Environment and Natural Resources Trust Fund (ENRTF)
M.L. 2013 Minnesota Aquatic Invasive Species Research Center
Sub-Project Work Plan

Date of Report: July 31, 2017

Date of Next Status Update Report: January 31, 2017

Date of Work Plan Approval: September 2, 2017

Sub-Project Completion Date: June 30, 2018

Project Completion Date: June 30, 2019

Does this submission include an amendment request? Yes

SUB-PROJECT TITLE: MAISRC Sub-Project 13: Eco-epidemiological Model to Assess Aquatic Invasive Species Management

Sub-Project Manager: Dr. Nicholas Phelps

Organization: Minnesota Aquatic Invasive Species Research Center, University of Minnesota

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Location: Statewide

Total ENRTF Sub-Project Budget:	**Sub-Project Budget:**	**$215,000**
	Amount Spent:	**$90,502**
	Balance:	**$124,498**

Legal Citation: M.L. 2013, Chp. 52, Sec. 2, Subd. 06a

Appropriation Language:
$4,350,000 the first year and $4,350,000 the second year are from the trust fund to the Board of Regents of the University of Minnesota to develop and support an aquatic invasive species (AIS) research center at the University of Minnesota that will develop new techniques to control aquatic invasive species including Asian carp, zebra mussels, and plant species. This appropriation is available until June 30, 2019, by which time the project must be completed and final products delivered.

I. SUB-PROJECT TITLE: Eco-epidemiological Model to Assess Aquatic Invasive Species Management

II. SUB-PROJECT STATEMENT:
New evidence-based decision-making tools using robust and updated information are needed for AIS. These tools can be used to generate effective intervention strategies, predict impacts, test what-if scenarios, increase stakeholder buy in, and design cost-effective surveillance programs to mitigate and prevent AIS spread. To that end, we will develop a first of its kind eco-epidemiological model that will forecast the potential risk of AIS spread in Minnesota. Our risk model will focus on three high-priority AIS, including Zebra mussel (*Dreissena polymorpha*), Heterosporis (*Heterosporis sutherlandae*), and Eurasian watermilfoil (*Myriophyllum spicatum*). The model will be composed of three main risk-components, including the introduction probability, establishment probability, and levels of management interventions. In other words, we aim to answer and integrate the questions: Can the AIS be introduced? If so, can the AIS survive? And lastly, can management intervention influence the risk? The collaborative process and resulting information will build upon ongoing AIS research, provide immediate value to the design of evidence-based AIS management plans in Minnesota and will significantly advance future AIS research.

III. SUB-PROJECT STATUS UPDATES:

Sub-Project Status as of: January 31, 2017

The ecological niche model for Heterosporosis was developed to achieve outcome 1 from Activity 1. Thus, we were able to identify the geographic areas in Minnesota with suitable conditions for the establishment or presence of this fish disease and produce risk maps for use by managers and researchers. These findings will be submitted for peer-review in late January to the open access journal *Frontiers in Veterinary Science* (Working title: "Novel methods in disease biogeography: A case study with Heterosporosis").

The early results of this project were presented at the 2016 MAISRC showcase, to more than 200 participants (https://goo.gl/atJ1Zm). The audience was interested in the project's outputs and requested future presentations showing how the suitability and network models will identify lakes where preventive measures should be implemented and prioritized. A second manuscript is currently under review in the scientific journal *Reviews in Fisheries Science and Aquaculture,* with a broad overview of MAISRC studies, including this project, ("Aquatic invasive species in the Great Lakes region: An overview.").

Data for the zebra mussels risk maps were collected and cleaned and models are under development. Data for the network models is currently being organized and cleaned by Dr. Huijie Qiao, the visiting researcher involved with the project. This status provides us confidence to achieve the results according to our schedule.

Sub-Project Status as of: July 31, 2017
The project attempts to forecast invadable areas for an invasive pathogen, a plant, and an animal, assessing risk of invasion and establishment in Minnesota. The ecological niche model for the pathogen Heterosporosis has been completed and was published. Thus, results are currently available to the international scientific community and the managers in Minnesota (Escobar, L. E., Qiao, H., Lee, C., & Phelps, N. B. D. (2017). Novel methods in disease biogeography: A case study with Heterosporosis. Frontiers in Veterinary Sciences doi:10.3389.fvets.2017.00105). The second manuscript of the project ("Aquatic invasive species in the Great Lakes region: An overview.") has received the first round of reviews. We expect to publish this manuscript as a guide for students and citizens about the state of aquatic invasive species in Minnesota, including the gaps in the knowledge and the ongoing research at the Minnesota Aquatic Invasive

Species Research Center at the University of Minnesota (MAISRC). The ecological niche model for zebra mussel was completed and predictions to Minnesota were done at a fine spatial resolution. We are now working on the forecasts for the invasive plant, see Amendment below.

A second part of this project includes the exploration of pathways for the spread of invasive species to suitable lakes in which species can establish populations. For this component, a visiting scholar, Dr. Huijie Qiao, worked at MAISRC from December 2016 to June 2017. During his collaboration, Dr. Qiao developed a first of its kind database with spatial distances between lakes and the connection of lakes via streams/rivers. These databases are essential to the development of network models and will likely have value in many other water resource issues.

Progress is currently being made to host a workshop in August to present the current status of this project to key stakeholder groups. This will result in the development of management scenarios that, when hypothetically implemented in the models in the coming months, could affect the risk of AIS establishment.

Amendment Request (07/31/2017)

We are requesting a change in scope to include starry stonewort, instead of Eurasian watermilfoil, in this project. There would be no change to the budget or timeline as a result of this amendment request. When this project was proposed, the true concerns for starry stonewort were not apparent. Since then, in numerous conversations with AIS managers and researchers, it is clear that there would be more value in using our predictive models to identify lakes at greatest risk of starry stonewort to prioritize efforts and control a new invader. The selection of starry stonewort is considered a minor change as the overall risk estimations and models have broad applications to other species, in particular invasive plants. This change also fits well with ongoing collaborations between the Phelps and Larkin labs that have already published multiple papers on the ecological niche of starry stonewort and one more is in development. Both publications explain important biogeographic features of the invasive species in North America with emphasis on Minnesota: (1) Romero-Alvarez, D. A., Escobar, L. E., Varela, S., Larkin, D. J., & Phelps, N. B. D. (2017). Forecasting distributions of an aquatic invasive species (*Nitellopsis obtusa*) under future climate scenarios. PLoS ONE, In press, and (2) Escobar, L. E., Qiao, H., Phelps, N. B. D., Wagner, C. K., & Larkin, D. J. (2016). Realized niche shift associated with the Eurasian charophyte *Nitellopsis obtusa* becoming invasive in North America. Scientific Reports, 6, 29037.

We request an amendment to move $3,183 from the capital equipment budget line to the non-capital equipment budget line, all within Activity 1. This is because we were able to purchase our computer workstation cheaper as components than as a package. Some of the costs were therefore considered capital equipment (i.e., over $5,000) and others non- capital equipment. Funds are now needed to cover costs originally budgeted under non-capital equipment.

Sub-Project Status as of: January 31, 2018

Overall Sub-Project Outcomes and Results:

IV. SUB-PROJECT ACTIVITIES AND OUTCOMES:

ACTIVITY 1: *Estimate probability of introduction and establishment at a lake scale for three high priority AIS in Minnesota*

Description:
There are many risk factors that will determine the likelihood of a waterbody becoming infested with AIS; however, for the purposes of this study, we will first assume there are two primary components: 1) Introduction probability and 2) Establishment probability.

1) Introduction probability: To understand the potential exposure of waterbodies in Minnesota to AIS, based on their connectivity, we will conduct network analyses at the lake scale. In this network analysis, lakes will be considered as nodes and three types of pathways, including water connectivity, boater movement, and geographic proximity, will be the connections. The pathways were selected based on availability of data and assumption of high risk. The three connection types will be modeled and visualized by social network analysis using R software. The output will be compared with the temporal records of zebra mussel, Heterosporis, and Eurasian watermilfoil spread in Minnesota. Ultimately, we will estimate the probabilities of AIS introduction between lakes to identify highly connected (i.e. 'super spreaders') and disconnected (i.e. 'protected') lakes.

2) Establishment probability: To understand the potential establishment of AIS in Minnesota, we will use next-generation ecological niche modeling (ENM) techniques under current environmental conditions for zebra mussels, Heterosporis, and Eurasian watermilfoil. We will incorporate up-to-date information on species location, remote sensing data, and other available ecological features determined relevant by collaborating species experts at a fine scale (<1km) spatial resolution. A variety of software packages will be used for this effort, including R, Arc-GIS, and NicheA. Each model will be validated based on historical species distributions. The resulting risk maps will be made openly available on GoogleEarth.

The integration of the introduction and establishment models will identify individual lakes or areas of the state at higher risk for AIS. For example, this approach will elucidate, super spreader lakes in terms of high connection (natural or human assisted) and highly vulnerable lakes in terms of high environmental suitability – both of which are critical risk factors to prioritize management efforts. Based on these results, informed decisions and policy can be developed and evaluated.

Summary Budget Information for Activity 1:

ENRTF Budget:	**$ 110,279**
Amount Spent:	**$ 73,471**
Balance:	**$ 36,808**

Activity Completion Date:

Outcome	**Completion Date**
1. *Ecological niche model for Heterosporis*	*Nov 2016*
2. *Ecological niche model for Eurasian watermilfoil*	*Feb 2017*
3. *Ecological niche model for Zebra mussel*	*May 2017*
4. *Network model of geographic distance between lakes*	*June 2017*
5. *Network model of boater movement*	*Dec 2017*
6. *Network model of lakes and rivers*	*May 2018*
7. *Scientific and public presentations (n=2; i.e. MAISRC Showcase, research meeting)*	*June 2018*
8. *Publication of peer-reviewed manuscripts (n=1)*	*June 2018*

Activity Status as of: January 31, 2017

We completed the Outcome proposed for this update: Ecological Niche Model for Heterosporosis and have a near-complete draft of the manuscript for submission. Ongoing efforts to achieve the rest of Outcomes in this Activity include data curation and exploratory analysis of lakes connections in terms of rivers and

geographic distance between lakes. Under our current plan, we anticipate that the lakes connection models based on geographic distances and rivers connections will be ready by the June 2017. Activity 1 included the participation of the visitor researcher Dr. Huijie Qiao. Dr. Qiao is one of the most important developers of ecological modeling tools and methods in the world and will be helping to build this cutting-edge capacity in the project. Currently, Dr. Qiao is based on the Minnesota Aquatic Invasive Species Research Center facilities in the University of Minnesota in the Saint Paul campus.

Activity Status as of: July 31, 2017
We remain on track to complete this activity on time and within budget. Since the last update, we have completed the ecological niche model for zebra mussels and have a near-complete draft of the manuscript for submission. We have also completed the network model for geographic disease of infested lakes to all other non-infested lakes. In addition, we have spent considerable time organizing massive datasets of boater movement and water connectivity and expect to describe these network models in the coming months.

Activity Status as of: January 31, 2018

Final Report Summary: July 31, 2018

ACTIVITY 2: *Using the spread model to evaluate management intervention scenarios for three high priority AIS in Minnesota*

Description:
Integrating management decisions into the models developed in Activity 1 has the potential to significantly change the risk of AIS introduction and/or establishment. Through two workshops, the project team will work with AIS managers (i.e. county-based managers, MN DNR, US FWS, etc) to develop, test, and evaluate what-if scenarios for zebra mussels, Heterosporis, and Eurasian watermilfoil spread in Minnesota.

Participants in the first workshop will develop plausible intervention strategies for each AIS using quantitative and semi-quantitative methods. The goal will be for managers to identify a range of management scenarios to influence the introduction and establishment of AIS, ranging from no intervention (level 1) to significant intervention (level 5). For each intervention, the model will be tuned to reflect the management decision. For example, level 5 interventions could decease the introduction probability if lake connections were reduced (e.g. 'shutting down' highly connected lakes in the network) or reducing establishment suitability by aggressive herbicide use. More moderate examples could include a reduction in introduction risk by increased education and boat ramp inspection. In the second workshop, participants will evaluate the outcomes of the intervention scenarios. In other words, how did the management decision ultimately affect the risk of AIS spread? Not all results from this process will be intuitive, leading to new and informed decision making processes. The evidence-based decision-support tools developed throughout the study will be provided to workshop participants for further refinement and used to inform management decisions.

Summary Budget Information for Activity 2:

ENRTF Budget:	**$ 104,721**
Amount Spent:	**$ 17,031**
Balance:	**$ 87,690**

Activity Completion Date:

Outcome	Completion Date

1. *First workshop: Categorization of management strategies*	*Aug 2017*
2. *Final cumulative risk model for the three AIS selected*	*Apr 2018*
3. *Second workshop: Evaluation of final cumulative risk model*	*May 2018*
4. *Scientific and public presentations (n=2; i.e. MAISRC Showcase, research meeting)*	*June 2018*
5. *Publication of peer-reviewed manuscripts (n=2)*	*June 2018*

Activity Status as of: January 31, 2017

No updates are for Activity 2 as it depends on the outputs from Activity 1. However, we are currently planning the workshops; we anticipate that researchers and managers (n=6) will be invited to participate in the workshop 1, as well as state managers including Minnesota Department of Natural Resources personnel (n=2), and local experts including county personnel and water shed district personnel (n=2). The status of Activity 2 is currently in accordance to the schedule of the project.

Activity Status as of: July 31, 2017
The workshop to be held in August 2017 is currently in preparation. The final date is dependent on participant availability, however it is likely to be between August 21-25. Invited participants include AIS managers from the MN DNR, counties, and watersheds, as well as lake association representatives and researchers. This is a broader group than originally proposed, but we believe their insight and opinions into AIS management approaches will prove valuable.

Activity Status as of: January 31, 2018

Final Report Summary: July 31, 2018

V. DISSEMINATION:

The members of the project team have a history of stakeholder engagement and have been highly productive in similar efforts with publications, reports, and presentations. At least three publications will be published in specialized open-access scientific journals. The project team will share downloadable material (i.e. maps, tables) on the MAISRC website and use social media to disseminate project outputs to the scientific and non-scientific communities. In addition, the risk maps generated during this project will be incorporated into the MAISRC Detectors and Trackers programs to inform their outreach and monitoring programs. Lastly, the evidence-based decision-support tools developed throughout the study will be provided to workshop participants for further refinement and used to inform management decisions.

Activity Status as of: January 31, 2017

The early results of this project were presented at the 2016 MAISRC showcase, to more than 200 participants (https://goo.gl/atJ1Zm). The audience was interested in the project's outputs and requested future presentations showing how the suitability and network models will identify lakes where preventive measures should be implemented and prioritized. One manuscript will soon be submitted to the open access journal *Frontiers in Veterinary Science* (Working title: "Novel methods in disease biogeography: A case study with Heterosporosis"). A second manuscript is currently under review in the scientific journal *Reviews in Fisheries Science and Aquaculture,* with a broad overview of MAISRC studies, including this project, ("Aquatic invasive species in the Great Lakes region: An overview.").

Activity Status as of: July 31, 2017
This project continues to receive considerable attention for AIS manager, lake associations and other researchers. Consequently, we have shared findings broadly and through diverse methods. This has included presentations at the annual meetings of the International Biogeography Society (Tuscon, AZ) and the American Fisheries Society – Fish Health Section (East Lansing, MI). Presentations were also provided to lake associations and one-on-one meetings with AIS managers to discuss applications and implications of the project results. In addition, one paper was published describing the potential environmental range of the invasive fish disease Heterosporosis: link here (*Escobar, L. E., H. Qiao, C. Lee, N. B. D. Phelps. 2017. Novel methods in disease biogeography: A case study with Heterosporosis. Frontiers in Veterinary Science doi:10.3389/fvets.2017.00105*). A second manuscript will be submitted soon that defines the ecological niche of zebra mussels.

Activity Status as of: January 31, 2018

Final Report Summary: July 31, 2018

VI. SUB-PROJECT BUDGET SUMMARY:

A. Preliminary ENRTF Budget Overview:

Budget Category	$ Amount	Explanation
Personnel:	$ 165,150	The salary for two years for Dr. Luis Escobar (2.0 FTE), Researcher 6, is a core component of the project. Dr. Escobar will collect the data, clean and organize the data for the network and niche modeling processes, coordinate with management agencies, write manuscripts and reports, and develop final analyses in close collaboration with the project manager and the two external researchers (Drs. A. T. Peterson and Huijie Qiao). The salary for the Dr. Nick Phelps (0.3 FTE) is in kind to provide overall oversight and direction of the project, communication, leading Objective 2, and preparation of manuscripts. The salary of the two UMN faculty members Dr. Meggan Craft (0.1 FTE) and Dr. Eva Enns (0.1 FTE) provides support for the network analysis in collaboration with Dr. Escobar. The funded research team has broad experience of the necessary analytical techniques, risk assessment, and management evaluation from the fields of ecology and public health.
Professional/Technical Services and Contracts:	$26,750	Professional services contract with visiting scientist, Dr. Hujie Qiao, for a total of eight months during the project period. Dr. Qiao is one of the most important developers of

		ecological modeling tools and methods in the world and will be helping to build this cutting-edge capacity in Minnesota. ($22,750) Peer-reviewed publications. ($4,000).
Equipment/Tools/Supplies:	$17,100	**Supplies** Office & Gen Operations: Supplies (i.e. flip charts, markers, notebooks, etc) and food (i.e. coffee, lunch) for workshops. ($4,200) **Equipment (Non-Capital Lab and/or Field)** One basic MacBook Air computer, two 3 TB external hard drives and computer software. ($2,900) **Equipment (Capital)** Computer equipment is necessary for data management and analyses. See below for explanation. ($10,000)
Travel:	$6,000	**Travel, outside Minnesota** Conference travel to present the result of the project at two scientific meetings.
Other:		
TOTAL ENRTF BUDGET:	$215,000	

Explanation of Use of Classified Staff:
No classified staff will be used for this project.

Explanation of Capital Expenditures Greater Than $5,000:
This project has a strong analytical and computational component and computer equipment is necessary for data management and analyses. Thus, the computer equipment cost considers one workstation with 6th generation inter core i7 processors, RAM 120GB, 2 TB hard drive, 3 monitors, keyboard, mouse. The computer will also serve as a platform to use the virtual facilities and massive computing power of the Minnesota Supercomputing Institute free of cost. NOTE: The computer workstation will be returned to MAISRC at the completion of the project.

Number of Full-time Equivalents (FTE) Directly Funded with this ENRTF Appropriation:
2.2 FTE

Number of Full-time Equivalents (FTE) Estimated to Be Funded through Contracts with this ENRTF Appropriation:
0.7 FTE

B. Other Funds:

Source of Funds	$ Amount Proposed	$ Amount Spent	Use of Other Funds
Non-state	$10,000	$0	*Private funds available through MAISRC for research travel*
University of Minnesota	$40,949	$0	*In-kind salary for Dr. Nick Phelps*

TOTAL OTHER FUNDS:	**$45,949**	**$0**	

VII. SUB-PROJECT STRATEGY:

A. Sub-Project Team/Partners:

Dr. Nicholas Phelps (Project Manager; UMN) will be involved in all aspects and provide overall guidance for the project. Drs. Luis Escobar (UMN) and Huijie Qiao (Chinese Academy of Science) have extensive experience modeling invasive species and disease spread, big-data management and analysis, and will perform the modeling activities. Drs. Meggan Craft (UMN) and Eva Enns (UMN) will collaborate in the network analysis. Dr. A. Townsend Peterson (University of Kansas) will collaborate with the ecological niche modeling process and the risk algorithm assembly. Dr. Daniel Pons (University of Andres Bello) will advise on the cumulative algorithm assembly. Additional subject matter experts committee to advise this research as needed include: Drs. Michael McCartney (zebra mussels), Dan Larkin (Eurasian watermilfoil), Paul Venturelli (Heterosporis), Adam Kokotovich (social science); MDNR AIS managers: Heidi Wolf, Dr. Kelly Pennington, Chip Whelling, and Gary Montz; and other interested AIS managers ranging from US FWS to county agencies.

B. Sub-Project Impact and Long-term Strategy:

AIS management decisions are commonly based on human expertise and perception which is very useful, but largely qualitative and susceptible to bias. We propose a model, assembling robust quantitative analyses of all lakes in Minnesota. This model will allow, for the first time, exploring "what-if" scenarios of AIS spread and management in Minnesota. Once fitted, the resulting model will be useful to all levels of AIS managers and policy makers, in particular the MDNR and county agencies.

The outputs generated will also have value beyond AIS management. The matrix of waterbody connections will be highly valuable for the Minnesota Pollution Control Agency, Minnesota Department of Agriculture, and MDNR water quality managers to evaluate contaminant spills, restoration efforts, and treatment. The network analysis of boater movement will be useful for fisheries managers to evaluate waterbody popularity, patterns, and trends overtime. Lastly, the methods employed to evaluate management strategies will serve as an example for other disciplines challenged with complex decision-making.

The multidisciplinary and collaborative nature of this project to generate AIS management scenarios will enhance the collaboration among AIS management agencies including the alliance between MAISRC and the Minnesota Department of Natural Resources (MDNR), a key participant and main user of the proposed risk model.

The current project involves three AIS with different biological features (i.e., pathogen, plant, animal) and distribution patterns, allowing us to assess AIS spread risk under divers study cases. Future risk model applications will need to develop translocation and suitability maps for other AIS. However, current efforts of our team aim to automate ecological niche modeling protocols and estimate risk for other AIS (http://mmweb.animal.net.cn/aboutmmweb.jsp). Such automated risk assessment platforms could be hosted by the MAISRC website. Future direction of this project include considering climate change effect on AIS in Minnesota and exploring geographic ranges beyond the state of Minnesota to forecast biogreographic extents beyond administrative borders. Additional funding will be pursued to enhance our modeling capacities including an ongoing application to NIH R03 (PA-15-011) to consider uncertainty in our risk estimation.

Longer term, our goal is to develop the tool into a user-friendly online format that allows managers to 'toggle on/off' management decisions or geographic extents. Visualizing the outcome of intervention strategies in real-time would provide that ability to rapidly respond to emerging issues. A similar program was developed for management intervention to mitigate the spread of infectious salmon anemia virus in the Chilean salmon industry [unpublished].

C. Spending History:

Funding Source	**M.L. 2008 or FY09**	**M.L. 2009 or FY10**	**M.L. 2010 or FY11**	**M.L. 2011 or FY12-13**	**M.L. 2013 or FY14**
	None	None	None	None	None

VIII. ACQUISITION/RESTORATION LIST: N/A

IX. VISUAL ELEMENT or MAP(S):
Attached Research Addendum

X. ACQUISITION/RESTORATION REQUIREMENTS WORKSHEET: N/A

XI. RESEARCH PROPOSAL:
Attached Research Addendum

XII. REPORTING REQUIREMENTS:
Periodic work plan status update reports will be submitted no later than January 31, 2017, July 31, 2017, and January 31, 2018. A final report and associated products will be submitted within two months of the anticipated sub-project completion of June 30, 2018.