine species moving in both directions from continual maritime trade transit in those directions. Pacific coast ports shipping frequency and volume help define the transport matrix of shipping with marine invasive species vectors of ballast water and hullfouling over space and time. This matrix is a part of the dynamic equation that defines the movement of nonnative marine species that are potentially invasive in both directions. Data and growth equations for two marine invasive species, *Bugula neritina* and *Nemertea (ribbon worm)* are referenced from Kuris *et al.* (1992ab) and Haygood (2000). The *Bugula neritina* moves from north to south through the vectors and *Nemertea* moves from south to north.

The two marine invasive species have varied impacts that are taken into account in the analysis, as it influences the asymmetric incentives to motivate any action on marine invasive species. Commercial value of native shellfish species damages in Canada and recreational value as damages from Nemertea are referenced from Kuris *et al.* (1992ab).

Pharmaceutical value of *Bugula neritina* is referenced from Haygood (2000) as an potential commercial value from harvesting the invasive bryozoan (*Bugula neritina*). Empirally estimated preventative and reactive abatement cost functions for hull maintenance (cleaning) along with antifouling paints on the ship hull and are based on data from Taylor and Johnson (2003). Likewise, on board and off shore ballast water treatment cost functions are estimated with data from Tamburri *et al*. (2002). Note, the reason for this form of treatment is because most vessels moving along the South to North space would not motor out beyond 200 nautical miles to carry out open water exchange due to time and fuel costs that would be expended instead of an on board alternative that does not require the significant distance from shore to carry out. An economic incentive that motivates the commercial shipping sector separate from any potential regulation is the chance for fuel savings from strategies to prevent hull biofouling such as hull maintenance (cleaning and drydocking) as well as antifouling paints (Younqlood *et al*. 2003). For example, 30% reduction in fuel and expenditures is possible from bearing the abatement costs from investing in antifouling coatings and management practices included in the preventative cost functions of the study. Additionally, the on board treatment of ballast water saves in time and effort to motor out beyond 200 nautical miles away for open water ballast exchange, the option suggested under the 2004 IMO Convention for the Control and Management of Ship's Ballast Water and Sediments.

The comparative analysis is able to assess quantitatively between several options: cooperation and prevention, cooperation and reactive strategies, noncooperation and prevention and noncooperation and reactive strategies. Of the four options, cooperation with prevention is found to be the best at cost minimizing between the countries by reducing damages from *Nemertea* with higher benefits from harvest value of *Bugula neritina* and fuel savings for the region. This result can be the basis of benefit sharing across trading participants to offset abatement costs with the generated savings and actual revenues from the harvested species.

10.4 Analysis 2: Port and Ship Incentives for both Ballast Water and Hull Fouling Policy

Analysis (2) focuses on the shipping industry and ports with different information on marine invasive species risk while both may be aware of potential damage from both shipping vectors of invasion (ballast water and hull fouling). The shipper clearly knows more than the port about any abatement of non native marine species he has undertaken onboard in the form of treating ballast water and abating hull fouling. This is the premise of the analysis by Fernandez (2008) in order to design policy options that take into account these variations in information between relevant participants in the potential controls of shipping vectors of marine invasive species to the Arctic.

Another premise for the analysis is that ballast water has received attention at the international level translated into guidelines from the IMO for numerical limits on marine invasive species concentrations in ballast water through the International Convention for the Control and Management of Ship's Ballast Water and Sediments of 2004. Instead of a policy similar to the IMO Convention on ballast water and sediment, there is a ban on tributyltin coating, that had been used in the past by shippers to control biofouling. The coating was found to harm to surrounding marine life, thereby leading to the International Convention on the Control of Harmful Antifouling Systems on Ships in 2001. There exist some draft guidelines on anti fouling practices rather than a formal international policy on the order of the ballast water convention of 2004.

In analysis (2), both vectors (ballast water and hull fouling) and the information divide between shippers and ports require the same number of policies to match the vectors and information issue plaguing public good protection from marine invasive species. The analysis proceeds to evaluate technology subsidies and ballast water reporting fees in a manner that assesses the effectiveness in combination with liability rules from maritime ship safety law of the IMO. The numerical analysis helps in exploring the possibility to finetune existing policies working in combination, including the maritime ship safety liability rule of the IMO, the tax in the form of the port access fee and west coast ballast water reporting fee and the subsidy from the U.S. Coast Guard technology assistance cost share and grant program for implementing new abatement technology. Results from the analysis show that combining a subsidy with liability or a tax with liability can help address information problems and uncertain damages. Liability influences the distribution of benefits between the shipper and the rest of society, but it does not influence the levels of abatement for investing in both abatement of ballast water and hull fouling. Subsidies and taxes achieve the same level of abatement and economic welfare. The difference is shipper profits are lower with taxes.

The following suggestions from analysis (2) can apply in the current drafting of the Polar Code that needs to augment the search and rescue and operational safety topics to include environmental concerns such as marine invasive species. Aim to tie current technology subsidy for ballast water treatment to liability and potential damages. Also, tie current port reporting fee to liability in a manner such that the QUALSHIP 21 program of U.S. Coast Guard rewards vessels that have complied with international safety and environmental requirements by reducing the inspection frequency.

Additionally, the NZ 1993 Biosecurity Act, Section 154, an existing policy with a variation of combining a liability rule with a tax can offer more experience in this effort (Floerl, 2014, this issue). That Act has a penalty for incorrect information about abatement and disobeying directions that includes fines and possible prison time. There is room to explore combining such policy instruments beyond the public resource manager and regulator of a country to include viable entities such as maritime shipping insurance companies too.

10.5 Analysis 3: Recreational Boats

Analysis (3) looks beyond commercial maritime shipping to across the boating industry and recreational boaters in various countries noting their vital role in addressing the marine invasive species threat to the Arctic. Recreational boaters constitute a hull fouling vector for hitchhiking marine invasive species to the Arctic. In analysis (3), the boating industry refers to the supply side of abatement control options for hull fouling on recreational boats. The empirical focus of analysis (3) centers on the cost and availability of supplies and services to control marine invasive species on recreational boats traveling along the West Coast of North America (including Mexico, U.S. and Canada) (Johnson and Fernandez, 2011). Specific attention is placed on comparing metal based and non toxic anti fouling paints. Metal based paints do not have an international policy like the International Convention on the Control of Harmful Antifouling Systems on Ships in 2001 that implemented a ban on tributyltin antifouling paints for hulls. The present concern has been with copper based antifouling paints posing a hazard to marine life beyond the target marine invasive species as hullfouling (Johnson and Fernandez, 2011). The ablative properties of copper based paints results in copper build up from deposition to the benthic layer below where boats are situated.

In order to conduct this analysis, Johnson and Fernandez (2011) conducted a survey of various entities of the boating industry to generate data. Managers of marinas, harbors, yacht clubs, boat repair yards, in-water hull cleaning companies, slip liner companies and boat lift companies participated in the international survey of the boating industry conducted by Johnson and Fernandez (2011). Slip liners and boat lifts are two alternatives to anti fouling paints to deter biofouling on recreational boats. The survey results indicate 48% of boats rarely leave the marina where stationed and for that reason the rate of deposition of metal based paints can be quite large. For those stationary boats and protection at the marinas, non toxic (non metal based) anti fouling paints are the best option, if available. With the 48%, focus is on preventing the heavy metal deposition and there is less of a threat from these boats transporting marine invasive species if they stay in the marina. Given that 48% of boats never leave their own harbor, performance bonds and "evergreen leases" for slip space are viable policies for implementing nontoxic coatings to avoid exceeding Total Maximum Daily Loads on copper in harbors that are the focus on many marinas along the Pacific Coast of North America (from California through British Columbia).

Statistical analysis of the survey data indicates the following results. Awareness of nontoxic coatings is statistically significant in influencing anti fouling coating choice. Cost and location are not statistically significant for recreational boaters. Education has positive influence on choice of nontoxic coating. For recreational boats that do engage in long-distance trips by leaving the marina, there is a higher risk of transporting marine invasive species via hull fouling and less risk of contributing to deposition of metal based coating in benthic layer below marina slip. Therefore, the availability of metal based paints for those recreational boats proves a viable option. For boats leaving harbors, avoiding additional fuel and speed loss costs from hull fouling offers incentive to regularly remove biofouling whether they are involved in racing recreation or less rapid travel for leisure.

A comparison of the calculated average cost per foot to use each type of antifouling paint included in the analysis indicates the most widely available copper based anti fouling paints are cheapest followed by zinc based and subsequently epoxy (the nontoxic) coating that is available. When expected service life is factored in, epoxy based coatings gain in cost effectiveness against heavy metal based paints (copper and zinc) due to the lasting twice as long the metal based options in terms of lifetime prior to replacement. The capacity of industry to service nontoxic paints needs expanding everywhere.

10.6 Analysis 4: Coastal Waters, Aquaculture and Other Leasers

Analysis (4) is conducted by Fernandez (2011) in coastal public waters where aquaculture and aquarium trade may take place. In this setting, the need for coordination between aquacultural operators and others similar to slip leasers in a marina is obvious from the potential harm from spreading problems in common space. Here, shared marine invasive species risk among users is a quantifiable component to include in decisions by leasers of the public coastal space in how they use and maintain that space to prevent marine invasive species from plaguing their space and surrounding connected space.

With the absence or incomplete presence of a separate policy to address marine invasive species in these coastal shared setting, a remedy may be through existing lease arrangements by instilling an environmental bond where upfront payment of a lump sum to cover any potential impact is part of the requirement in obtaining a lease. Coordinated not unilateral action will help to prevent damage from aquaculture, aquarium trade in coastal area and marina slips and foster long run positive revenues not losses if avoid the marine invasive damages. The presence of environmental bonds imposes a cost on potential damage that is forfeited if the damage occurs. However, the bond is refunded for damage avoided by vigilant abatement effort in each leaser's own space. Cooperation increases with increased bonds or deposit-refund amounts because there would be more to lose if abatement is not done and the threat is larger to all leasers. Existing leases can be fine-tuned for incentives, such as along lines of the U.S. Leaking Underground Storage Tank Trust that has addressed ubiquitous threats to water quality throughout the country in a manner that insures any harmful impacts are fully financed with upfront and continuous pooled resources from the commercial industries depending on the tanks for their livelihood.

10.7 Conclusion

The four analyses were undertaken with attention towards integrating marine ecology and economic components for analytical gain in assessing viable strategies over several vectors of marine invasive species to impact the Arctic. The analyses provide comparisons that help gauge tradeoffs between lack of coordination and coordination when the scale of the vectors extends internationally and responsiveness of policy or abatement action may be at different scales to compare. The analyses also indicate tangible economic incentives in various forms that directly influence the timing and scale of response towards stewardship of protecting against marine invasive species. Some incentives are identified through the comparisons of net benefits to preventative versus reactive policies and action to combat marine invasive species. Cost savings in the form of less fuel, weight and lost time in transit by commercial and recreational marine vessels may be realized through responses to policies to address ballast water and hull biofouling vectors of marine invasive species, provided the policies stimulate those cost savings. Economic incentives are also shared in terms of the avoided risk in coastal public space shared by aquaculture producers or leasers in a marina faced with a shared threat of marine invasive species changing their productive space once invaded. A common finding in the analyses is the gain from coordination at various scales.

These analyses can inform the Polar Code currently under development. The Polar Code can contribute to acting on the chance to stop marine invasive species in the Arctic. With that international policy focused on the special ecological settings of the poles, there is a potential to match the scale of policy to the scale of the marine invasive species threat, that is, the international scale. Cooperation is a necessary condition among the Arctic countries endowed with ports that are recipients of the vectors mentioned in the four analyses summarized in this section for any efforts to address marine invasive species threat to the Arctic involving the rest of the world as well.

10.8 References

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