Spring 2019

Eating some invasive species could help to mitigate the impacts of climate change-related invasions, and may increase future food security

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Iceland and Greenland: Climate Change and the Arctic

Winter 2019

ABSTRACT

Climate change is predicted to increase the spread and abundance of invasive species and to erode global food security. I hypothesized that by incorporating edible invasive species into local food sheds, these two problems could help to mitigate each other. I set out to answer two questions: could eating invasive species reduce their spread and abundance? And could eating invasive species minimize the impacts of climate-change related food shocks? To answer these questions, I surveyed the existing literature on human consumption of invasive species, created a list of criteria that make an invasive species suitable for management through human consumption, and identified what components of global food security could be strengthened by edible invasive species. I found that some invasive species populations could be reduced by human consumption, but that careful management would be required to ensure eating invasive species did not create perverse market incentives that facilitated further invasions. I found that invasive species might offer possible interventions to increase food quantity, promote food access, increase food safety, and contribute to environmental stability, four important components of food security. However, no studies exist specifically on the topic of invasive species and food security, and much further research is required to substantiate my hypotheses. In order to ground my research in practical applications and communicate my results to a wide audience, in addition to written results, I created two recipes using edible invasive species in Iceland, informed by my research on invasive species population biology and climate change-related food insecurity.

ACKNOWLEDGEMENTS

Throughout this project, many people have shared their time, expertise, and their knowledge of Iceland’s species with me. All of your help allowed me to complete this project, and I am grateful to each and every one of you.

I want to thank Jennifer Smith and Kári Þór Jóhannsson for meeting with me at the fish shop and for recommending people to talk to about finding invasive species.

Thank you Noah Martin for talking with me about invasive species and about your work with FM13, and for sharing your series of books on edible invasive species with me. I really enjoyed reading them, and I think you are doing such important work!

Thank you Theresa Henke for meeting with me for coffees to talk about flounder. I wish you all the best as you begin your PhD research, and I am excited to hear what you discover.

I want to thank Henry Fletcher for our wonderful phone conversation about foraging in the Westfjords, and for sharing your manuscript with me. The information you shared with me gave me the confidence to go out foraging without worrying about accidently poisoning myself, and I am so happy I was able to include wild Icelandic plants in my recipes.

Many, many thanks to Peter Weiss for giving me one of the rabbits you raised and slaughtered. I know this was quite a busy time of the year, and it means a lot to me that you were willing to go out of your way to bring me one of your rabbits.

Thank you Alex Tyas for recommending people to speak with about invasive species, and thank you for talking with me when I couldn’t decide where to live for.

I want to thank Dan Govoni for all of your help on this project; for meeting with me and answering my questions, for supporting my foraging excursions, for being a taste tester for my recipes, and most of all, for encouraging us all to do research that interests us.

Finally, I want to thank my parents, Jo D. Saffeir and Kris Carr, for your support, for encouraging me study abroad, and for being two badass environmentalists and teaching me the importance of caring about our planet.

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LITERATURE REVIEW

Invasive Species

Invasive species are a major driver associated with species extinctions worldwide, second only to habitat loss (Allendorf and Lundquist 2003; Bellard et al. 2016). Increasing globalization has facilitated the spread of species across the planet, and some of these species establish themselves outside of their native range. Not all introduced species are invasive, however. Many introduced species die out or incorporate themselves harmlessly into new ecosystems. An organism may be considered invasive if it has been introduced from one part of the world to another by human activities and causes decreases in ecosystem functioning in the new habitats in which it has become established (Simberloff et al. 2013).

A population must pass through four steps before becoming invasive (Hellman et al. 2008). The first step is transport outside of the species native range. Most introduced species die in the new habitat as they cannot tolerate the environmental conditions. Those that live reach the second step, colonization. Nonnative species successfully colonize an area if some individuals survive in the new habitat. In many cases, a non-native species colonizes a new habitat, but the population does not grow. The third step is establishment, which occurs when a species colonizes an area and then the population grows. This does not necessarily mean the population has become invasive, since an organism must negatively impact an ecosystem to be considered invasive. The fourth step, invasion, occurs only after a species has been transported outside its native range, colonizes the area, establishes itself, and then spreads across the landscape disturbing the species already present (Hellman et al. 2008). Sometimes there is a delay between establishment and invasion. Species can remain in the establishment stage for decades, and then suddenly spread become invasive (Allendorf and Lundquist 2003; Simberloff et al. 2013). For this reason, invasion biologists suggest removing established nonnatives to ensure they do not cause an invasion later on (Simberloff et al. 2012).

Once a population has become invasive, it can disrupt ecosystem function in a variety of ways. Invasive species can reduce native biodiversity and cause extinctions of native species through predation, herbivory, and competition (Pimintel et al. 2000). Invasive species can affect the physical structure of habitats – altering erosion rates and susceptibility to drought or fire – which in turn affects community structure (Simberloff et al. 2013). They can also act on ecosystem functions in much less visible ways. For example, invasive decomposers and nitrogen-fixing plants alter nutrient cycling, indirectly impacting the functioning of the entire ecosystem (Simberloff et al. 2013). Invasive organisms can be vectors for diseases, or they can be a virus, bacterium, or parasite themselves (Pimintel et al. 2000).

Invasive species harm ecosystems, human and animal health, crops, and economies (Paini et al. 2016). In 2000, a study by Pimintel et al. estimated that invasive species in the US cost the country 137 billion dollars each year. The authors calculated the monetary value of the damages due to invasions to ecosystem services, crop yields, timber production, fisheries, and human and animal health, and added this to the amount that the US spends on control and eradication programs (Pimintel et al. 2000). The full economic cost of invasive species is likely much higher than this estimate because people have not kept comprehensive records of the data on damages and control for many invasive species (Jardine and Sanchirico 2017). Moreover, through contributing to species extinctions, through causing human deaths, and through decreasing food security (Paini et al. 2016), invasive species cause additional damages that cannot be quantified in dollars.

While invasive species threaten ecosystems and societies worldwide, some ecosystems are more vulnerable to invasions than others. Island ecosystems and arctic ecosystems are particularly at risk (Barry et al. 2013; CAFF and PAME 2017; Reaser et al. 2007). Cut off from the rest of the word, island ecosystems have facilitated the evolution of unique species. Because few species are able to migrate to islands, biodiversity tends to be low (Reaser et al. 2007). Volcanic islands, which typically exhibit drastic changes in elevation, have a wide range of microclimates and habitats. These habitats host a small number of species evolved to thrive in a very particular set of environmental conditions (Reaser et al. 2007). Many islands have few or no native mammals, and many lack large predators, which has made it unnecessary for island species to develop many defenses (Reaser et al. 2007).

Specialized niches, small populations, a lack of natural predators, and isolation make island ecosystems very vulnerable to outside disturbances (Reaser et al. 2007). While distance from continents limits the number of nonnative species that can reach islands, the species that do successfully travel there are more likely to have a negative impact on the ecosystem (Reaser et al. 2007). With fewer taxa present on islands, a single species, particularly a predator or grazer, can have cascading effects on tropic structure. Small niches hosting small populations can quickly be overrun by a single species. All of these interactions make it such that invasive species cause much higher extinction rates on islands than on continents (Reaser et al. 2007).

Like islands, the Arctic hosts a small number of species and is relatively isolated from the rest of the world, making it disproportionately vulnerable to invasions (CAFF and PAME 2017). However, additional factors put the Arctic at risk of invasions. Invasive plants thrive in recently disturbed areas, and regular freezing and thawing as well as melting glaciers creates open space and facilitates colonization by invasive plants (Barry et al. 2013). As the Arctic and Subarctic warm, tourism, mineral exploration, and shipping all have the potential to spread nonnative species. Invasions will likely have a substantial negative impact on human societies, because many arctic people rely on native species for subsistence or job opportunities (Barry et al. 2013).

Because Iceland is an island and has territory in the Arctic and Subarctic, its geography and ecology puts it at risk of disproportionately large negative impacts from invasive species (Wasowicz et al. 2013). Given these risks, Iceland is an important place to study invasive species. Research on invasive organisms in Iceland may also offer insights into how invasive species could impact other colder areas of the Arctic as these places begin to warm enough to become suitable habitats for new species (Wasowicz et al. 2013).

Invasive Species and Climate Change

Climate change is predicted to increase the spread and abundance of invasive species through a variety of mechanisms. Experimental studies and theoretical papers based on invasion biology and climate projections have concluded that climate change will likely facilitate human transport of nonnative species (Hellman et al. 2008), catalyze shifts in species ranges, alter ecological relationships between invasive species and native species (Rahel and Olden 2008), increase invasive species performance relative to native species performance (Liu et al. 2017), and influence species phenotypes such that nonnative species that were once harmless become invasive (Barry et al. 2013; Rahel and Olden 2008; Simberloff et al. 2013). Increased invasions as a result of climate change coupled with more direct ecosystem impacts from climate change pose a threat to ecosystems and human societies that will increase as climate change progresses.

Warmer temperatures and higher CO_2 concentrations favor invasive species. Liu et al. conducted a phylogenetically controlled meta-analysis in 2017 assessing the responses of 74 invasive plant species and 117 native plant species to increased CO_2, increased temperature, changes in precipitation, and increased N deposition. They found that elevated CO_2 and elevated temperature significantly increased the performance of invasive plants relative to native plants, while invasive plants performed slightly worse with reduced precipitation ($p = 0.060$) (Liu et al. 2017). They concluded that while climate change-related droughts could reduce the performance of invasive plants relative to native plants, based on invasive plant performance in all other components of climate change they studied, it is likely that climate change will create increased favorable conditions for invasive plant species (Liu et al. 2017).

Liu et al. (2017) hypothesized that the genetic factors that increase a species' likelihood of becoming invasive also increase the likelihood that it will benefit from climate change – a hypothesis that is supported by many other studies as well (Hellman et al. 2008; Rahel and Olden 2008). Species that tolerate a wide range of environmental conditions and exhibit greater than average phenotype plasticity are more likely to become invasive and are also better able to adapt to changing climatic conditions (Hellman et al. 2008; Liu et al. 2017). Due to their broad tolerance, they will likely be able to remain in their current ranges while also moving towards the poles as these areas warm (Hellman et al. 2008). In the event that climate change does alter their current ranges enough to become uninhabitable, invasive plants species typically mature quickly and have light seeds that disperse easily, which allows for rapid range shifts (Hellman et al. 2008). Invasive organisms typically grow so fast that they require more nutrients than native species. Increased availability of CO_2, nitrogen, and water removes limitations on their growth. Invasive species already outcompete native species and removing these limiting factors could augment their fitness even more relative to that of native species (Liu et al. 2017; Rahel and Olden 2008).

Interactions between invasive species' biological characteristics, human activity, and climate change increase the likelihood for invasion at all four stages of invasive species establishment. At the first stage, transport, climate change could alter tourist destinations and shipping routes, particularly in the Arctic (Barry et al. 2013), which could spread invasive species to new areas. Extreme weather or changes to ocean currents could displace species outside their native ranges, some of which could become invasive (Hellman et al. 2008). At the second stage, colonization, temperature limited introduced species may respond positively to warmer conditions and colonize areas in which they had previously not been able to survive (Hellman et al. 2008). At the third stage, establishment, changing temperature and precipitation could allow current populations of introduced species to grow and become invasive (Hellman et al. 2008; Wasowicz et al. 2013). At the final stage, invasion, climate change could alter interactions between already existing invasive species and native species (Hellman et al. 2008). Liu et al. (2017) hypothesized that climate change will increase invasive species' fitness more than that of native species, intensifying the negative impacts of invasive species on native species. Climate change could also change tropic interactions in ways that favor invasive species (Hellman et al. 2008) An example of this is already happening in the southeastern United States. Flea beetles currently control invasive alligator weed in its southern range, but as alligator weed moves northward with warming temperatures, the flea beetle is not moving with it (Hellman et al. 2008).

It is difficult to predict exactly how climate change will impact the spread and abundance of invasive species because so many different processes will occur simultaneously. However, the literature overwhelmingly suggests that invasive species will benefit more from climate change than will native species. Given the strong likelihood that climate change will increase the negative impacts of invasive species on ecosystems and human societies – and may in fact already be doing so (Hellman et al. 2008) – mitigating the impacts of invasive species on future biodiversity and human security will require both steep emission cuts and rigorous invasive species management.

Climate Change and Food Security

Recent studies suggest that climate change is already reducing crop yields (Campbell et al. 2016; Vermeulen et al. 2012), and this trend is projected to continue as climate change become more severe. For every degree Celsius of warming, crop yields are projected to decrease between 3 and 10 percent (Campbell et al. 2016). However, crop yield is only one determinant of global food security. Campbell et al. identify food quantity, food access, food quality, and environmental stability as the four major components of food security. The most direct impacts of climate change on food security will be through contributing to environmental instability, and unstable ecosystems in turn impact food quantity, food access, food quality.

Climate change will reduce food quantity both through temperature increases and extreme weather events. While each degree of warming above preindustrial levels is projected to decrease yields by between 3 and 10 percent (Campbell et al. 2016), sudden, extreme weather and pest events amplify these reductions. Biophysical shocks to agriculture are predicted to cause food shocks, which are sudden, dramatic reductions in yield and subsequent spikes in food prices (Nelson et al. 2014). Extreme events such as floods, high winds, pest events, drought, and heatwaves are predicted to have a much greater impact on crop yields than is increasing average temperature (Vermeulen et al. 2012). For example, an analysis of historical crop yields data indicated that for each day above 30 degrees Celsius, maize yield in Africa was reduced by an additional 1% under normal moisture conditions and 1.7% under drought conditions (Lobell et al. 2011).

A study by Nelson et al. (2014) attempted to quantify the total global crop losses and resulting changes to price caused by biophysical shocks to agriculture. Using nine global economic models of agriculture, two climate models, and five crop models, Nelson et al. applied the biophysical shocks from the IPCC's RCP 8.5 in order to project yield reductions, food price increases, and food consumption reactions by 2050. The models predict a 17% reduction to global crop yields by 2050, corrected to a total yield reduction of 11% after producers increase production to account for losses (Nelson et al. 2014). The models predict that prices will increase 20% in response, and global consumption will be reduced by 3%, with a disproportionately large amount of the reduction occurring in poor, rural areas (Nelson et al. 2014).

Climate change is projected reduce peoples' ability to access food. Climate change-related events will likely disrupt food access by damaging the physical infrastructure of food systems, including roads and warehouses. In countries recovering from colonialism where food systems infrastructure is already inadequate to meet current needs, climate change will likely have a disproportionately negative effect on infrastructure (Vermeulen et al. 2012). A large portion of the global food supply moves through the cold chain, a system of refrigerated transport and storage, and any damage to this infrastructure will result in spoilage and food loss (Vermeulen et al. 2012). Finally, in order for families to access food, they must have a reliable household income. Climate change is virtually certain to reduce economic security, particularly in rural communities that rely on income from agriculture (Campbell et al. 2016; Nelson et al. 2014; Vermeulen et al. 2012). All of these factors together suggest that climate change will make food access much more precarious in the future.

Climate change is projected to decrease food safely and food quality. Studies have found reductions in leaf protein, and macro- and micronutrients associated with elevated CO_2

(Campbell et al. 2016). High temperatures increase microbial growth, while drought will decrease the amount of water available for sanitation (Campbell et al. 2016). Both are risks to food safety. Food born illness poses the greatest threat to people living in areas without access to public health services.

In response to the overwhelming likelihood that climate change will have far reaching negative effects on food quantity, food access, food quality, and environmental stability, and that people already in poverty will feel the brunt of these effects, food systems researchers are calling for increased action-oriented research (Campbell et al. 2016). Building resilience to climate change into our current food systems will require innovative solutions that simultaneously reduce greenhouse gas emissions from agriculture, ensure high yields, and build social and economic safety nets to combat food insecurity.

Food insecurity and invasive species

Climate change is predicted to increase the abundance of invasive species, and simultaneously decrease global food security. Is it possible these two problems could mitigate each other? Given that climate change is likely to create favorable conditions for invasive species, species which typically exhibit fast growth rates and rapid population growth, invasive species could potentially be an untapped source of nutrients. Global vulnerability to food shocks from extreme climate-related events is exacerbated by the interconnectedness of global food systems (Vermeulen et al. 2012). This level of integration makes it such that a crop failure in one country can have ripple effects throughout many regions of the world. Could taking advantage of widely available local calories from invasive species help buffer people from climate-related food shocks, thus creating a safety net for food security? And in harvesting invasive species for human consumption, could people lessen the damage that invasive species cause to ecosystems?

No research has yet evaluated whether eating invasive species could contribute to future food security. However, there has recently been an uptick in popular interest in eating invasive species, or “invasivorism” as a way of reducing the ecological impacts of invasive species (Eat the invaders! n.d.). In 2004, Joe Roman, a conservation biologist, published an article in Audubon Magazine, arguing that since people are exceptionally good at causing species extinctions through overharvesting, we should direct our appetites towards eradicating invasive species. In response to this idea, people have begun foraging for invasive species, and many chefs have begun serving invasive species and publishing invasive species cookbooks (Eat the invaders! n.d.). However, few studies have evaluated the efficacy of this management strategy, and those that have suggest that Roman's argument may be an oversimplification (Nuñez et al. 2012; Varble and Secchi 2013).

RESEARCH OBJECTIVES AND RATIONAL

Given the threat invasive species pose to ecosystems and human societies as climate change progresses, promoting biodiversity and human security will require more research on cost-effective strategies for managing invasive species. Given the threat that climate change poses to crops and food systems, ensuring future food security will require additional research and innovative restructuring of food systems. This project sits at the intersection of these two areas of research, and since no studies have yet considered dual solutions to these problems, it attempts to begin to fill this gap in the research. My goals in this project are to identify places for future research related to invasive species and food security and offer a possible example of how future research could consider climate change and its impacts synergistically in order to tackle multiple problems at once.

In this project, I will synthesize the results of the few studies written about eating invasive species and discuss the feasibility of managing invasive species by human consumption. While no academic works have discussed the potential role of edible invasive species in alleviating food insecurity, based on studies of invasive species population dynamics and literature on climate change's predicted effects on food availability, I will discuss the potential role that invasive species could play in building resilience to future food shocks. My research will be guided by two questions: 1. What qualities, if any, make an invasive species a good candidate for management through human consumption? 2. Could incorporating invasive species into local food-sheds as an alternative food source serve as a buffer against climate change-related food shocks?

In addition to synthesizing literature on the topics of climate change-related food insecurity and climate change-related species invasions, I will attempt to apply my synthesis to invasive species in Iceland. I will do this in writing and by creating recipes. Given Iceland's position as an island and an Arctic state, it is likely at greater risk of climate change-related invasions than are most regions of the world (Barry et al. 2013; CAFF and PAME 2017; Reaser et al. 2007), and thus an understanding of the variety of effective strategies available for removing invasive species will be essential to mitigating climate change's ecosystem impacts in Iceland. Iceland, as a wealthy nation, is not one of the more vulnerable nations to food insecurity (Campbell et al. 2016; Nelson et al. 2014; Vermeulen et al. 2012). I use Icelandic species as an example because I am here, but my goal in this project is to develop an idea that could be adapted to many regions of the world.

METHODS

1. *Literature Synthesis*

Managing invasive species through human consumption

I conducted a literature search of articles related to the topic of edible invasive species. In Google Scholar, Scopus, and the Bates College Online Library I entered the search terms "edible invasive species," "eating invasive species," "commercial harvest" "invasive species removal," and “human consumption” “invasive species removal.” These searches yielded 271 sources.

I eliminated duplicate sources and sources that mentioned the keywords but were not on the topic of eating invasive species. I limited my searches to only peer reviewed articles, since many members of the public have written books about eating invasive species without first consulting scientific literature (Nuñez et al. 2012). Finally, I eliminated studies on only one invasive species, under the justification that since I was not conducting a metanalysis I could not draw meaningful inferences about overall invasive species management from studies on a single species. Applying these filters reduced the number of sources to three.

I read each of the articles. Based on their findings and recommendations, I created a list of nine criteria that make an invasive species a viable candidate for management by human consumption.

Edible invasive species in Iceland

I searched “Iceland” in the Global Invasive Species Database and The Nobanis Network on Invasive Alien Species, which produced lists of all the invasive species in Iceland. I noticed that some of the introduced species that have recently been flagged as potentially invasive in Iceland were not yet listed in the databases (Iceland Ministry for the Environment and Natural Resources 2010; Thorarinsdottir et al. 2014; Wasowicz et al 2013). I assumed the databases had not been updated, and I chose to include these species in my results.

I created a list of invasive species present in Iceland. I included species listed as “potentially invasive,” “uncertain invasiveness” or “invasiveness unspecified” because based on the precautionary principle, invasive species biologists recommend removing species that likely have a negative impact on ecosystems (Simberloff et al. 2012).

I assessed each species present in Iceland based on the nine criteria I created to determine the feasibility of managing the species by human consumption. The output of this assessment became the list of edible invasive species that I could use in recipes.

Incorporating invasive species into food systems to diminish the impacts of climate change-related food insecurity:

Given that none of the articles I could find on eating invasive species discussed the potential for edible invasive species to reduce food insecurity, my results are a synthesis of articles about edible invasive species and articles about food security. Based on the four major components of food security I summarized in my literature review: quantity, access, quality, and environmental stability (Campbell et al. 2016), I discussed whether eating invasive species could create an intervention that would mitigate the impact of climate change on any of these four components.

2. *Creative Project*

I reached out to Daniel Govoni, Alexandra Tyas, and Jennifer Smith, who gave me suggestions of local fishers, researchers, foragers, and farmers whom I could contact about finding invasive species. I reached out to nine people involved in these activities and we discussed invasive species in Iceland and how to access them this time of year. Due to the seasonality of invasive fish species in the Westfjords and restrictions on fishing, I chose to cook with a rabbit. Peter Weiss from the University Center of the Westfjords generously gave me a rabbit he had raised and slaughtered.

I contacted Henry Fletcher, a forager and wilderness leader involved in the project Wildfjords. Henry and I discussed foraging in the Westfjords (Fletcher 2019), and he was kind enough to share an unpublished manuscript of a book he is currently writing, *Walking and Wayfinding in the Westfjords of Iceland*. From a journal article titled Edible Wild Plant Use in the Faroe Islands and Iceland (Svanberg and Ægisson 2012), my conversation with Henry, and Henry's book, I learned to identify edible wild plants to use in my recipes.

I gathered edible wild plants and tried out different methods of cooking them to see what tasted good. I purchased ingredients grown in Iceland and combined these with rabbit meat and wild plants to make my first recipe. For my second recipe I purchased cheap bulk items and combined these with rabbit meat. I calculated cost per serving for my second recipe using the formula (Σ (price of ingredient per unit *units used))/number of portions. The prices per unit ingredient are based off of current prices in Nettó in Ísafjörður. I did not include the cost of the rabbit in the recipes, since Peter did not charge me for the meat.

From April 22nd to May 13th, I spent 8 hours trying to acquire invasive species, 7 hours foraging, 3 hours gathering other ingredients, 4 hours doing background reading on my ingredients and how to cook them, 12 hours experimenting with recipes, 3 hours writing recipes and 1 hour performing cost analysis, for a total of 38 hours spent on the creative component of my ISP.

Ethics

One rabbit was killed for this research. During its life it had ample space indoors, and outdoors as well when the weather would allow it. It had company from other rabbits. It was killed as quickly and painlessly as possible.

When harvesting wild native species, I took care not to disturb the plants around me. I picked only a few leaves and stalks from each plant so they would grow back. I gathered plants in Ísafjörður in areas where foraging is permitted. Friends and I ate all the food that I cooked so that nothing went to waste.

I have properly cited all the sources that have informed this research. To the best of my ability I have attempted to correctly represent the findings of other researchers' studies. I recognize that since much of my results section is theoretical, my findings cannot be considered objective, and all require further research. In my results, discussion, and conclusion sections I attempt to fully acknowledging the range of implications that other researchers' findings have on the results of this project, in hopes that this will limit, as much as possible, any personal biases from influencing my conclusions.

This project did not involve human subjects.

RESULTS

1. Literature Synthesis

Managing invasive species through human consumption

The three studies I reviewed about human consumption of invasive species suggest that if implemented properly, eating invasive species could be an important part of invasive species management. However, they all caution that haphazard approaches to harvesting invasive species could result in the invasive species spreading and causing more damage. They conclude that strong incentives for total removal and an understanding of invasive species population dynamics are both essential to creating effective efforts to manage invasive species through human consumption.

Eating invasive species could reduce their populations both directly by intentional overharvesting, and indirectly by raising awareness of invasive species and thus galvanizing support for more traditional management efforts (Nuñez et al. 2012). Hunting, fishing, and foraging for small populations of invasive species confined to one geographic location is a cost-effective form of invasive species management (Nuñez et al. 2012; Pasko and Goldberg 2014). Removing recently introduced species reduces the chance that they will permanently impact an ecosystem (Pasko and Goldberg 2014). The findings of the articles I reviewed suggest that efforts to manage invasive species through human consumption will have the greatest positive effects on local biodiversity if the population of invasive species is small, centralized, and recently introduced.

However, efforts to manage invasive species through human consumption could backfire if left to market forces alone. Creating demand for invasive species could in turn create perverse market incentives to conserve the invasive species or even to introduce it to new locations (Nuñez et al. 2012; Pasko and Goldberg 2014; Varble and Secchi 2013). If people's livelihoods come to depend on an invasive species, or if the species becomes culturally significant, this could generate addition incentives to conserve it (Nuñez et al. 2012; Varble and Secchi 2013). Some invasive species only exhibit population declines when individuals of all sizes are harvested. However, not all size classes are marketable (Varble and Secchi 2013) and in the absence of subsidies for harvesting the smaller individuals, the population would not decline. In cases where the invasive species is widely dispersed or has a low population density, harvesting it quickly because prohibitively expensive, and subsidies would also be required to incentivize harvests (Nuñez et al. 2012; Pasko and Goldberg 2014). Finally, if enough individuals are harvested to reduce the population, as the population declines there will be decreasing returns to efforts to harvest the species (Pasko and Goldberg 2014). This could disincentivize the harvest of the last remaining individuals and allow the population to rebound.

Moreover, many invasive species cannot or should not be managed through human consumption. Some invasive species are poisonous, and some are vectors for disease (Nuñez et al. 2012). Some, while edible, taste bad or are simply unappealing to many people, and so trying to establish a market for them would be impractical (Varble and Secchi 2013). For many species of invasive plants, removing the parts that are eaten, leaves and stalks, does not impact the plant's ability to reproduce and so does not affect the population (Nuñez et al. 2012). In other cases, removing an invasive species that has been in an ecosystem for long enough to irreversibly change the community structure can cause more harm than good. Rather than restoring the ecosystem to its original condition, removing the species can open a niche for an even more harmful species to establish itself (Pasko and Goldberg 2014).

The studies stress that since not all invasive species are good candidates for removal by human consumption, a robust understanding of markets and invasive species' population dynamics is essential to creating effective management programs (Nuñez et al. 2012; Pasko and Goldberg 2014; Varble and Secchi 2013). Bioeconomic models – models that approximate the interactions between population dynamics and market behavior – can help resource managers determine whether market price alone will provide enough incentives to fully remove an invasive species through commercial harvesting or if additional subsidies will be required (Pasko and Goldberg 2014).

Based on the findings of the articles, I created a list of criteria for evaluating whether a species could be a good candidate for harvest for human consumption. Given the time and resources required to create species specific bioeconomic models, these criteria can act as a rapid screening to determine whether a bioeconomic model should be developed to further evaluate the species' potential to be managed through human consumption. An invasive species should be considered for management by human consumption only if exhibits the following nine traits:

1. Non-poisonous
2. Not a common vector for parasites and diseases
3. Removing edible parts reduces the population
4. Appealing to consumers
5. Recent introduction/has not had a permanent impact on community structure
6. High population density throughout range
7. Can be easily harvested with equipment that is already in use in that area
8. Other economic opportunities exist in the same area that require a similar skillset to foraging/hunting/fishing the invasive species
9. Is found in an area where funding is available for invasive species control

Edible invasive species in Iceland

Nineteen invasive species are known to be present in Iceland. Of these species, 8 are poisonous or are vectors for disease (Table 1).

Of the species that are safe for human consumption, four meet the criteria for consideration for management through human consumption: *Cancer irroratus* (rock crab), *Crangon crangon* (brown shrimp), *Oryctolagus cuniculus* (rabbit) and *Platichtys flesus* (flounder) (Table 1). These four species are not poisonous, and not common vectors for disease or parasites (Thorarinsdottir et al 2014). Eating them will kill them. They are considered tasty food in many parts of the world. They have been introduced within the last 20 years (Iceland Ministry for the Environment and Natural Resources 2010; Thorarinsdottir et al 2014) and so are less likely than a longtime invasive species to have permanently impacted local ecosystems (Pasko and Goldberg 2014). All have a high population density (Iceland Ministry for the Environment and Natural Resources 2010; Thorarinsdottir et al 2014). Equipment for fishing and hunting these species exists in Iceland, and some is already being used experimentally for catching rock crab (Jónsson 2019). Iceland's economy is characterized by a flexible labor market and diverse natural resources (Fjeldsted et al. 2018), so it is unlikely that harvesting invasive species to extinction could result in job losses for hunters and fishers. Finally, funding for invasive species removal is available in Iceland (Iceland Ministry for the Environment and Natural Resources 2010).

Table 1. Invasive species in Iceland, and their potential to be managed by human consumption (See Appendix 1 for sources).

Name	Invasive status	Safe to eat?	Meets all 9 criteria	Reason for not meeting criteria if safe to eat
Anthriscus sylvestris	Invasive	Yes	No	Bitter taste. Leaves eaten; does not kill plant
Arion lusitanicus	Invasive	No	No	
Bromus tectorum	Invasive	Yes	No	Seeds eaten; does not kill plant
Campylopus introflexus	Invasive	No	No	
Cancer irroratus	Potentially invasive	Yes	Yes	
Crangon crangon	Potentially invasive	Yes	Yes	
Didymosphenia geminata	Unspecified	No	No	
Fucus serratus	Potentially invasive	Yes	No	Has been established for over 100 years
Heracleum mantegazzianum	Unspecified	No	No	
Heracleum persicum	Potentially invasive	No	No	
Lotus corniculatus	Uncertain	No	No	
Lupinus nootkatensis	Invasive	No	No	
Mya arenaria	Unspecified	Yes	No	Low population density, few individuals
Neovison vison	Invasive	No	No	
Oryctolagus cuniculus	Potentially invasive	Yes	Yes	
Oxyura jamaicensis	Unspecified	Yes	No	Low population density, few individuals
Platichtys flesus	Potentially invasive	Yes	Yes	
Vespula germanica	Invasive	Yes	No	Insect, not likely to be appealing to consumers in Iceland
Vespula vulgaris	Invasive	Yes	No	Insect, not likely to be appealing to consumers in Iceland

Incorporating invasive species into food systems to diminish the impacts of climate change-related food insecurity:

If bioeconomic models of an edible invasive species indicate that managing it through human consumption will not be effective or affordable, this does not necessarily negate its potential as a food source. Due to high fecundity, rapid growth rates, dispersal across a large or inaccessible geographic area, or a lack of political will to fund removal efforts, some species cannot be removed, through human consumption or more traditional means (Carroll 2011; Nuñez et al. 2012; Pasko and Goldberg 2014). Moreover, in some cases, longtime invaders should not be removed as this could further destabilize the ecosystem (Carroll 2011; Pasko and Goldberg 2014). If they are safe to eat and appealing to consumers, permanent invasive species could become a reliable source of affordable local food. As climate change erodes global food security, edible invasive species could help promote all four major components of food security: food quantity, food access, food quality, and environmental stability.

Making use of locally available edible invasive species would increase food quantity without taxing valuable natural resources such as cropland or water. Species that become invasive exhibit rapid growth rates and high compensation rates to culling (Pasko and Goldberg 2014; Varble and Secchi 2013). Because they are less vulnerable to overharvest than are native species (Nuñez et al. 2012), they are a more stable source of calories. Since invasive species tolerate a wider range of environmental conditions than do native species (Hellman et al. 2008; Liu et al. 2017; Rahel and Olden 2008) populations of invasive species are more likely be resilient to climate change-related biophysical shocks that threaten other sources of food.

Food access, the next component of food security, depends on the infrastructure to transport food, food prices, and the purchasing power of households. As climate change damages physical infrastructure for shipping and storing food (Vermeulen et al. 2012) local invasive species could offer an alternative food source that does not require long distance transport. Climate change is predicted to increase food prices (Nelson et al. 2014) and invasive species are typically very affordable due to their abundance (Varble and Secchi 2013). People whose livelihoods depend on natural resources are at a disproportionate risk of economic insecurity due to climate change (Campbell et al. 2016), and as climate change alters what natural resources are available, edible invasive species could provide an alternative source of income, thus bolstering the purchasing power of households.

Climate change is projected to have a negative impact on food safety and quality. Increasing reliance on local food, including food from invasive species, would limit the amount of time food spends in transportation and the cold chain, thus decreasing the risk of spoilage.

Finally, eating invasive species could contribute to environmental stability by relieving stress on ecosystems. Invasive species require no fertilizer or inputs to grow, and if harvested locally, would require only a small amount of fossil fuels for transportation, which could reduce the carbon footprint of agriculture. If people overharvested the invasive species, as discussed in the previous section of the literature synthesis, this could lessen the ecosystem impacts of invasive species and augment ecosystem and agroecosystem productivity.

2. *Creative Project*

Oven braised leg of rabbit with wild spring greens and roasted root vegetables (figure 1)

One serving

Rabbit:
15 spruce tips, collected in early spring
Light beer vinegar
3 dl diced fresh rhubarb
1.5 dl water
25 ml honey
4.5 ml salt
50 ml clarified butter, melted
1 clove garlic
¼ small onion, chopped
1 hind leg of rabbit
Clarified butter for pan

Place the spruce tips in a jar, fill jar with enough beer vinegar to submerge the spruce tips. Let sit in fridge for 2 weeks.
Combine the rhubarb, water, honey, and salt in a small saucepan. Bring to a boil then simmer, covered, for 20 minutes or until the rhubarb softens and falls apart. Add the butter, garlic, onion, and 15 ml of spruce infused vinegar and blend in a food processor until until smooth.
Inspect the rabbit for lead shot, then wash and pat dry. Pour the rhubarb mixture over the rabbit and let sit at room temperature for two hours.
While the rabbit sits, preheat over to 180°C.

Heat clarified butter in in frying pan, pull rabbit from the marinade, and brown rabbit on all sides. Place rabbit in a cast iron pot, slather with the marinade, and add water to cover meat. Bring to a boil on the stovetop, then place in oven and braise until tender, about 2 hours.

Wilted dandelion greens:
30 ml spruce infused vinegar
2 dl loosely packed dandelion greens
Butter and salt to taste

Fill a frying pan half way with water and bring to a boil. Add vinegar and a generous amount of salt. Wilt the dandelion greens in the water. Strain, and toss with butter and salt.

Roasted vegetables:
1 beet
1 turnip
½ rutabaga
Clarified butter, melted
Coarse salt

Preheat oven to 200°C.
Peel and cut the root vegetables into exact cubes ranging from 2 to 3 cm. Discard peel and retain trimmings. Toss the cubes of each type of vegetable in butter individually so the beets don't stain the lighter vegetables. Sprinkle with salt. Place on a sheet pan, keeping vegetables separate. Roast until soft, about 25 minutes, flipping once half way through.

Root vegetable purée:
Root vegetable trimmings, sliced thinly
Clarified butter
15 ml canola oil
10 ml spruce infused vinegar
Needles from one spruce tip
Half a clove of garlic
Salt to taste

Sauté the root vegetables in clarified butter until soft. Place in blender with all the other ingredients and blend until smooth. Add water as needed to reach desired consistency.

Sweet cicely oil:
1 dl olive oil
1 handful sweet cicely leaves
Splash of beer vinegar (to keep the leaves green)
Salt to taste

Blend together.

Garnishes
Arctic thyme leaves and flowers
Sweet cicely leaves
Sweet cicile stems, steamed and sliced into thin diagonal ovals.

Assembly:

Spoon root vegetable purée onto plate and smear out with a spoon. Place meat on plate with a generous dollop of braising liquid. Twirl dandelion green around a fork and place next to meat; sprinkle roasted vegetables on top. Drizzle around the rim of the plate with sweet cicely oil. Sprinkle plate with sweet cicely stems, small sweet cicely leaves, thyme leaves, and thyme flowers.

Figure 1. Oven braised leg of rabbit with wild spring greens and roasted root vegetables

Rabbit Stew (figure 2)
8 servings, 92 ISK per serving

1 rabbit, 6 cut
Cooking oil for pan
2 onions, diced

½ head garlic, minced
A handful of fresh herbs, or 10 ml dried herbs, minced
1 ml cayenne pepper
4 ml paprika
2 ml black pepper
1 can tomatoes
3 bouillon cubes, chicken or vegetable flavor
Water
2 large carrots, diced
1 medium turnip, diced

Inspect rabbit for lead shot, wash, and pat dry.
Heat oil in a cast iron pot. Brown the rabbit pieces on all sides. Remove from pot. Add onions to pot and cook until translucent. Add garlic and herbs and cook for 5 minutes more. Add spices, tomato, and bouillon cubes. Place rabbit back in pot, and fill pot with enough water to cover meat. Bring to a boil, cover, and simmer for 1.5 hours.
Add carrots and turnips, and continue to simmer until meat is fork tender, about 1 hour more. Shred meat from bones with a fork, remove bones, and serve.

Figure 2. Rabbit Stew

DISCUSSION

Invasive species management by human consumption

In my first research question I asked what qualities, if any, make an invasive species a good candidate for management through human consumption. I attempted to answer this question in my literature synthesis by developing a list of qualities that an invasive species should exhibit if it is to become a candidate for management through human consumption. Each of these factors should be taken into consideration before attempting to develop a market for an invasive species to ensure that eating the invasive species does not facilitate its conservation or introduction into new habitats (Nuñez et al. 2012).

The invasivorism movement has not yet incorporated the findings of studies on edible invasive species into its advocacy (Eat the invaders! n.d.). Non-academic sources on edible invasive species suggest that eating invasive species will reduce their populations, but they do not address biological compensation rates of individual species or perverse market incentives. Invasive species biologists would do well to make greater efforts to communicate the nuances of eating invasive species to the public.

Effective efforts to manage invasive species through human consumption will require communication and collaboration between scientists, government agencies, resource managers, foragers, fishermen, hunters, chefs, environmental activists, and the public. Scientists could collaborate with government agencies and resource managers to build management plans for invasive species informed by bioeconomic models. Bioeconomic models can help determine if developing a commercial market will be enough to decrease the population (Pasko and Goldberg 2014; Varble and Secchi 2013), or if government subsidies will be required (Pasko and Goldberg 2014). Resource managers and people involved in harvesting invasive species could collaborate with chefs to grow markets for invasive species. Scientists could communicate their findings about eating invasive species to environmental activists and the public to amass support for invasive species removal and to ensure that the public has accurate information. As climate change is predicted to increase the severity of invasions (Hellman et al. 2008; Liu et al. 2017; Rahel and Olden 2008) collaboration between many groups of people can build strong and multifaceted plans to address the issue.

Collaboration between groups with diverse interests will be essential to building a nuanced understanding of the ecological, economic, cultural, and social aspects of eating invasive species. Efforts to create commercial markets for invasive species will need to consider consumer taste preferences and environmental values, an area that still has received relatively little attention from invasive species biologists studying human consumption of invasive species (Varble and Secchi 2013). Research on food neophobia suggests that people experience the strongest aversions to new animal-based foods (Pliner and Pelchat 1991). In my evaluation of Iceland's invasive species, only animal species were good candidates for management through human consumption (Table 1). While I cannot make generalizations to other parts of the world based on my findings, the fact that animals are always killed by eating them, but plants are not always, suggests that invasive animal species might be better candidates for human consumption than are plants. If so, edible invasive species could be met with strong neophobia from consumers, which would also affect willingness to pay (Varble and Secchi 2013).

However, a study on consumer willingness to pay for invasive carp found that most consumers were interested in trying carp, and most were willing to pay for it. Consumers were significantly more willing to pay for the carp if it was locally caught (Varble and Secchi 2013). The authors of the study asked participants to rank their awareness of the negative ecosystem impacts of carp, but then did not mention in their results whether awareness was significantly correlated with willingness to try or pay. While they missed an opportunity to evaluate whether invasiveness impacts demand and willingness to pay, their finding that localness of invasive carp is an appealing factor for consumers suggests that the impacts of localness of invasive species on demand and willingness to pay could be an important area for future research. Collaboration with chefs and social scientists could provide useful data for this area of invasive species research.

Due to the need for better communication and collaboration, I have attempted to contribute to public outreach on eating invasive species with the list of criteria that make an invasive species a good candidate for human consumption. This list distills the body of research on edible invasive species into a simple, easily communicated form. The list could be a useful tool for people who are interested in invasivorism to consult before going out foraging or advocating for the commercial harvest a particular invasive species. Additionally, this list can help facilitate invasive species management because it can be used as a screening process for an invasive species before researchers build a bioeconomic models for it. Since bioeconomic models are expensive and time consuming to build, a systematic screening process could help eliminate the chance that models be built unnecessarily.

Invasive species and food security

In my second research question I asked if incorporating invasive species into local food-sheds as an alternative food source could serve as a buffer against climate change-related food shocks. I was unable to give a definitive answer to this question. In the absence of studies on the potential for edible invasive species to mitigate food insecurity, this area of my research is purely speculative. However, my synthesis of literature on invasive species population dynamics and literature on the need for stable food sources during food shocks (Campbell et al. 2016) suggests that invasive species could be a promising component of building resilience to future food shocks. Eating invasive species could increase the amount of food available for human consumption without putting additional stressors on cropland and water resources, could increase food access by providing stable local food sources as well as job opportunities in harvesting, fishing, and hunting, could reduce the chance of spoilage by providing a food source outside of the global food supply, and could promote environmental stability by relieving stress on ecosystems already taxed by climate change.

Further research is needed to evaluate the potential for invasive species to help alleviate climate change-related food insecurity. Based on the number of places I identified where edible invasive species could be an intervention, this seems to be a promising area for future research. Moreover, this research has the potential to address two major problems at once: food insecurity and increasing species invasion. Given the magnitude of predicted global environmental changes and the interconnectedness of the systems they will impact, we urgently need interventions that address multiple problems synergistically.

Recipes

My first recipe, oven braised leg of rabbit with wild spring greens and roasted root vegetables (figure 1), is a creative response to my first research question: what qualities, if any, make an invasive species a good candidate for management through human consumption? Rabbits in Iceland fit all the criteria for management through human consumption. I hope that incorporating invasion science into culinary arts will help the public become more aware of the nuances of managing invasive species by eating them.

In this dish, I paired rabbit with locally foraged wilds foods and locally grown produce. Besides olive oil in the sweet cicely oil (for which canola oil could be substituted) all the ingredients come entirely from Iceland. I chose to use local foods in this recipe because Varble and Secchi's (2013) study indicated that localness might be an important factor in people's willingness to try and pay for invasive species. This recipe is intended for a wealthy audience, as wealthy consumers have a higher willingness to pay for local food (Adams and Salois 2010) and may have a higher willingness to pay for invasive species (Varble and Secchi 2013).

The dish itself is bold and flavorfully complex. Dishes that taste complete do so because they successfully balance all five flavors, sweet, salty, sour, bitter, and umami. This dish accomplishes this goal – the bitter greens mellow when paired with salt and sour vinegar, the honey and overwintered root vegetables add a sweet element, the sour rhubarb serves the dual role of tenderizing the meat and further balancing the extreme bitter of the greens. The gamy meat and the clarified butter add umami flavor, giving the dish depth and richness. Clarified butter is richer than olive oil, which is typically used for browning meat. I chose to use butter both because it is local to Iceland and because its richness rounds out the flavor of the lean rabbit meat. The bright flavor of the sweet cicely contrasts with the winter root vegetables, and likewise the bright colors of the greens, beet purée, and thyme flowers contrast with the earth tones of the meat and roasted root vegetables. These contrasts make the dish visually and flavorfully exciting and attempt to capture the sudden transition between winter and spring in Northern Iceland.

My second recipe, rabbit stew (figure 2) is a creative response to my second research question: could incorporating invasive species into local food-sheds as an alternative food source serve as a buffer against climate change-related food shocks? Based on my synthesis of the literature, I hypothesize that edible invasive species could build resilience to food shocks by providing abundant, cheap, and locally available food. In this recipe, I pair invasive rabbit with affordable Icelandic ingredients. Because these ingredients are not part of the global foods supply chain, their prices will not be as vulnerable to food shocks occurring in other parts of the world (Nelson et al. 2014). Given that climate change is likely to impact food transportation infrastructure, and particularly the cold chain (Campbell et al. 2016), I used root vegetables and canned tomatoes, foods that do not need refrigeration. All ingredients in this recipe are currently quite cheap. One generous portion (more than I could eat in a siting) costs 92 ISK. This price does not include the cost of the rabbit; however, other invasive species are very cheap given their abundance (Varble and Secchi 2013). It is also worth noting that all food prices are predicted to be substantially higher in the future as climate change reduces crop yields (Nelson et al. 2014).

The stew tastes hearty and delicious. Stewed, rabbit has a similar taste and texture to the dark meat on a chicken or turkey. It is a simple recipe to make; the ingredients are easy to find, it gets few dishes dirty, and it requires very little active cooking time.

The first recipe I created will be integral to the success of the second. Everyone deserves to feel dignity about the food they eat. Invasive species should not be considered famine food; rather, they should be considered another possible component of building resilient food systems. If invasive species are adopted as part of a country's food culture, there is no shame in eating them as an affordable food option. I hope that incorporating invasive species in fine dining helps bring dignity to anyone who chooses to use them to feed their family on a budget.

By creating these two recipes I intended to ground both of my research questions in practical applications, to demonstrate the versatility of invasive species as food sources, to contribute to meeting the need for action oriented research on the topics of climate change and food systems (Campbell et al. 2016), and to create results that engage a broad audience.

Research limitations

No studies that I was able to find have yet documented successful or unsuccessful attempts to eliminate an invasive species through human consumption. The body of research I reviewed synthesizes economic theory, invasive species biology, and case studies on invasive species removal to reach conclusions about the benefits and limitations of human consumption as a control strategy for invasive species. Because these papers are not grounded specifically in studies about eating invasive species, one of the limitations of this work is the lack of examples of how effective human consumption would be in practice.

The screening process that I contributed to this body of research is likewise only theoretical and will require further research to evaluate its practical value. With more time and resources, I would have liked to apply this screening process to multiple invasive species, create bioeconomic models for the invasive species, and compare the results of both to determine the success rate of my screening process in identifying species that could be managed by human consumption.

The section of my research focused on food security is even more speculative. No studies have evaluated the role of invasive species in augmenting current or future food security. Future research in this area could combine climate models, economic models, crop models, and population models for edible invasive species to attempt to predict the severity and spatial distribution of food insecurity and the availability of edible invasive species in the areas where food insecurity is likely to be most severe.

Because I could not use statistical tests for my research, the conclusions I reached came from syntheses of past research rather than from methodical processes. While I attempted to fully and accurately represent the results of the papers I synthesized, my personal biases could have influenced my results. Personal biases have influenced invasion biology in the past, even in studies that use scientific research methods and statistical analysis (Young and Larson 2011). A survey of invasion biologists by Young and Larson (2011) suggests that xenophobia may have led invasion biologists to perceive greater negative impacts of nonnative species than are actually present and may have led biologists to classify harmless nonnative species as invasive. The claim that invasive species are the second most important driver of species extinction is now under scrutiny (Young and Larson 2011). The justification for my paper rests on the assumptions that invasive species are responsible for biodiversity loss and that invasions will cause greater damage as climate change progresses. If xenophobia has led invasion biologists to overstate the risk of invasive species, my research has also been influenced by these biases through the sources I have cited.

CONCLUSION

Climate change is projected to decrease food security and increase species invasions. In this paper, I set out to evaluate whether these problems might be able to help mitigate each other. I found that not all invasive species that are edible make good candidates for management through human consumption, and that an understanding of market forces and the invasive species' population dynamics is essential to creating an effective management plan. While no studies evaluate the potential for edible invasive species to mitigate climate change-related food insecurity, invasive species appear to be a promising intervention because they could address all components of food security: quantity, access, quality, and environmental stability. This could be an important area for future research. I was not able to answer definitively whether invasive species and food insecurity are two problems that could mitigate one another, but my results suggest that at least for some species this might be possible. Further research in this area could include building bioeconomic models that project population growth of edible invasive species, locations of invasions, food prices, and the spatial distribution of food insecurity.

In my research I found a discrepancy between the information gathered by invasive species biologists on eating invasive species and the information publicized by invasivores. Clearly, better communication is needed between scientists and the public. Given that the participation of resource managers, hunters and fishers, chefs, and the public is necessary for creating effective plans to remove invasive species through human consumption, I recommend that invasion scientists put greater effort into public outreach. I attempted to contribute to outreach efforts in my project by creating recipes informed by invasion biology and by creating a short and simple list of criteria that make an invasive species suitable for management through human consumption.

In this paper I attempted to pair two climate change-related problems to see if they could be used to mitigate one another, and while this type of problems solving is important for dealing with a problem as complex and interconnected as climate change, it is also important to recognize that this type of research is addressing symptoms of a larger problem. A much more effective way of minimizing climate change-related invasions and climate change-related food insecurity would be immediate and drastic actions to reduce global greenhouse gas emissions.

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Appendix 1. Invasive species in Iceland, and their potential to be managed by human consumption (with sources)

Name	Invasive status	Safe to eat?	Meets the 9 criteria	Reason for not meeting criteria if safe to eat	Sources
Anthriscus sylvestris	Invasive	Yes	No	Bitter taste. Leaves eaten; does not kill plant	Nobanis Network on Invasive Alien Species; Iceland Ministry for the Environment and Natural Resources 2010; Wasowicz et al 2013
Arion lusitanicus	Invasive	No	No		The Nobanis Network on Invasive Alien Species
Bromus tectorum	Invasive	Yes	No	Seeds eaten; does not kill plant	Global Invasive Species Database; Wasowicz et al 2013
Campylopus introflexus	Invasive	No	No		The Nobanis Network on Invasive Alien Species
Cancer irroratus	Potentially invasive	Yes	Yes		Thorarinsdottir et al. 2014
Crangon crangon	Potentially invasive	Yes	Yes		Thorarinsdottir et al. 2014
Didymosphenia geminata	Unspecified	No	No		Global Invasive Species Database; Iceland Ministry for the Environment and Natural Resources 2010
Fucus serratus	Potentially invasive	Yes	No	Has been established for over 100 years	Thorarinsdottir et al. 2014
Heracleum mantegazzianum	Unspecified	No	No		Global Invasive Species Database; The Nobanis Network on Invasive Alien Species; Wasowicz et al 2013
Heracleum persicum	Potentially invasive	No	No		Wasowicz et al 2013
Lotus corniculatus	Uncertain	No	No		Global Invasive Species Database; Wasowicz et al 2013 (Global Invasive Species Database lists it as invasive, but Wasowicz et al 2013 suggest it is not invasive)
Lupinus nootkatensis	Invasive	No	No		Global Invasive Species Database; Iceland Ministry for the Environment and Natural Resources 2010; The Nobanis Network on Invasive Alien Species; Wasowicz et al 2013
Mya arenaria	Unspecified	Yes	No	Low population density, few individuals	Global Invasive Species Database; The Nobanis Network on Invasive Alien Species; Thorarinsdottir et al. 2014
Neovison vison	Invasive	No	No		Global Invasive Species Database; Iceland Ministry for the Environment and Natural Resources 2010; The

					Nobanis Network on Invasive Alien Species
Oryctolagus cuniculus	Potentially invasive	Yes	Yes		Iceland Ministry for the Environment and Natural Resources 2010
Oxyura jamaicensis	Unspecified	Yes	No	Low population density, few individuals	Global Invasive Species Database
Platichtys flesus	Potentially invasive	Yes	Yes		Thorarinsdottir et al. 2014
Vespula germanica	Invasive	Yes	No	Insect, not likely to be appealing to consumers	Global Invasive Species Database
Vespula vulgaris	Invasive	Yes	No	Insect, not likely to be appealing to consumers	Global Invasive Species Database