Professional Services Qualifications for a Vulnerability and Habitat Suitability Analysis for Aquatic Invasive Species in Lake Chelan

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Qualifications and Proposal for

Vulnerability and Habitat Suitability Analysis for Aquatic Invasive Species in Lake Chelan

Prepared by: **Herrera Environmental Consultants, Inc.**

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Introduction

Lake Chelan is one of the premier lakes in Washington State. It is enjoyed by many recreational enthusiasts, provides source water for irrigation and domestic use, and is used for hydropower production. Many of these beneficial uses are threatened by the risk of aquatic species invasions in the future, the most notable being quagga and zebra mussels due both to their proximity and the economic and ecosystem impacts from an infestation. Aquatic invasive species (AIS) such as quagga and zebra mussels can fundamentally transform freshwater ecosystems. The resultant loss in beneficial uses from these invasions as well as other direct and indirect costs associated with infestation can cost 100's of millions of dollars. Given this level of potential impact, and with zebra and quagga mussels established west of the Rocky Mountains, a scientifically defensible plan for preventing invasion and for responding rapidly and efficiently to new invasions is needed.

Successful curtailment of the colonization and establishment of AIS will require early detection and rapid-response activities, whereas controlling invader spread will be most effective when focused on likely sources of propagules and preventing conditions that promote proliferation. However, common approaches to invasion species risk assessments rarely incorporate the likelihood of each of the phases of invasion. Here, we will apply modern analytical approaches to develop an integrative risk assessment for Lake Chelan that includes the introduction, establishment, and impact stages to help managers make more efficient and targeted use of limited resources. Results from this research will lead to management recommendations to decrease the risk of invasions in Lake Chelan, and help guide planning, monitoring, inspection, infrastructure, and education and outreach actions. The recommendations and prioritization of recommendations will reflect a balance between the level of risk and potential impacts.

Development of a scientifically defensible plan that garners stakeholder and public support requires the expertise of limnologists, invasive species experts, and public involvement specialists. As described below, the Herrera team is comprised of professionals who understand and advocate for lakes and reservoirs, and who are leading scientists in the fields of lake management and invasive aquatic species; while our approach outlined is based on science and pragmatism.

Project Team

Herrera is one of very few firms in the Pacific Northwest to specialize in lake studies and we have been providing this expertise to the region since 1980. While we are a small firm by industry standards, we are proud to have three professional limnologists on staff who have been involved in many of the significant lake and reservoir research projects in Washington. We actively participate in regional and national associations to improve our understanding of lakes and reservoirs. We have teamed with Dr. Julian Olden from the University of Washington, a nationally recognized expert in aquatic invasive species. Dr. Olden's research has included a diverse set of aquatic invasive species (e.g., mussels, crayfish, fish, plants) and diverse environments, thus he brings a robust understanding of the science and management of invasive aquatic species to this project.

Our teams relevant project experience includes:

- Extensive research on ecosystem vulnerability from species as diverse as black bass, spiny water flea, rusty crayfish, Eurasian watermilfoil, and dreissenid mussels.
- Development of analytical tools for synthesizing distributional and demographic data and development of predictive models for species invasion and establishment.
- Research into interactive impacts of climate change, land use modification, and AIS.
- Detailed evaluations of aquatic plants, phytoplankton, zooplankton, periphyton, benthic invertebrate, aquatic invasive species (AIS) and fish communities for various lake management projects.
- Restoration of lakes using various in-lake treatments (aluminum sulfate, calcium hydroxide, aeration, dilution/flushing, and dredging), watershed controls (stormwater management and source control of development and agriculture), and aquatic plant control (physical, mechanical, chemical, and biological techniques).
- Lake and reservoir research on topics such as toxic cyanobacteria, sediment phosphorus fractionation, microbial source tracking, and nutrient budget modeling.

Our team has extensive skills of the type needed for this project as well as the practical experience needed to ensure success. In terms of roles, the Dr. Olden and his students will lead the data analysis steps including any field work and Herrera will provide overall project management, lead the stakeholder involvement, and develop the final report and detailed implementation plan. Qualifications of key staff are summarized below. Relevant project examples are provided at the end of this submittal.

The Herrera team is led by **Joy Michaud** a Herrera Principal and head of their Olympia office, has over 30 years of experience as a water resource professional. Joy will serve as project manager and lead the stakeholder involvement process. Joy has a long track record of successfully managing large, multidisciplinary teams on projects with complex technical requirements and high visibility to the public. Joy's broad technical expertise and effective communication skills has enhanced her ability to work successfully with a wide variety of stakeholder groups. She has provided facilitation services to State agencies such as Ecology, WSDOT, WDFW, NMFS, and others with review of different programs or policies. Joy has worked with diverse groups of lake residents tasked with making decisions about management and restoration alternatives for their lakes. The diversity of this experience speaks to her aptitude for understanding and articulating issues and assisting development of manageable solutions. Joy is also a limnologist with extensive lake management experience including developing plans for management of invasive species.

Rob Zisette of Herrera will act as Herrera's lead scientist. Rob is an expert limnologist who has conducted many lake management studies and performed complex water quality technical analyses for projects throughout the Pacific Northwest. This experience has included assessment and evaluation of a wide diversity of lake management activities, including phosphorus inactivation with aluminum sulfate, dredging, dilution, flushing, aeration, and aquatic invasive species control.

Julian Olden is a Professor in the School of Aquatic and Fishery Sciences at the University of Washington. His research seeks to advance the science and inform the practice of conserving freshwater ecosystems with a focus on invasive species, climate change, and hydrology. An author of over 220 peer-reviewed publications, Julian's research has supported novel advancements in our understanding of species invasion and led to scientifically-informed decisions to better manage AIS in Washington State and beyond. Past and current research focus on a diversity of issues involving both plant and animal AIS, including risk of species introductions, diagnosing pathways of species introductions, traits-based approaches to identifying AIS, species distribution models to assess environmental suitability for AIS establishment, modeling AIS population dynamics and spread, forecasting species invasions in response to climate change, assessing ecological impacts of AIS, conducting economic analyses to quantify the impact of AIS, evaluating the success of AIS eradication efforts, developing integrative risk assessment frameworks, and investigating of how AIS policies support local management decisions. Results from this body of research are used for setting conservation priorities for identifying vulnerable freshwater systems and focusing management activities on the invasion stage most amenable to human intervention. Previous leadership in the field of invasion ecology includes serving as the Principal Investigator on numerous grants studying the ecology and management of AIS, and participation on numerous panels including the WDFW Ballast Water AIS Committee, National Invasive Species Council – Advisory Committee, and the Environmental Law Institute initiative to assess gaps and needs for invasive species management in a changing climate.

Project Approach

Task 1 – Background Data Review

The project will begin with our collection and review of the relevant data available to accomplish an AIS assessment for Lake Chelan. This will include identifying priority species in the recreational boating pathway, collecting available data on boat launch use and movement behavior, and collating the list of physical and ecological factors responsible for defining AIS establishment probability (e.g., water quality data such as temperature, hardness, calcium, velocity, and nutrient levels). This process will result in a robust understanding of relevant information available from different stakeholders such as the PUD and WDFW. We will also collect and map infrastructure data such as locations of boat launches, dams, hatcheries, water supply intakes, and discharges.

Task 2 – Stakeholder Involvement

We foresee a minimum of four meetings with a diverse set of stakeholders. During the initial meeting we will discuss the full list of potential AIS (See Task 3.1) and agree on those that should be the focus of this effort. During this meeting we will also begin the process of collecting more detailed information from stakeholders about their specific concerns, such as those associated with infrastructure or economic implications of AIS management actions.

At the second meeting with the stakeholder group we will outline the methodological approach to the integrative risk assessment, specifically the analytic models used to examine the three stages of invasion risk (i.e., risk of invasion, risk of establishment, and analysis of impacts), identify any data gaps, and an evaluation of the value of the gap against the cost to fill it. For example, we expect that some data gaps may be addressed by using knowledge from other large lake ecosystems, whereas other data might be deemed important enough to justify new data collection.

A third meeting will be held with the stakeholder group to review results of Task 3 (Data Analysis). At this meeting Dr. Olden will present his results, related to the three topics of Risk of Introduction, Risk of Establishment, and Analysis of Potential Impacts. The presentation will be followed by an open discussion on the sensitivity of the results to data assumptions, recommended actions, priorities, and implementation needs.

A fourth meeting will occur after release of the draft report (Task 4) and will be used to solicit final input on the detailed recommendations and implementation plan as well as to lay out next steps and responsibilities for gaining support and funding outside of the stakeholder group.

Herrera will coordinate with Chelan County on preparation of the agendas and will facilitate the meetings as well as provide meeting summaries to document progress. While the stakeholder meetings would be open to the public and the County's website could be used to document progress and decisions, it may be advantageous to also have specific community focused meetings that lay out the project findings. Since these can be costly, and poorly attended depending upon the community, we have not included public meetings as part of the project budget, but it is something we will expect to discuss during project scoping.

Task 3 – Data Analysis

Task 3.1 – Risk of Invasion

The arrival of viable propagules or colonists of aquatic invasive species to Lake Chelan is a critical step of the invasion process and the first of three stages of our proposed integrated risk assessment. Recreational boating is a primary transmission pathway for aquatic invasive species, via the accidently movement of organisms on watercraft and fishing gear, as well as the intentional release of live bait and sport fish.

First, we will establish a list of AIS associated with recreational boating/fishing and illegal ("bucket biologists") introduction pathways using a multi-tiered approach that includes the subset of species that are: (1) currently established in other freshwater waterbodies of Washington State according to the USGS Non-indigenous Aquatic Species Data; and (2) included in Washington State Prohibited Aquatic Animal Species (RCW 77.12.020). Next, this list of AIS will be narrowed to a priority list for Lake Chelan during the first stakeholder meeting. We anticipate this process will result in prioritization of 3–5 species, and will include dreissenid mussels.

Second, boater movement behavior is typically quantified through a variety of empirical approaches (e.g., interviews, mail surveys) that vary widely in effort, cost, and efficacy. We plan to map the degree of shoreline residential development and quantify boater traffic at boat launches to quantify potential propagule pressure of new AIS introduced into Lake Chelan. To accomplish this, we will collate existing and collect new boat behavior data using in-person surveys at launch locations during summer 2019, as well as distribute a mail or internet questionnaire in the Lake Chelan region. Information regarding the risk of introduction will be used to identify data gaps between boater travel routes into Lake Chelan compared to the location of state inspection programs, and to make recommendations to better target educational campaigns (e.g., clean, drain, dry message).

Task 3.2 – Risk of Establishment

We will deploy two complementary approaches to quantify the risk of establishment (defined as self-sustaining populations) of AIS in Lake Chelan. First, we will conduct a trait-based risk assessment to evaluate for each species their likelihood of establishing a population in Lake Chelan, given Lake Chelan's unique characteristics. Previous studies have demonstrated that traits are highly predictive of nonnative species establishment, for example, essential nutrients (calcium), climate requirements, trophic status, fecundity, spawning habitat requirements and history of invasion outside the native range, have emerged as robust indicators of establishment success. From the literature and databases collated previously by Dr. Olden, we will develop statistical models using a suite of ecological and biological traits that have been previously associated with the establishment stage of invasion. Second, species distribution models will be constructed using novel machine-learning algorithms to quantity habitat suitability as a proxy for establishment risk in Lake Chelan. These predictive models will relate species occurrence data to a suite of environmental characteristics that have been deemed important for the establishment of nonnative species in Washington lakes and in the western United States, again based on research by Dr. Olden. Model projections will identify the suitability of Lake Chelan (as well as specific locations within the lake when possible) to the establishment of dreissenid mussels and the other priority AIS. For the sake of budget preparation, we have assumed that quagga and zebra mussels are the priority species to be addressed. If more than 3 to 5 are prioritized during Task 3.2 we expect they can be included in the modeling approach with only moderate impact to the level of effort unless those species have vastly different data requirements.

Task 3.3 – Analysis of Potential Impacts

Quantifying the degree of ecological and economic impacts associated with established AIS is notoriously difficult. We plan to assess the risk of impacts of the priority in Lake Chelan using a systematic literature review of previously published research. Specifically, meta-analyses provide strong insight into the impacts of nonnative fishes, crayfishes, dreissenid mussels, and a variety of other freshwater groups. This systematic review will allow us to identify the likelihood (low, moderate, high) that each invasive species will negatively impact major ecological and economic outcomes. Since this is a literature review based analysis the inclusion of a larger number of aquatic species is possible with only a modest impact on our budget estimate.

Task 4 – Vulnerability and Habitat Suitability Analysis Report

This final report for the project will provide a synthesis of the work completed under Task 3 as well as provide detailed and prioritized recommendations. It will also provide a step-by-step implementation plan with assigned responsibilities, a proposed schedule, and costs for their completion. We will prepare a draft report for stakeholder review, and then a final report addressing comments and providing recommendations based on input from the fourth stakeholder meeting.

Task 5- Project Management

Herrera has an excellent reputation for delivering our projects on time and within budget, frequently under challenging conditions. This is due to our focus on effective project management. We understand that effective project management is first and foremost tied to effective communication. At the outset of this project, Joy Michaud, our project manager will define preferred communication approaches with the County's project manager to be sure we are tailoring our communications to project needs. Joy will convene a consultant team kickoff meeting immediately after receiving the Notice to Proceed, to clearly outline the scope of work, client expectations and unique needs, schedule and budget, orienting the team in the right direction

Throughout the project Joy will maintain regular communication with the County's project manager and provide detailed progress reports each month with project invoices. She will coordinate the team efforts, track and communicate any project issues and provide the focus for technical decision-making and standards of quality. She will be supported by a dedicated contract administrator and accounting staff to ensure that monthly invoicing, subconsultant contracting, and other administrative project management activities are handled consistently and in a timely manner to support each project's schedule and contract requirements.

Project Timeline

Table 1 presents the schedule assuming a Notice to Proceed of around November 1, 2018. The project timeline has purposefully been developed to allow for phased release and review of the three Technical Memorandums associated with Task 3, while allowing for the boater survey to be conducted in the summer of 2019.

Table 1. Project Schedule and Milestones.

Date/Timeframe	Tasks
Early November 2018	• Notice to Proceed
November through December 2018	• Complete Task 1 • Convene initial meeting with stakeholders • Deliver matrix of species and identified data gaps • Agree on priority AIS to conduct risk assessment
January through March 2019	• Develop and approve data analysis methods • Develop boater survey approach • Convene second meeting with stakeholders • Develop stakeholder review draft for Task 3.2 Technical Memorandum
April through June 2019	• Finalize Task 3.2 Technical Memorandum • Develop stakeholder review draft for Task 3.3 Technical Memorandum
July through September 2019	• Conduct boater survey • Evaluate boater survey data • Finalize Task 3.3 Technical Memorandum
October through December 2019	• Develop stakeholder review draft for Task 3.1 Technical Memorandum • Convene third meeting with stakeholders
January through March 2020	• Finalize Task 3.1 Technical Memorandum • Prepare stakeholder review draft report for Task 4 • Convene fourth meeting with stakeholders • Prioritize recommendations and schedule of actions • Finalize Task 4 Report

Detailed Budget

Table 2 provides a budget based on the approach to the project described above. While there are many assumptions that went into developing this budget, the two that are important drivers for the budget are the number of species addressed and the level of effort spent on the boater survey. As described above, for the sake of preparing a credible budget we have assumed that as many as four aquatic invasive species will be prioritized for inclusion in the study and that these species will have similar transport pathways, i.e., boating and fishing. Although we made this assumption to anchor the budget, adding additional animal species would not have a proportionate impact on the budget; it would primarily impact level of effort required for Tasks 3.2 and 3.3. For the boater survey we have assumed an in-person survey over two holiday weekend days and distribution of a brief questionnaire to Lake Chelan area residents. During project scoping we would expect to discuss assumptions and details and adjust the budget and level of effort to meet the needs of the County.

Table 2. Detailed Budget

Task	Herrera	UW	Indirect Costs	Total
1 Data Review	$3,827	$9,525	$0	**$13,353**
2 Stakeholder Involvement	$14,352	$9,632	$1,635	**$25,619**
3.1 Risk of Introduction	$4,785	$20,459	$90	**$25,334**
3.2 Risk of Invasion	$5,742	$37,801	$0	**$43,543**
3.3 Analysis of Impacts	$3,350	$19,975	$0	**$23,325**
4 Vulnerability and HSA Report	$23,181	$758	$0	**$23,939**
5 Project Management	$13,233	$0	$0	**$13,233**
TOTAL	**$68,470**	**$98,151**	**$1,725**	**$168,346**

Related Experience

The following includes research abstracts from some of Dr. Olden's relevant research work as well as project examples from Herrera's many lake-related projects.

Project Experience - Dr. Julian Olden

Integrated Assessment of Biological Invasions

Authors: Ine´ S Iba´ N˜ Ez, Jeffrey M. Diez, Luke P. Miller, Julian D. Olden, Cascade J. B. Sorte, Dana M. Blumenthal, Bethany A. Bradley, Carla M. D'antonio, Jeffrey S. Dukes, Regan I. Early, Edwin D. Grosholz, and Joshua J. Lawler

As the main witnesses of the ecological and economic impacts of invasions on ecosystems around the world, ecologists seek to provide the relevant science that informs managers about the potential for invasion of specific organisms in their region(s) of interest. Yet, the assorted literature that could inform such forecasts is rarely integrated to do so, and further, the diverse nature of the data available complicates synthesis and quantitative prediction. Here we present a set of analytical tools for synthesizing different levels of distributional and/or demographic data to produce meaningful assessments of invasion potential that can guide management at multiple phases of ongoing invasions, from dispersal to colonization to proliferation. We illustrate the utility of data-synthesis and data-model assimilation approaches with case studies of three well-known invasive species—a vine, a marine mussel, and a freshwater crayfish—under current and projected future climatic conditions. Results from the integrated assessments reflect the complexity of the invasion process and show that the most relevant climatic variables can have contrasting effects or operate at different intensities across habitat types. As a consequence, for two of the study species climate trends will increase the likelihood of invasion in some habitats and decrease it in others. Our results identified and quantified both bottlenecks and windows of opportunity for invasion, mainly related to the role of human uses of the landscape or to disruption of the flow of resources. The approach we describe has a high potential to enhance model realism, explanatory insight, and predictive capability, generating information that can inform management decisions and optimize phase-specific prevention and control efforts for a wide range of biological invasions.

Forecasting the Spread of Invasive Rainbow Smelt in the Laurentian Great Lakes Region of North America

Authors: Norman Mercado-Silva, Julian D. Olden, Jeffrey T. Maxted, Thomas R. Hrabik, and M. Jake Vander Zanden

Rainbow smelt (Osmerus mordax) have invaded many North American lakes, often resulting in the extirpation of native fish populations. Yet, their invasion is incipient and provides the rationale for identifying ecosystems likely to be invaded and where management and prevention efforts should be focused. To predict smelt presence and absence, we constructed a classification-tree model based on habitat data from 354 lakes in the native range for smelt in southern Maine. Maximum lake depth, lake area, and Secchi depth were the most important predictors. We then used our model to identify lakes vulnerable to invasion in three regions outside the smelt's native range; northern Maine (52 of 244 lakes in the nonnative range), Ontario (4447 of 8110), and Wisconsin (553 of 5164). We further identified a subset of lakes with a strong potential for impact (potential-impact lakes) based on the presence of fish species that are affected by rainbow smelt. Ninety-four percent of vulnerable lakes in the nonnative range in Maine are also potential-impact lakes, as are 94% and 58% of Ontario and Wisconsin's vulnerable lakes, respectively. Our modeling approach can be applied to other invaders and regions to identify invasion-prone ecosystems, thus aiding in the management of invasive species and the efficient allocation of invasive species mitigation and prevention resources.

Integrating Landscape Connectivity and Habitat Suitability to Guide Offensive and Defensive Invasive Species Management

Authors: Ben Stewart-Koster, Julian D. Olden and Pieter T. J. Johnson

Preventing the arrival of invasive species is the most effective way of controlling their impact. Preventative strategies may be 'offensive' aimed at preventing the invader leaving colonized locations or 'defensive' aimed at preventing its arrival at uninvaded locations. The limited resources for invasive species control must be prioritized, particularly for numerous vulnerable locations or uncertainty about which sites are already invaded.

We developed an integrative modelling framework to prioritize locations for either strategy by incorporating connectivity and habitat suitability. We applied this framework to a data set comprising 5,189 water bodies in Wisconsin and Michigan, U.S.A, for zebra mussels Dreissena polymorpha and Eurasian watermilfoil Myriophyllum spicatum. We developed the framework with a spatial graph based on recreational boater movement and habitat suitability models. An historical graph comprised 3,105 natural lakes connected in one of 18 components, whereas a total of 3,944 water bodies (lakes and reservoirs) were connected in one of 13 separate components in a graph of the contemporary system. Habitat suitability models accounted for around half of the deviance in the distribution data for each species.
There was a distinct spatial pattern in the levels of risk and subsequent recommended allocation of management interventions across several levels of investment. Higher risk water bodies were generally found in the largest component of the spatial graph. At comparatively low levels of investment, where managers target 5% of all locales to control D. polymorpha, the results suggested that 71% and 27% of this effort should be committed to defensive and offensive strategies, respectively, in the largest component. For M. spicatum, 92% and 8% of this effort should be allocated in this component to defensive and offensive strategies, respectively. It is only with much greater investment that water bodies in other components should be targeted.

Allocating limited resources to prevent the spread of invasive species is a challenge that transcends ecosystems and geography. We successfully identified a reduced number of locations to target for offensive and defensive intervention strategies for two species. This framework is readily applicable to other aquatic and terrestrial ecosystems vulnerable to invasive species.

Forecasting the Vulnerability of Lakes to Aquatic Plant Invasions

Authors: Mariana Tamayo and Julian D. Olden

Prevention is an integral component of many management strategies for aquatic invasive species, yet this represents a formidable task when the landscapes to be managed include multiple invasive species, thousands of waterbodies, and limited resources to implement action. Species distributional modeling can facilitate prevention efforts by identifying locations that are most vulnerable to future invasion based on the likelihood of introduction and environmental suitability for establishment. We used a classification tree approach to predict the vulnerability of lakes in Washington State (United States) to three noxious invasive plants: Eurasian watermilfoil (Myriophyllum spicatum), Brazilian egeria (Egeria densa), and curlyleaf pondweed (Potamogeton crispus). Overall, the distribution models predicted that approximately one-fifth (54 out of 319 study lakes) of lakes were at risk of being invaded by at least one aquatic invasive plant, and many of these predicted vulnerable lakes currently support high native plant diversity and endemism. Highly vulnerable lakes are concentrated in western Washington in areas with the highest human population densities, and in eastern Washington along the Columbia Basin Irrigation Project and the Okanogan River Basin that boast hundreds of lakes subject to recreational use. Overall, invasion potential for the three species was highly predictable as a function of lake attributes describing human accessibility (e.g., public boat launch, urban land use) and physical–chemical conditions (e.g., lake area, elevation, productivity, total phosphorous). By identifying highly vulnerable lake ecosystems, our study offers a strategy for prioritizing on- the-ground management action and informing the most efficient allocation of resources to minimize future plant invasions in vast freshwater networks.

Assessing Ecosystem Vulnerability to Invasive Rusty Crayfish

Authors: Julian D. Olden, M. Jake Vander Zanden, And Pieter T. J. Johnson

Despite the widespread introduction of nonnative species and the heterogeneity of ecosystems in their sensitivity to ecological impacts, few studies have assessed ecosystem vulnerability to the entire invasion process, from arrival to establishment and impacts. Our study addresses this challenge by presenting a probabilistic, spatially explicit approach to predicting ecosystem vulnerability to species invasions. Using the freshwater-rich landscapes of Wisconsin, USA, we model invasive rusty crayfish (Orconectes rusticus) as a function of exposure risk (i.e., likelihood of introduction and establishment of O. rusticus based on a species distribution model) and the sensitivity of the recipient community (i.e., likelihood of impacts on native O. virilis and O. propinquus based on a retrospective analysis of population changes). Artificial neural networks predicted that 10% of 4,200 surveyed lakes (n ¼ 388) and 25% of mapped streams (23,523 km total length) are suitable for O. rusticus introduction and establishment. A comparison of repeated surveys before vs. post-1985 revealed that O. virilis was six times as likely and O. propinquus was twice as likely to be extirpated in streams invaded by O. rusticus, compared to streams that were not invaded. Similarly, O. virilis was extirpated in over three-quarters of lakes invaded by O. rusticus compared to half of the uninvaded lakes, whereas no difference was observed for O. propinquus. We identified 115 lakes (3% of lakes) and 5000 km of streams (6% of streams) with a 25% chance of introduction, establishment, and extirpation by O. rusticus of either native congener. By identifying highly vulnerable ecosystems, our study offers an effective strategy for prioritizing on-the-ground management action and informing decisions about the most efficient allocation of resources. Moreover, our results provide the flexibility for stakeholders to identify priority sites for prevention efforts given a maximum level of acceptable risk or based on budgetary or time restrictions. To this end, we incorporate the model predictions into a new online mapping tool with the intention of closing the communication gap between academic research and stakeholders that requires information on the prospects of future invasions.

Assessing the Effects of Climate Change on Aquatic Invasive Species

Authors: Frank J. Rahel and Julian D. Olden

Different components of global environmental change are typically studied and managed independently, although there is a growing recognition that multiple drivers often interact in complex and nonadditive ways. We present a conceptual framework and empirical review of the interactive effects of climate change and invasive species in freshwater ecosystems. Climate change is expected to result in warmer water temperatures, shorter duration of ice cover, altered streamflow patterns, increased salinization and increased demand for water storage and conveyance structures. These changes will alter the pathways by which nonnative species enter aquatic systems by expanding fish culture facilities and water gardens to new areas and by facilitating the spread of species during floods. Climate change will influence the likelihood of new species becoming established by eliminating cold temperatures or winter hypoxia that currently prevent survival and by increasing the construction of reservoirs that serve as hotspots for invasive species. Climate change will modify the ecological impacts of invasive of invasive species by enhancing their competitive and predatory effects on native species and by increasing the occurrence of some diseases. As a result of climate change, new prevention and control strategies such as barrier construction or removal efforts may be needed to control invasive species that currently have only moderate effects or that are limited by seasonally unfavorable conditions. Although most researchers focus on how climate change will increase the number and severity of invasions, some invasive coldwater species may be unable to persist under the new climate conditions. Our findings highlight the complex interactions between climate change and invasive species that will influence how aquatic ecosystems and their biota will respond to novel environmental conditions.

Project Experience - Herrera

Chelan River Riparian Feasibility Investigation

Reach 1 of the Chelan River begins immediately below the Lake Chelan Hydroelectric Project Dam in Chelan Washington. Due to many years of high volume discharge from the dam, the river bed is highly modified consisting of very large cobbles and small boulders with little fine sediment or organic material. As a requirement of dam relicensing, the PUD was tasked with carrying out a feasibility study to characterize the opportunities for the establishment of riparian vegetation on the banks of the Chelan River. Herrera performed this feasibility assessment. After a field visit and literature search into native plants we characterized the river at a sub reach scale, including: inundation depth and flow velocity and variability in these characteristics across the months of the year; existing channel morphology and expected future changes; substrate size, sediment sources, hydraulic features, precipitation patterns; and the depth to the saturated zone along the river banks. We then created a potential plant list that summarized each species general habitat requirements and reproduction characteristics, including; preferred substrate, flow velocities that each plant species and planting technique can withstand, water depth and inundation duration ranges, dispersion or reproduction strategies, typical planting densities, appropriate planting techniques, and site potential heights (for large shrubs and trees). This matrix provided the basis for determining the key constraints that exist in each sub reach; whether and where there are constraints that can be used to eliminate portions of the reach from further consideration and/or whether one or more sub reach is most suited to establishment of riparian vegetation under existing conditions. Our results indicated that with appropriate plant selection and quality and use of specialized planting techniques it would be feasible to establish vegetation in portions of the river. In follow on work we developed a shading model to predict impacts to stream temperature from implementation of our plan.

Capitol Lake Management Alternatives and AIS Analysis

Herrera led development of the Phase I project to assist an interagency committee with evaluating impacts associated with different management alternatives; including a number of alternatives that involved dam removal and restoration of estuary conditions as well as a lake management alternative. This project involved reviewing more than 50 technical documents covering a wide range of topics, from sediment characterization and transport models, to limnology and nutrient dynamics, to hydraulics and flooding, to social and economic impacts. These technical reports were used to prepare a comparative analysis of impacts of five management alternatives on sediment management needs, invasive species, water quality, flooding (including that associated with sea-level rise), recreation, fish and wildlife, and local economics and more. Herrera identified constraints associated with an infestation by the New

Zealand mudsnail for disposal of excavated lake sediments at open-water sites in Puget Sound, and developed sediment treatment procedures for eradication of mudsnails from the excavated sediments prior to upland disposal. Herrera developed or coordinated development of each of the impact analysis sections and worked with the interagency committee to refine the evaluations in preparation of the final alternatives analysis. Herrera is currently working on the EIS for Phase II of the project that includes identifying options for managing mudsnails and other aquatic invasive species in the lake for analysis of the lake and estuary alternatives.

Lake Youngs AIS Protection Plan and Limnological Studies

Herrera has conducted numerous limnological studies of Lake Youngs Reservoir for Seattle Public Utilities to address a variety of water quality issues with this drinking water reservoir, which serves over 1 million customers. Herrera identified an early infestation of Eurasian watermilfoil during aquatic macrophyte mapping of the reservoir, and immediately developed and implemented an eradication plan using physical controls (bottom barriers and handpulling) that successfully eradicated this aquatic invasive species (AIS) from the reservoir without the use of herbicides. Herrera assessed vectors and vulnerability of the reservoir to AIS infestation and determined that the source of infestation was plant fragments on a boat trailer that had recently been used for a sewer inspection in Lake Washington. Herrera developed an AIS protection plan addressing potential infestations by zebra mussels and other AIS for all of Seattle's drinking water reservoirs that eliminated the shared use of Seattle's boats among the reservoirs and infested waters and established rigorous boat inspection and decontamination procedures for contractor vessels. Other limnological studies included monitoring and testing of periphyton control methods for reducing taste and odor problems, monitoring and assessment of a Didymo (rock snot) infestation of Cedar River source waters, evaluating causes of shifts in phytoplankton dominance to filter clogging species, modeling effects of nutrient loading from the introduction of salmon to the Cedar River above the water intake, quantifying water quality impacts of phosphorus loading from fluoride applications to inflow waters, and inventorying all aquatic species in the reservoir and its watershed.

Morse Lake Contaminant Transport Study and Protection Plans

Herrera designed and implemented a contaminant spill and transport study for evaluating water quality impacts from fuel spills on Chester Morse Lake for Seattle Public Utilities that included an inventory of the quantities and types of contaminants stored near the lake, compilation of applicable drinking water and surface water quality regulations, research on the human and ecological risks for each contaminant of concern, identification of various potential spill scenarios, and development of a spill transport model to determine the concentration of contaminants at Masonry Dam after they are affected by the processes of evaporation, mechanical spreading, and dissolution. Herrera also prepared a watershed and water quality protection plan, which set out specific guidelines for construction and operations practices necessary to protect the quality of the municipal water supply.

Cedar River Watershed Aquatic Plant Surveys and Milfoil Management

Herrera monitored aquatic plant communities in the Cedar and Rex river deltas of Chester Morse Lake Reservoir to evaluate effects of water level fluctuations on this important component of bull trout habitat for Seattle Public Utilities. Surveys were conducted from a boat using GPS, fathometry (split-beam recording echosounder), and underwater video to locate, map, identify, and estimate cover and biovolume of aquatic plants by species or species group. Specimens of each plant species were collected, pressed, and labeled for accession in the University of Washington Herbarium. Herrera also surveyed aquatic plants in the Cedar River below the reservoir and in Walsh Lake, which is a natural lake with high habitat value that drains to the Cedar River above the drinking water intake. Herrera identified an early infestation of Eurasian watermilfoil (milfoil) in Walsh Lake, and immediately developed and implemented an eradication plan using physical controls (bottom barriers and handpulling) and without the use of herbicides, which are prohibited in the watershed. Herrera divers had nearly eradicated all milfoil plants until a new infestation was identified across the lake from the original infestation in an isolated beaver canal through a large cattail stand. Herrera identified beavers as a vector within the lake and intensified surveys of emergent vegetation to eradicate milfoil and fragrant water lily from the lake.