**Problem Statement**

Introductions of contaminants and non-native species to aquatic ecosystems are ecological problems of global significance. Contaminants are accumulated and transported by physical and biological processes, including by organisms as they migrate between ecosystems, which can lead to human and wildlife health concerns **(1)**. Non-native species are introduced both intentionally and unintentionally and are recognized as an important cause of global biodiversity loss and environmental change **(2)**. While intentionally introduced organisms can be beneficial, especially if commercially valuable, the ecological consequences of intentional introductions are often complex and difficult to predict **(3)**. Such environmental problems rarely operate in isolation. More often, they work synergistically with other problems to have unanticipated impacts on ecosystems.

The Great Lakes Basin (GLB) and its associated fisheries face multiple environmental threats, including the proliferation of non-native species and a legacy of contamination by multiple pollutants **(4)**. Over 90 non-native fish species have been introduced to the GLB, with detrimental impacts on the environmental and economic health of the region **(5)**. Non-native Pacific Salmon (*Oncoryhnchus* spp.) and Brown Trout (*Salmo trutta*) have been actively stocked in the GLB for over five decades, and Pacific Salmon have become a key component of the >$7 billion GLB fishery **(6)**. While salmon can provide substantial economic benefits, they can also have important ecological effects on the ecosystems in which they migrate to spawn, including the delivery of organic pollutants and mercury that bioaccumulate while salmon mature **(1)**.

Since the introduction of Pacific Salmon and Brown Trout to the Great Lakes, native Brook Trout (*Salvelinus fontinalis*) abundance has declined in tributaries for unknown reasons **(7)**. Within the native range of salmon, the resources they deliver to tributaries during spawning

migrations can increase resident fish growth, but influences outside their native range are uncertain **(8)**. In Great Lakes tributaries, inputs from salmon are positively correlated with pollutant concentrations in stream-resident fish **(9)**. Mercury, in particular, is a contaminant of concern in the GLB, due to increased atmospheric mercury deposition in the Great Lakes and the adverse effects associated with its identification as a neurotoxin **(10)**. Thus, current proposals in Michigan to increase fish passage at dams could have widespread, but understudied, effects on resident trout populations, including through mercury biotransport.

The objective of this research study is to determine if salmon-derived material has a differential effect on growth and mercury bioaccumulation of native Brook Trout when compared to introduced Brown Trout. If Brown Trout confer a greater growth benefit from salmon material consumption, an increase in fish passage at dams could further diminish the abundance of native Brook Trout. Conversely, the provision of salmon material could release Brook Trout from competition with Brown Trout, enabling the two species to better coexist. Further, the provision of salmon material could negatively impact both resident trout species through increased mercury contamination.

**Project Description**

During the summer of 2014, through the support of a College of Science Summer Undergraduate Research Fellowship, I conducted a mesocosm experiment to determine whether the presence of salmon tissue has a differential effect on the growth rates of co-occurring Brook Trout and Brown Trout. I reared both species for 7 weeks in flow-through mesocosms, with regular rations of bloodworms or bloodworms augmented by salmon tissue, and measured fish mass and length weekly. The results of the mesocosm experiment suggest that salmon tissue may equally benefit both native Brook Trout and introduced Brown Trout. However, average growth

rates of Brook Trout were significantly greater than Brown Trout – an unforeseen result not previously reported in the primary literature **(ct. 11)**.

To determine if significant increases in growth were a result of increased salmon tissue consumption, I conducted extensive stable isotope analyses on the bloodworms, salmon tissue, and experimental fish. In the presence of salmon tissue, both Brook Trout and Brown Trout exhibited isotopic ratios reflecting a predominance of salmon tissue in their diet. However, neither species conferred a growth benefit from consumption of salmon tissue. This result has numerous implications. First, where salmon are introduced, the material they deliver may serve as a resource for resident fish but not a resource subsidy. Second, in the native range of salmon, observed growth increases in resident fish may be mediated by a specific pathway (i.e., direct consumption of salmon eggs as opposed to direct consumption of salmon tissue). Third, growth responses to salmon material consumption may be component-dependent (i.e., carbohydrate-rich salmon eggs may confer a greater growth benefit than protein-rich salmon tissue).

To complement the data obtained from the mesocosm experiment and the stable isotope analyses, I am requesting $1,400 to cover the consumable costs for use of a Direct Mercury Analyzer (DMA) and a bomb calorimeter. Through extensive mercury analyses, I will determine if mercury bioaccumulation is positively correlated with increased consumption of salmon tissue. Because shifts in isotopic ratios towards that of salmon tissue and elevated mercury concentrations are both indicative of increased salmon tissue consumption, the results of the mercury analyses will complement the results obtained from the stable isotope analyses. By using two complementary analyses, I will not only strengthen the implications of the results obtained, but I will further assess the extent of salmon tissue consumption by each species. Additionally, the mercury analyses will add another dimension to the study – the potential for

introduced salmon to negatively impact resident fish through mercury contamination.

Through use of a bomb calorimeter, I will be able to assess for differences in the energetic densities of bloodworms and various components of salmon material (e.g., eggs, tissues, fats). The energy density data will be combined with the physical parameters of the mesocosm (e.g., water temperature) and incorporated into a bioenergetics model. The bioenergetics model will allow me to run simulations of the expected growth responses of resident Brook Trout and Brown Trout to introduced salmon tissue. Thus, by combining the energy density data with a bioenergetics model, I will determine whether growth responses of resident fish to salmon material consumption are mediated by the component of salmon material consumed. An identification of the particular components of salmon material that confer growth benefits to resident fish would allow for more informed predictions of the effects of salmon introductions on both growth and survival of resident fish species.

I am conducting my research under the guidance of Dr. [redacted] and Ph.D. student [redacted]. Dr. [redacted] and Mr. [redacted] have served as my research mentors for over two years, and they have both spent a significant amount of time helping me to structure and apply my research in ways that enable novel and meaningful results. I am grateful for the support that both Dr. [redacted] and Mr. [redacted] have showed me, and I am committed to producing a poster for a local and national meeting and developing a manuscript for publication.

**Methodology and Time Frame**

To complete the proposed analyses, I will use the Direct Mercury Analyzer (DMA) located in the Center for Environmental Science and Technology (CEST) and the bomb calorimeter that belongs to the Chemistry and Biochemistry teaching laboratories located in the Jordan Hall of Science. As of fall 2015, CEST requires all users to cover the consumable costs

(e.g., catalysts, joint sets, reference materials) for use of the DMA. Similarly, the College of Science will not cover consumable costs for use of the bomb calorimeter (e.g., ignition wires, combustion dishes, crucibles). I have completed the necessary training for use of the instruments located in CEST. Additionally, I have contacted Dr. [redacted], Dept. of Chemistry and Biochemistry, and he has agreed to allow me to use the bomb calorimeter.

I will begin conducting the mercury analyses in early February, and I expect to complete both analyses within a month. Use of the DMA requires limited sample preparation, and I expect to analyze 90 samples per day. At that rate, I expect to finish analyzing all 400 samples within a week. Upon completion of the mercury analyses, I will begin using the bomb calorimeter. Use of the bomb calorimeter is more labor-intensive than the DMA. According to Dr. [redacted], each sample analysis requires approximately 20 minutes. At a rate of six samples per day, I expect to finish analyzing all 70 samples within two weeks. Thus, factoring in an additional week for unforeseen complications, I expect to complete all my analyses by mid-March. I will then have over a month to evaluate my results and incorporate them into a poster for a presentation at COS-JAM on April 29th. The poster produced for COS-JAM will then serve as a template for both a poster for the American Fisheries Society Meeting in August and a manuscript for publication.

**Products of Proposed Research**

The results of the mercury analyses and the bioenergetics model will be combined with the results of the mesocosm experiment and the stable isotope analyses, and used to generate a manuscript for publication. This publication will provide a comprehensive assessment of the ecological effects of non-native Pacific Salmon and Brown Trout on native Brook Trout in Great Lakes tributaries. Additionally, I will present the results obtained at the College of Science Joint Annual Meeting in the spring of 2016 and at a national meeting during the summer, such as the

American Fisheries Society (AFS) Meeting. At the AFS Meeting, I will share my data with the fisheries professionals who devise and implement management and conservation strategies.

**Outcomes and Broader Impacts**

The outcomes of the proposed research will have numerous benefits. First, the information gained through the proposed study will help to better inform management decisions regarding dam removals and fish introductions in the Great Lakes region. Second, the data obtained will contribute to the information necessary for a balanced assessment of the ecological benefits and costs of Pacific Salmon management in the Great Lakes. Third, the data will provide insights for the potential impacts of contaminant biotransport on tributaries of the Great Lakes and potential management options for the future. While the introduction of Pacific Salmon has provided significant economic benefits to the Great Lakes, the ecological costs are not well understood. Overall, the proposed research will contribute to the information base necessary to understand and manage the Great Lakes ecosystem for sustainable production of non-native Pacific Salmon and native Brook Trout. In this way, the proposed study will improve the conservation and sustainability of both fishery resources and aquatic ecosystems.

**Credentials**

For two and a half years, I have conducted undergraduate research in the Stream Ecology Laboratory under the guidance of Dr. [redacted] and Ph.D. student [redacted]. During the spring of 2014, I was awarded a College of Science Summer Undergraduate Research Fellowship to conduct an independent research study. Through the process of designing and conducting the mesocosm experiment described above, I became more familiar with the scientific process and gained confidence in conducting independent research studies. Additionally, I gained experience in collecting and analyzing data and performing statistical

analyses. Furthermore, through my coursework in classes like aquatic ecology, tropical marine ecology, and evolutionary biology, I have gained a more academic understanding of the potential effects associated with interactions between non-native and native species.

Aside from the research that I have conducted in the Stream Ecology Laboratory, I have assisted on a research project in Glover's Reef, Belize and conducted independent research in South Caicos, Turks and Caicos Islands. While assisting on a Shark Conservation Project in Belize, I gained experience in following detailed protocols and preparing tissue samples. Through my independent research study on the abundance and habitat use of elasmobranchs off the coast of South Caicos, I gained further experience in devising and conducting research studies. Additionally, I became more familiar with the field procedures commonly associated with aquatic research, such as the deployment of drumlines and baited remote underwater videos. Thus, through my experiences in the classroom and in the field, I have obtained the knowledge and the skills necessary to conduct the proposed research.

**Relation to Academic Goals**

As a biological sciences major with a deep interest in the field of ecosystem ecology and its implications for fisheries management, the proposed research will further advance my current research agenda. More specifically, the proposed analyses will fill the gaps that are currently hindering a more thorough understanding of the results that I have obtained thus far. Once these gaps are filled, I will have the information necessary to present and publish a manuscript on the ecological effects of non-native Pacific Salmon and Brown Trout on native Brook Trout in Great Lakes tributaries. The publication of a manuscript is crucial for my current career trajectory, as it would greatly enhance the competitiveness of my applications for graduate school programs and future doctoral programs. Additionally, participation in a national meeting, such as the AFS

Meeting, will have numerous benefits. Through my independent presentation, I will gain both experience and confidence in presenting the findings of my work - preparing me for future presentations in graduate school and beyond. Through attending the presentations of others, I will build my knowledge base and become more aware of the developing trends in the area of fisheries management. Finally, through opportunities to interact with professionals in various fields relating to fisheries management, I will be able to expand my professional network while also gaining career advice.

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