

ICAIS
2019



21ST INTERNATIONAL CONFERENCE ON AQUATIC INVASIVE SPECIES

AQUATIC INVASIONS IN THE ANTHROPOCENE

OCTOBER 27 to 31, 2019

Le Centre Sheraton, Montreal, QC, Canada

PROGRAM AND ABSTRACTS

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**Invasive
Species
Centre**

Conference Secretariat

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Conference at a Glance

Sunday, October 27, 2019

3:00 PM to 6:00 PM

Conference Registration Check-in
Speaker PowerPoint Submission

Monday, October 28, 2019

7:00 AM to 5:00 PM

Conference Registration Check-in
Speaker PowerPoint Submission

7:30 AM to 8:30 AM

Networking Breakfast

8:30 AM to 8:45 AM

Opening Remarks

8:45 AM to 9:30 AM

Keynote Presentation

9:30 AM to 10:00 AM

Networking Break

10:00 AM to 11:20 AM

Concurrent Sessions

11:30 AM to 12:15 PM

Keynote Presentation

12:15 PM to 1:30 PM

Networking Luncheon

1:30 PM to 2:50 PM

Concurrent Sessions

2:50 PM to 3:20 PM

Networking Break

3:20 PM to 4:40 PM

Concurrent Sessions

5:30 PM to 7:30 PM

Poster Session

Tuesday, October 29, 2019

7:00 AM to 5:00 PM

Conference Registration Check-in
Speaker PowerPoint Submission

7:30 AM to 8:30 AM

Networking Breakfast

8:30 AM to 8:45 AM

Opening Remarks

8:45 AM to 9:30 AM

Keynote Presentation

9:30 AM to 10:00 AM

Networking Break

10:00 AM to 11:20 AM

Concurrent Sessions

11:30 AM to 12:15 PM

Keynote Presentation

12:15 PM to 1:30 PM

Networking Luncheon

1:30 PM to 2:50 PM

Concurrent Sessions

2:50 PM to 3:20 PM

Networking Break

3:20 PM to 5:00 PM

Concurrent Sessions

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7:00 AM to 5:00 PM

Conference Registration Check-in
Speaker PowerPoint Submission

7:30 AM to 8:30 AM

Networking Breakfast

8:30 AM to 8:45 AM

Opening Remarks

8:45 AM to 9:30 AM

Keynote Presentation

9:30 AM to 10:00 AM

Networking Break

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Keynote Presentation

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Networking Luncheon

1:30 PM to 2:50 PM

Concurrent Sessions

2:50 PM to 3:20 PM

Networking Break

3:20 PM to 5:00 PM

Concurrent Sessions

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7:00 AM to 5:00 PM

Conference Registration Check-in
Speaker PowerPoint Submission

7:30 AM to 8:30 AM

Networking Breakfast

8:30 AM to 8:45 AM

Opening Remarks

8:45 AM to 9:30 AM

Keynote Presentation

9:30 AM to 10:00 AM

Networking Break

10:00 AM to 12:00 PM

Concurrent Sessions

12:00 PM to 1:00 PM

Networking Luncheon

1:00 PM to 4:30 PM

Special Session

4:30 PM

ICAIS 2019 Concludes



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The organizers of ICAIS 2019 encourage live tweeting during the conference under the hashtag #ICAIS2019. The conference organizers thank all tweeters for respecting the wishes of speakers and poster presenters who do not want live tweeting during or about their presentations.

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*Alexander Karatayev*¹, Lyubov Burlakova¹, Vadim Karatayev², Knut Mehler¹, Mark Rowe³, Ashley Elgin⁴, and Thomas Nalepa⁵, ¹Great Lakes Center, Buffalo State College; ²Department of Environmental Science and Policy, University of California, Davis; ³National Oceanic and Atmospheric Administration Great Lakes Environmental Research Laboratory; ⁴National Oceanic and Atmospheric Administration Great Lakes Environmental Research Laboratory; ⁵Water Center, Graham Sustainability Institute, University of Michigan
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*Benjamin Rubinoff*¹, Edwin Grosholz², ¹University of California, Davis Bodega Marine Laboratory; ²University of California, Davis Department of Environmental Science and Policy
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Monday, October 28, 2019

Opening Plenary Session

Session Chair: Bob Lambe, Invasive Species Centre

8:30 AM

Welcome to ICAIS 2019

Bob Lambe, President, Invasive Species Centre

8:45 AM

Keynote Presentation

Why Biogeographic Origins Matter to Invasion Science

Anthony Ricciardi, Redpath Museum, McGill University, Canada

9:30 AM – 10:00 AM

Networking Break

Session A1

Impacts on Biodiversity and Ecosystems

Session Chair: Mattias L. Johansson, University of North Georgia

10:00 AM

Villains in a Half-Shell: Assessing the Impacts and Risks of Emerging and Future Invasive Alien Species

James W.E. Dickey, Queen's University Belfast

10:20 AM

Invasive Wetland Grass Influences Secondary Productivity and Aerial Insectivore Birds

Courtney Robichaud, University of Waterloo

10:40 AM

Egeria densa (Brazilian waterweed): An Ecosystem Engineer and "Blue Carbon" Sink

Judith Z. Drexler, U.S. Geological Survey

11:00 AM

Non-native Chain Pickerel and Smallmouth Bass Integration and Impacts in Maritimes Freshwater Food Webs

Jason E. LeBlanc, Nova Scotia Fisheries and Aquaculture

Session A2

New Developments in Management and Control

Session Chair: Olivier Morissette, Ministère des Forêts, de la Faune et des Parcs

10:00 AM

Barring the Way to Asian Carp Invasion of Quebec Inland River Systems

Rémy Pouliot, Ministère des Forêts, de la Faune et des Parcs

10:20 AM

Grass Carp Incident Command Exercise: Two Levels of Government Coming Together

Becky Cudmore, Fisheries and Oceans Canada

10:40 AM

Experimental eDNA Studies in Two Complex Riverine Systems to Improve Invasive Species Detection

Guillaume Côté, Ministère des Forêts, de la Faune et des Parcs du Québec

11:00 AM

Bridging Science and Enforcement – An Invasive Species Management Approach in British Columbia

Martina Beck, British Columbia Ministry of Environment and Climate Change Strategy

Session A3

Policy and Public Outreach

Session Chair: Sophie Monfette, Ontario Federation of Anglers and Hunters

10:00 AM

Dreissenid Prevention across the Pacific Northwest, USA

Stephen Phillips, Pacific States Marine Fisheries Commission

10:20 AM

Watercraft Inspection and Decontamination Programs in the Western Region of the United States

Debra Davis, Pacific States Marine Fisheries Commission

10:40 AM

Aquatic Invasive Species Outreach – Zebra Quagga Mussel Prevention in Columbia Shuswap, British Columbia Canada

Robyn Hooper, Columbia Shuswap Invasive Species Society and Erin Vieira, Shuswap Watershed Council

11:00 AM

Testing the Use of Metaphor and Message Framing on Audience Engagement with Advertising to Prevent the Spread of Aquatic Invasive Species

Tim Campbell, University of Wisconsin Division of Extension, Wisconsin Department of Natural Resources

Plenary Session

Session Chair: Anthony Ricciardi, Redpath Museum, McGill University

11:30 AM

Keynote Presentation

The Impact of Invasive Alien Crustacea and Parasitic Diseases on Aquatic Ecosystems, and Opportunities to Slow their Spread

Alison Dunn, University of Leeds, England

12:15 PM – 1:30 PM

Networking Luncheon

Monday, October 28, 2019

Session B1

Emerging Vectors, Pathways and Invasion Threats

Session Chair: Pierre Béland, International Joint Commission

1:30 PM

The Eurasian Tench (*Tinca tinca*): A Globally Invasive Fish Arrives in the Great Lakes

Suncica Avlijas, McGill University

1:50 PM

Population Dynamics and Distribution of Tench (*Tinca tinca*) in the St. Lawrence River: Managing a Problematic Invader

Jaclyn Hill, Fisheries and Oceans Canada

2:10 PM

Habitat Utilization and Recruitment Sources of Eurasian Tench in the St. Lawrence River by Otolith Microchemistry

Olivier Morissette, Ministère des Forêts, de la Faune et des Parcs du Québec

2:30 PM

Zebra Mussels in Lake Winnipeg: Elucidating Invasion Pathways using Population Genetics

Mattias Johansson, University of North Georgia

2:50 PM – 3:20 PM

Networking Break

Session B2

New Developments in Management and Control

Session Chair: Stephen Phillips, Pacific States Marine Fisheries Commission

1:30 PM

Eradication of Invasive Roach (*Rutilus rutilus*). Rotenone Distribution and Degradation in Three Norwegian Lakes

Roar Sandodden, Norwegian Veterinary Institute

1:50 PM

Glyphosate Effects and Accumulation in Wetland Macrophytes Grown in Outdoor Microcosms

Verena Sesin, Trent University

2:10 PM

The Distribution and Impact of *Eccritotarsus catarinensis* and *Eccritotarsus eichhorniae* on Water Hyacinth in South Africa

Zolile Maseko, Rhodes University

2:30 PM

Fighting an Invasive Fish Parasite in Complex Subarctic Norwegian Rivers. The End of a Long Story?

Pål Adolfsen, Norwegian Veterinary Institute

2:50 PM – 3:20 PM

Networking Break

Session B3

Policy and Public Outreach

Session Chair: Rochelle Sturtevant, NOAA

1:30 PM

Using Knowledge Surveys to Inform Education and Outreach Initiatives on Asian Carps in Canada

Rebecca Schroeder, Invasive Species Centre

1:50 PM

Using Mock Scenarios to Improve Rapid Response in Pennsylvania

Sara Stahlman, Pennsylvania Sea Grant

2:10 PM

Novel Educational Tools and Best Practices for Increasing Awareness and Knowledge on Prevention and Management of Invasive Alien Species

Laura Verbrugge, University of Twente, Department of Water Engineering and Management

2:30 PM

An Assessment of the Buddhist Practice of Life Release in the Mississippi River Basin

Tim Campbell, University of Wisconsin Division of Extension, Wisconsin Department of Natural Resources

2:50 PM – 3:20 PM

Networking Break

Monday, October 28, 2019

Session C1

Emerging Vectors, Pathways and Invasion Threats

Session Chair: Jacob Walsh, University of Wisconsin - Madison

3:20 PM

Characterizing the Distribution Network of Aquatic Species-in-Trade: Towards a Pathway-level Risk Assessment

Farrah Chan, Fisheries and Oceans Canada

3:40 PM

Freshwater Snails and Mussels for Sale: The Ornamental Pet Trade as Pathway for Introduction of Invasive Alien Molluscs

Frank Collas, Radboud University Nijmegen, Netherlands Centre of Expertise for Aquatic Species (NEC-E)

4:00 PM

Silent Invaders – Ornamental Fish as a Leading Invader of Australian Freshwaters

Mariah Millington, Griffith University

4:20 PM

Horizon Scan of Invasive Alien Species – Predicting the Next Invasions for the Island of Ireland

Frances Lucy, Institute of Technology Sligo

Session C2

New Developments in Management and Control

Session Chair: Amy Benson, U.S. Geological Survey

3:20 PM

Utilizing an Adaptive Management Approach for Invasive Species Management: Lessons Learned from Implementing the Phragmites Adaptive Management Framework

Samantha Tank, Great Lakes Commission

3:40 PM

Developing Practical Biosecurity Recommendations for the use of High-Pressure Hot Water Spray Machines

Stephanie J. Bradbeer, University of Leeds

4:00 PM

The Use of TAED Derived Peracetic Acid as a Novel Agent for the Control of Zebra Mussels

Allister Theobald, Warwick Chemicals

4:20 PM

Preventing Dreissenid Mussel Settlement in a Flow-Through System: Is Carbon Dioxide a Sustainable Option?

Diane Waller, U.S. Geological Survey, Upper Midwest Environmental Sciences Center

Session C3

Policy and Public Outreach

Session Chair: Erika Jensen, Great Lakes Commission

3:20 PM

Great Lakes Aquatic Nonindigenous Species Gap Analysis

Rochelle Sturtevant, Michigan Sea Grant

3:40 PM

Community Science to Capture the Leading Edge of an Invasion: European Green Crab on Washington State's Inland Shorelines

Emily W. Grason, Washington Sea Grant

4:00 PM

Revisiting Classrooms and School Science Projects as Pathways for Invasive Species

Samuel Chan, Oregon Sea Grant College Program

4:20 PM

Crisis and Risks: the Sargassum Invasion in the Caribbean Islands

Florence Ménéz, Université des Antilles, Laboratoire caribéen des sciences sociales

Poster Session

Effectiveness of EarthTec QZ®, a Copper-Based Product, for Adult and Larval Dreissenid Mussel Control

Carlos Alonzo-Moya, University of Toronto

Can a Small-Bodied Non-Native Fish Impact upon Native Fish Communities in Temperate Ponds?

Tea Bašić, Cefas

Natural and Anthropogenic Drivers Facilitate Invasion of Riparian Areas by *Hedychium coronarium*

Ginevra Bellini, Universidade Federal do Rio Grande do Sul

Assessing Risk of Competition between Invasive and Native Fishes: Eurasian Tench (*Tinca tinca*) versus Redhorses (*Moxostoma* spp.)

Christophe Benjamin, McGill University

Recent Aquatic Introductions in the United States

Amy J. Benson, U.S. Geological Survey

Invasion Genomics of the Next Great Lakes Invader Fish Species, Eurasian Tench (*Tinca tinca*)

Thais A. Bernos, University of Toronto Scarborough

State of Maine Lake Vulnerability to Invasive Aquatic Plants: A Lake Vulnerability Analysis and Predictive Model

Denise Blanchette, Maine Department of Environmental Protection

Variation in Legislative Powers Related to Aquatic Invasive Species in Canada

François Bregha, Fisheries and Oceans Canada

Evaluating the Impact of a Removal Program for the Invasive European Green crab (*Carcinus maenas*) in Placentia Bay, Newfoundland

Caley Brennan, Marine Institute of Memorial University of Newfoundland

Potential Trophic Competition between Native and Non-Indigenous Bivalve Species: Complementary Approaches to Estimate Clearance Rates

Sara Cabral, MARE - Centro de Ciências do Mar e do Ambiente

The Microalgae *Didymosphenia geminata* in the Southern Hemisphere: Elucidating Potential Invasion Pathways by Population Genetics Analysis

Leyla Cárdenas, Universidad Austral de Chile

Distribution and Abundance of Invasive Octocoral *Carijoa riisei* in Ecuadorian Coast

Maritza Cárdenas-Calle, Bioelite S.A., Universidad de Guayaquil

Using Aquatic Invasive Species as Biomonitors of Microplastic Pollution

Genevieve D'Avignon, McGill University

Dreissenids' Need for Speed

Anouk D'Hont, GiMaRIS

Two-way Engagement with Stakeholders to Improve Biosecurity in the Workplace

Eithne Davis, Institute of Technology Sligo

Development of Molecular Approaches for the Monitoring of Marine Non-indigenous Species in Irish Waters: Supporting National Strategies and International Law

Sara Fernandez, Galway-May Institute of Technology

Interinstitutional and Scientific Networks to Prevent and Manage the Spread of Invasive Alien Species in the Corsican Wetlands

Marie Garrido, Environmental Agency of Corsica

Context-dependent Differences in the Functional Responses of Conspecific Native and Non-native Crayfishes

Jaime Grimm, Wildlife Conservation Society Canada

Arctic Marine Shipping and Non Indigenous Species: A Canadian Perspective

Kayla Grey, University of Ottawa

Selective Management of Exotic Watermilfoils and other North American Invasive Aquatic Plants with ProcellaCOR®, a Novel, Reduced-risk Aquatic Herbicide

Mark A. Heilman, SePro Corporation

Known Occurrences and Potential Distribution of Invasive American Bullfrog (*Lithobates catesbeianus*) Populations in Ecuador: Risk Analysis and a Management Protocol

Ileana Herrera, Universidad Espíritu Santo

U.S. Habitattitude™ Program Revitalized - Educating Consumers to Make Wise Pet Choices

Joshua Jones, Pet Industry Joint Advisory Council (U.S.)

Citizen Science Utilized to Report an Aquatic Invasive Species, the Chinese Mystery Snail (*Cipangopaludina chinensis*), in Atlantic Canada

Sarah Kingsbury, Saint Mary's University

Goldfish: Friend or Foe...

Frédéric Lecomte, Ministère des Forêts, de la Faune et des Parcs du Québec

Engaging Stakeholders through the Great Lakes Aquatic Nonindigenous Species Information System

El Lower, Cooperative Institute for Great Lakes Research

For Once, We Can be Positive: The Subsidiary Role Played by an Invasive Rockweed on Native Sandy Beach Organisms and Systems

K. Devon Lynn, University of Prince Edward Island

Poster Session continued

A Refuge against Invasive Predators: Not Every Habitat Protects Native Decapod Species the Same

K. Devon Lynn, University of Prince Edward Island

Systematic Review on the Efficacy of Recreational Watercraft Decontamination Measures to Reduce the Overland Dispersal of Aquatic Invasive Species

Shrisha Mohit, Queen's University

Mechanisms of Displacement of Native *Myriophyllum sibiricum* by Invasive *M. spicatum* in Northeastern United States

Anastasia Mozharova, University of Massachusetts - Boston

The NAS Alert System: Monitoring and Reporting the Leading Edge of Aquatic Invasions

Matthew E. Neilson, U.S. Geological Survey

Planning for Genetic Biocontrol of Invasive Species at the State of Minnesota

Kelly Pennington, Minnesota Department of Natural Resources

Biological Traits that Discriminate between Native and Invasive Benthic Invertebrates

Francesca G. Quell, University of Sheffield, Animal and Plants Department

Responses of Invasive Round Goby Populations to Elevated Temperatures in the Great Lakes-St. Lawrence River System

Heather Reid, McGill University

Validation of an Automated Cell Imaging System to Enumerate Living Microorganisms

Scott C. Riley, Excet Inc.

UV-C as a Freshwater Treatment Option against Microalgae

Jordan Roszell, University of Guelph, Integrative Biology

The Baltic Sea as Recipient and Donor of Non-indigenous Fish Species

Mariusz R. Sapota, University of Gdańsk

A Wisconsin Aquatic Invasive Species Pathways Priority: Outreach to Waterfowl Hunters

Jeanne Scherer, University of Wisconsin Division of Extension, Wisconsin Department of Natural Resources

Wisconsin's Aquatic Invasive Species Partnership: Partners as the Key to Prevention

Jeanne Scherer, University of Wisconsin Division of Extension, Wisconsin Department of Natural Resources

Amplifying Digital Reach Through Strategic Partnerships: Examples from Asian Carp Canada

Rebecca Schroeder, Invasive Species Centre

Dutch Harbor Invasive Species Bioblitz

Linda Shaw, National Marine Fisheries Service

The Neglected Pathway for Marine Alien Species: Biofouling

Alexander Smolders, Netherlands Food and Consumer Product Safety Authority

Developing a National Clean Drain Dry Program - a BC Pilot Project

Nicholas Wong, Invasive Species Council of BC

Mind the Gap: Using a Gap Analysis to Identify Elements Missing from an Outreach Program

Maude Tremblay, Fisheries and Oceans Canada

Functional Responses of Invasive Goldfishes under Warming Temperatures

Jessamine Trueman, McGill University

The Bait that Keeps on Wiggling: Vectors and Outreach for the Asian Jumping Worm

Linda Tucker Serniak, Oregon State University

How Well Do We Understand the Impacts of Invasive Alien Species on Cultural Ecosystem Services? Results from a Literature Review

Laura Verbrugge, University of Twente, Department of Water Engineering and Management

Pioneering in Chinese Mitten Crab (*Eriocheir sinensis*) Management in Flanders

Hugo Verreycken, Research Institute for Nature and Forest (INBO)

New Ammonia Based Piscicides: Getting from Science to Useable Management Tools

David Ward, U.S. Geological Survey

A Non-Native Freshwater Prawn's (*Macrobrachium nipponense*) Impact on Tropical Forest Stream Macroinvertebrate Communities

Darren C.J. Yeo, National University of Singapore

Tuesday, October 29, 2019

Plenary Session

Chair: Anthony Ricciardi, Redpath Museum, McGill University

8:30 AM

Welcome to Day 2

8:45 AM

Keynote Presentation

Managing Invasions on Land and in Water: What's Worked and What Hasn't

Daniel Simberloff, Nancy Gore Hunger Professor of Environmental Studies, University of Tennessee - Knoxville, USA

9:30 AM – 10:00 AM

Networking Break

Session D1

Emerging Vectors, Pathways and Invasion Threats

Session Chair: Hugo Verreycken, Research Institute for Nature and Forest (INBO)

10:00 AM

Risks and Management of Invasive Alien Crayfish Species in the Rhine-Meuse River Delta

Rob Leuven, Radboud University Nijmegen

10:20 AM

Tackling Unintentional Pathways of Introduction and Spread of Invasive Alien Freshwater Species in Belgium

Dido Gosse and Jane Reniers, National Scientific Secretariat on Invasive Alien Species – Belgium

10:40 AM

Mosquito Larvae Associated with the Water Lettuce “*Pistia stratiotes*” in a Lagoon of the Magdalena River, Barranquilla, Colombia

Mara Méndez Costa, Universidad del Atlántico

11:00 AM

Invasive Freshwater Mosquitoes as Emerging Disease Vectors Along a Caribbean Basin–Appalachian Plateau Transect

David Bruce Conn, Berry College

Session D2

New Developments in Management and Control

Session Chair: Nicholas Mandrak, University of Toronto Scarborough

10:00 AM

Recovery of a South African Native Fish Population after the Eradication of an Invasive Fish

Rowshyra Castañeda, University of Toronto Scarborough

10:20 AM

Structured Decision Making and Adaptive Management for AIS Responses: An Application to Grass Carp in Lake Erie

Lucas Nathan, Michigan Department of Natural Resources

10:40 AM

A New Approach to Manage Common Carp: Citizen-aided Carp Management

Przemek Bajer, University of Minnesota, MAISRC

11:00 AM

A Non-structural Fish Deterrent: Variation in Avoidance Responses across Species, and within Invasive Common Carp

Paul Bzonek, University of Toronto Scarborough

Session D3

Policy and Public Outreach

Session Chair: Thomas Therriault, Fisheries and Oceans Canada

10:00 AM

Engaging High School Students as Collaborators in Ecological Investigation of the Columbia River Estuary: Lessons from a Transdisciplinary University-High School Partnership

Gretchen Rollwagen-Bollens, Washington State University

10:20 AM

Fisheries and Oceans Canada's Role with Aquatic Invasive Species in the Prairies

Timothy Gingera, Fisheries and Oceans Canada

10:40 AM

Regional Operationalization of Canada's Federal Aquatic Invasive Species Regulation

Brendan Spearin, Fisheries and Oceans Canada

11:00 AM

Bridging the Gap between Invasive Species Research and Management

Carrie J. Brown-Lima, Cornell University

Plenary Session

Chair: Anthony Ricciardi, Redpath Museum, McGill University

11:30 AM

Keynote Presentation

Multiple Environmental Stressors Shape Community Response to Non-native Species

Shelley Arnott, Department of Biology, Queen's University, Canada

12:15 PM – 1:30 PM

Networking Luncheon

Tuesday, October 29, 2019

Session E1

Emerging Vectors, Pathways and Invasion Threats

Session Chair: Alexander Karatayev, Buffalo State University

1:30 PM

Exotic Parasites in European Freshwater Ecosystems: The Neglected and Forgotten Invaders

Jean-Nicolas Beisel, Université de Strasbourg – ENGEEs

1:50 PM

The Neglected Pathway for Marine Alien Species: Biofouling

Alexander Smolders, Netherlands Food and Consumer Product Safety Authority

2:10 PM

Phylogeography and Origin of Invasive Fish *Perccottus glenii* in Europe

Tomasz Rewicz, University of Lodz

2:30 PM

Phylogeography of the Invasive Amphipod (Crustacea) *Pontogammarus robustoides* in Native and Colonized Range

Tomasz Rewicz, University of Lodz

2:50 PM – 3:20 PM
Networking Break

Session E2

New Developments in Management and Control

Session Chair: Rob Phillips, International Joint Commission

1:30 PM

Analyzing the Decision Basis for Aquatic Invasive Species Management

Edwin D. Grosholz, University of California, Davis

1:50 PM

Evaluating the Recovery of Native Marsh Communities after Herbicide-based *P. australis* Control

Rebecca Rooney, University of Waterloo

2:10 PM

Effective Citizen Participation in Eradication of Invasive Alien Plant Species

Annerie Rutenfrans, Beleaf & Weet

2:30 PM

Invaders Must Die: Mortality of Invasive Macrophytes, Bivalves, and Crustacean Species following Exposure to Aquatic Disinfectants or Steam Treatments

Neil Coughlan, Queen's University Belfast

2:50 PM – 3:20 PM
Networking Break

Session E3

Ecophysiology and Adaptive Evolution of Invaders

Session Chair: Matthew Neilson, U.S. Geological Survey

1:30 PM

Predicting the Effects of Thermal Stress on Native and Invasive Fishes in Ontario Streams

Meagan M. Kindree, University of Toronto

1:50 PM

Could Water Temperature Stop the Round Goby Invasion

Mariusz R. Sapota, University of Gdańsk

2:10 PM

Morphological Differentiation in Trophic Traits of Round Goby across Multiple Invasion Events

Leopold Nagelkerke, Wageningen University & Research, Aquaculture Fisheries Group

2:30 PM

Is Salinity an Obstacle for Biological Invasions?

Elizabeta Briski, GEOMAR

2:50 PM – 3:20 PM
Networking Break

Tuesday, October 29, 2019

Session F1

Emerging Vectors, Pathways and Invasion Threats

Session Chair: Sarah Bailey, Fisheries and Oceans Canada

3:20 PM

Metabarcoding Reveals Deep Diversity in Ballast Water

John Darling, U.S. Environmental Protection Agency

3:40 PM

Testing Ship-borne Species Spread Models with a Global eDNA Metabarcoding Survey Dataset

Erin K. Grey, Governors State University

4:00 PM

Evaluation of a DNA Cell Proliferation Assay as a Cell Viability Measurement Technique

Vanessa Molina, Excet Inc.

4:20 PM

Predicting Hot Spots for Marine Aquatic Invasions in the Arctic

Jesica Goldsmit, Fisheries and Oceans Canada

4:40 PM

The Invasive Crayfish Collaborative: Bringing Together Research, Management, Outreach and Industry to Address a Threat to the Laurentian Great Lakes

Greg Hitzroth, Illinois-Indiana Sea Grant, Illinois Natural History Survey

Session F2

Special Workshop: Advice for Students and Early Career Researchers

Session Chair: Heather Reid, McGill University

3:20 PM

Panel Discussion

This student-led initiative offers a panel discussion with representatives from government, industry and academia to offer insight on their career paths and provide advice for those looking to build their careers. The first half of the session will be a panel discussion, and the second half will be a Q&A period where students and early career professionals can ask questions of the panelists.

Panelists:

Olivier Morissette, Ministère des Forêts, de la Faune et des Parcs du Québec

Rebecca Rooney, University of Waterloo

Brett van Poorten, BC Ministry of Environment and Climate Change Strategy

Jaclyn Hill, Fisheries and Oceans Canada

Other panelists to be announced

4:00 PM

Question & Answer Period

Session F3

Ecophysiology and Adaptive Evolution of Invaders

Session Chair: Lyubov Burlakova, Buffalo State University

3:20 PM

It is Going to be a Stormy Ride: Effect of Airflow on Survival of Dreissenids during Overland Transport

Frank P.L. Collas, Radboud University Nijmegen, Netherlands Centre of Expertise for Exotic Species (NEC-E)

3:40 PM

Lygodium microphyllum Spore Viability Collected from Soil samples in Hydric Habitats

Jeffrey T. Hutchinson, University of Texas San Antonio

4:00 PM

Variation in Traits that Influence Invasion Success in Clones of the New Zealand Mud Snail, *Potamopyrgus antipodarum*

Edward P. Levri, Penn State Altoona

4:20 PM

Habitat Degradation Promotes Non-native Fish Occurrences in Tropical Forest Streams

Kenny W.J. Chua, National University of Singapore

4:40 PM

Temperature Effects on Exploratory Behaviour and Learning Ability of Invasive Mosquitofish

Kit Magellan, University of Hong Kong

Wednesday, October 30, 2019

Plenary Session

Session Chair: Anthony Ricciardi, Redpath Museum, McGill University

8:30 AM

Welcome to Day 3

8:45 AM

Keynote Presentation

The Many Ways in which Humans Assist Biological Invaders Post-Arrival

Emma Johnston, University of New South Wales, Australia

9:30 AM – 10:00 AM

Networking Break

Session G1

Impacts on Biodiversity and Ecosystems

Session Chair: Patrick Nantel, Parks Canada

10:00 AM

Do Biological Invasions Mask the Effects of Ecological Restoration? A Case Study on the Old Rhine River (France-Germany)

Cybill Staentzel, Laboratoire Image, Ville, Environnement de Strasbourg

10:20 AM

Interactions Between Invasive Ponto-Caspian Goby Species and their Impact on Native Fishes in a Large Lowland River System

Hugo Verreycken, Research Institute for Nature and Forest (INBO)

10:40 AM

Plankton Community Change due to *Bythotrephes* Invasion Uncouples Indicators of Water Quality in Eutrophic Lake Mendota

Jake R. Walsh, University of Wisconsin - Madison Center for Limnology

11:00 AM

Biogeography Influences Endolithic Parasitism of Coexisting Invasive and Indigenous Mussel Species

Aldwin Ndhlovu, Rhodes University

Session G2

New Developments in Management and Control

Session Chair: Rob Leuven, Radboud University Nijmegen

10:00 AM

The Great Lakes Fishery Commission: Cooperative Management of the Great Lakes

Ted Lawrence, Great Lakes Fishery Commission

10:20 AM

Assessing the Effectiveness of a Passive Size-based Selective Fish passage for Managing Sea Lamprey (*Petromyzon marinus*)

McLean R. Smith, University of Guelph

10:40 AM

Getting to a Decision: Using Structured Decision Making to Gain Consensus on Approaches to Invasive Species Control

Brett van Poorten, British Columbia Ministry of Environment and Climate Change Strategy

11:00 AM

Developing a Bilateral Management Plan for European Green Crab in the Salish Sea: Advances and Challenges

Thomas W. Theriault, Fisheries and Oceans Canada

Session G3

Predictive Ecology and Risk Assessment

Session Chair: Suncica Avlijas, McGill University

10:00 AM

Predicting Invader Ecological Impacts in a Changing World: Further Development of Key Metrics Based on Relative Impact Potential (RIP) and Comparative Functional Responses (CFR)

Jaimie T.A. Dick, Queen's University Belfast

10:40 AM

Does Biosecurity Training Work? Applying the Concept of Hazard Perception to Assess Fieldworkers' Ability to Detect Biosecurity Hazards

Stephanie Bradbeer, University of Leeds

11:00 AM

Keep on RIPing in the Free World: New Metrics to Predict and Assess the Ecological Impacts of Aquatic Invaders

James W.E. Dickey, Queen's University Belfast

Plenary Session

Anthony Ricciardi, Redpath Museum, McGill University

11:30 AM

Keynote Presentation

Impacts of Species Invasions in a Changing World

Cascade Sorte, Department of Ecology and Evolutionary Biology, University of California Irvine, USA

12:15 PM – 1:30 PM

Networking Luncheon

Wednesday, October 30, 2019

Session H1

Impacts on Biodiversity and Ecosystems

Session Chair: Becky Cudmore, Fisheries and Oceans Canada

1:30 PM

Predicting the Effects of Reintroducing a Native Predator (European eel, *Anguilla anguilla*) into a Freshwater Community Dominated by Alien Species

Phillip J. Haubrock, Senckenberg Research Institute and Natural History Museum Frankfurt

1:50 PM

Prayer Animal Release: An Overlooked Pathway for Introduction of Invasive Aquatic Species

Kit Magellan, University of Battambang

2:10 PM

A Novel Survey Technique Provides Unique Insights into Invasion Biology, Ecological Impacts and Potential Management of Signal Crayfish (*Pacifastacus leniusculus*)

Eleri Pritchard, University of College London, Department of Geography, King's College London

2:30 PM

Balancing SAR Protection and Invasive Species Management: *Phragmites australis* Management in the Long Point Region

Heather Braun, Environment and Climate Change Canada

2:50 PM – 3:20 PM

Networking Break

Session H2

New Developments in Management and Control

Session Chair: Anett Trebitz, U.S. Environmental Protection Agency

1:30 PM

A Research Path to Achieving Control of Dreissenid Mussels throughout Entire Lakes

Daniel P. Molloy, Molloy & Associates, LLC

1:50 PM

eDNA: Bridging the Gap Between Science and Management

Stephanie Sardelis, Fisheries and Oceans Canada

2:10 PM

Using eDNA Surveys to Detect Small Populations of Non-native Fishes

Phil I. Davison, CEFAS, Bournemouth University

2:30 PM

Sequencing and Assembly of the Quagga Mussel (*Dreissena rostriformis bugensis*) Genome: A Tool for Development of Biocontrols

Yale Passamaneck, U.S. Bureau of Reclamation

2:50 PM – 3:20 PM

Networking Break

Session H3

Predictive Ecology and Risk Assessment

Session Chair: Jaimie Dick, Queen's University Belfast

1:30 PM

Biotic Resistance from Native Predators Predicts Mosquito Invasion Success and Informs Biocontrol Strategies

Ross Cuthbert, Queen's University Belfast

1:50 PM

Predicting Impacts of Invasive Fishes across Habitat Types

Suncica Avlijas, McGill University

2:10 PM

Influence of Climate Warming on the Ecological Impacts of Invasive Crayfishes

Victoria Chicatun, McGill University

2:30 PM

Predicting Grass Carp Spawning Success using a 3-D Hydrodynamic Model

Tej Heer, University of Toronto Scarborough

2:50 PM – 3:20 PM

Networking Break

Wednesday, October 30, 2019

Session 11

Impacts on Biodiversity and Ecosystems

*Session Chair: Leopold Nagelkerke,
Wageningen University*

3:20 PM

Long-Term Invasion Impacts: Coexistence or Extirpation for Native Mussels in the *Dreissena* Era?

Lyubov E. Burlakova, Buffalo State College

3:40 PM

Quantifying the Ecological Impacts of Invasive Freshwater Fish through a Controlled Release Experiment

Clara L.O. McGlade, Queen's University Belfast

4:00 PM

The Role of Native Marine Predators in Regulating Invasions: A South African Case-Study

Mhairi Alexander, University of the West of Scotland

4:20 PM

Invasive Species Change Ecosystem Functions in Lake Constance

Piet Spaak, Eawag

4:40 PM

Invasive Species Sleeper Populations: How Important Are They and What Do They Mean for Management?

Michael Spear, University of Wisconsin - Madison

Session 12

New Developments in Management and Control

Session Chair: Mike Farrell, Ontario Power Generation

3:20 PM

Alien Species Management Policies in the Trilateral Wadden Sea

Saa Kabuta, Rijkswaterstaat, Ministry of Infrastructure and Water Management

3:40 PM

Lessons Learned from Broad-spectrum Early-detection Monitoring in the Laurentian Great Lakes

Anett Trebitz, U.S. Environmental Protection Agency

4:00 PM

Development of a Coordinated Regional Program to Monitor for Dreissenid Mussels in the Columbia River Basin

Timothy D. Counihan, U.S. Geological Survey

4:20 PM

Avoidance Behavior of Cold-, Cool-, and Warm-water Fish Species to Zequanox®, a Biopesticide for Dreissenid Mussel Control

Matthew Barbour, U.S. Geological Survey, Upper Midwest Environmental Sciences Center

4:40 PM

Evaluation of an In-water Cleaning and Capture Technology

Matthew R. First, U.S. Naval Research Laboratory

Session 13

Predictive Ecology and Risk Assessment

Session Chair: Jaclyn Hill, Fisheries and Oceans Canada

3:20 PM

Global Aquatic Species Invasions in Urban Environments

Nicholas Mandrak, University of Toronto Scarborough

3:40 PM

Predicting Non-Native Plant Species Richness with Confidence in Undersampled Watersheds

Amy Davis, Ghent University

4:00 PM

Flood and Storm Tracker (FaST) Tool: Updates after the Initial Storm Season

Ian Pfingsten, U.S. Geological Survey (CNT)

4:20 PM

Predicting Trends in Climate Similarity of Global Aquatic Watersheds Under Multiple Climate-Change Scenarios

Justin A.G. Hubbard, University of Toronto

4:40 PM

Life-history Traits for Predicting Invasiveness in Non-native Freshwater Fishes

Gordon H. Copp and Michael Fox, Trent University

Thursday, October 31, 2019

Plenary Session

Session Chair: Anthony Ricciardi, Redpath Museum, McGill University

8:30 AM

Welcome to Day 4

8:45 AM

Keynote Presentation

Colonization Pressure and the Insights of Supply-Side Invasion Ecology

Julie Lockwood, Department of Ecology, Evolution and Natural Resources, Rutgers University, USA

9:30 AM – 10:00 AM

Networking Break

Session J1

Invasion Dynamics

Session Chair: Darren Yeo, National University of Singapore

10:00 AM

Lake Morphometry Determines Dreissena Invasion Dynamics

Alexander Y. Karatayev, Buffalo State College, Great Lakes Center

10:20 AM

Seasonally Migrating Round Goby in Lake Ontario: A Case of Missing Adults?

Chris Pennuto, Buffalo State College, Great Lakes Center

10:40 AM

Investigating the Effects of Eelgrass and Predation on Fouling Community Composition in a Temperate Estuary

Benjamin Rubinoff, University of California Davis

11:00 AM

Evaluating Upstream Passages and Challenges by Bigheaded Carp at a Mississippi River High-Head Dam

Andrea Fritts, U.S. Geological Survey

11:20 AM

Alien Species Dynamics Within the UNESCO World Heritage Site, the Wadden Sea

Adriaan Gittenberger, GiMaRIS

11:40 AM

Poeciliid Invasion Models

Kit Magellan, University of Battambang

Session J2

Ballast Water

Session Chair: David Reid, Saint Lawrence Seaway Development Corporation (Consultant)

10:00 AM

Effects of Ballast Water Exchange and Treatment on Microbial Community Structure

John Darling, U.S. Environmental Protection Agency

10:20 AM

Ballast Water Invasion Probability Tool: Simplifying the Application of Scientific Knowledge to Real-time Monitoring Decisions

Johanna Bradie, Fisheries and Oceans Canada

10:40 AM

Evaluating Ballast Water Management Systems to Prevent Biological Invasions

Oscar Casas-Monroy, Fisheries and Oceans Canada

11:00 AM

Scenario-based Cost-effectiveness Analysis of Ballast Water Treatment Strategies

Zhaojun Wang, University of Delaware

11:20 AM

Effectiveness of Ballast Water Exchange Plus Treatment as a Mechanism to Reduce the Introduction and Establishment of Aquatic Invasive Species in Canadian Ports

Sarah A. Bailey, Fisheries and Oceans Canada

11:40 AM

The Best Available Science Supports Most Probably Number (MPN) Testing Methods for Type Approval of Ballast Water Management Systems

John Cullen, Dalhousie University, Department of Oceanography

12:00 PM – 1:00 PM

Networking Luncheon

Thursday, October 31, 2019

Special Session

1:00 PM – 4:30 PM

Integrating Invasion Science and Management Across Realms: Learning from Terrestrial, Marine and Freshwater Experiences

This session aims to identify ways in which knowledge and tools can be more effectively exchanged between scientists and managers working in different study systems. It will compare successes and challenges for risk assessment, eradication, biological control and other management approaches used to deal with invasive species in terrestrial, freshwater and marine environments to set the stage for collaboration to improve outcomes across taxa boundaries.

1:00 PM – 1:05 PM

Introductory Remarks

Joe Caffrey, INVAS Biosecurity Ltd., Session Moderator

1:05 PM – 1:25 PM

Optimal Planning of Invasive Species Surveillance Campaigns

Denys Yemshanov, Natural Resources Canada - Canadian Forest Service

1:25 PM – 1:45 PM

A Management Perspective on Risk Assessment for the Live Trade Industry

Becky Cudmore, Fisheries and Oceans Canada

1:45 PM – 2:05 PM

Experiences in Ballast Water Management across Freshwater and Marine Ecosystems

Sarah Bailey, Fisheries and Oceans Canada

2:05 PM – 2:20 PM

Break

2:20 PM – 2:40 PM

New Technologies for Invasion Management: Will they Work in Water?

Daniel Simberloff, University of Tennessee - Knoxville

2:40 PM – 3:00 PM

Asian Long-Horned Beetle versus Emerald Ash Borer Eradication: Even with Good Ingredients You Still Need a Recipe for Success

Taylor Scarr, Natural Resources Canada - Canadian Forest Service

3:00 PM – 3:20 PM

Biological Control of Invasive Alien Species in the Anthropocene

Peter G. Mason, Agriculture and Agri-Food Canada

3:20 PM – 3:40 PM

Overcompensation, Eradication Failure and the Case for Functional Eradication of Aquatic Invasive Species

Edwin Grosholz, University of California Davis

3:40 PM – 4:20 PM

Audience Questions and Interactive Panel Discussion

4:20 PM – 4:30 PM

Moderator Closing Remarks

4:30 PM

Conference concludes

Keynote Presentations

Monday, October 28, 2019



Anthony Ricciardi, *Redpath Museum, McGill University, Canada*

Dr. Anthony Ricciardi is a Professor of Invasion Biology at the Redpath Museum & McGill School of Environment at McGill University. For 25 years, his research has examined the causes and consequences of biological invasions using field experiments, lab experiments, empirical modeling and meta-analysis. He is a recipient of the Frank Rigler Award, the highest honour given by the Canadian Society of Limnologists.

8:45 AM to 9:30 AM

Why Biogeographic Origins Matter to Invasion Science

Anthony Ricciardi¹, ¹*Redpath Museum, McGill University*

Several opinion articles in scientific journals and the popular media have claimed that native species are just as likely as non-natives to become invasive and cause environmental disruptions, including extinctions. Therefore, these articles argue, the biogeographic origin of a species has no practical value to conservation or ecosystem management. However, these articles ignore burgeoning evidence of the role of evolutionary history in determining the colonization success and impact of an introduced species. For example, introduced species tend to disrupt communities that lack evolutionary experience with functionally similar organisms; such evolutionary mismatches are a major reason why nonnative species are many times more likely than natives to cause extinctions. Native species tend to become 'invasive' (rapidly superabundant and dominant) within their historic ranges only after evolved biotic constraints have been reduced by disturbance. Using evidence from experiments, field surveys, and meta-analyses involving freshwater fishes and invertebrates, I will show how understanding the biogeographic origins and evolutionary histories of introduced species can inform risk assessment and policy.



Alison Dunn, *University of Leeds, England*

After working as a Nature Research Warden, a Lab Technician, Dr. Dunn returned to academia to undertake a PhD in Parasitic Sex Ratio Distorters at the University of Leeds. Returning to the University of Leeds as a NERC Research Fellow, then as a University Research Fellow, before joining the academic staff full-time in 2005. Dr. Dunn's labs focuses on the impacts of invasive predators on native species and behavioural, ecological and evolutionary responses in aquatic systems to multiple abiotic (climate) and biotic (disease, invasive species) stressors.

11:30 AM to 12:15 PM

Invasive Alien Species in Aquatic Ecosystems and Opportunities to Slow their Spread

Alison Dunn¹, ¹*University of Leeds, School of Biology*

Trophic interactions between Invasive Alien Species and native species are key to the success and impact of invasive alien species. Work from our lab demonstrates the top-down (predatory) as well as bottom-up effects of invasive species on native species, exploring how these interactions may be altered by further stressors including climate and parasitic disease.

Prevention measures including biosecurity are essential to reducing the introduction and spread of invasive alien species and of infectious diseases. We have developed and tested practical, pragmatic biosecurity practices for use in the field. However, knowing the best way to clean equipment and vehicles isn't enough. Preventing introduction and secondary spread also requires behaviour change by stakeholders from a range of environment sectors. We have used interviews with key environmental stakeholders to explore motivation and to identify barriers and opportunities for biosecurity. I will discuss our work with stakeholders from business, conservation and government agencies to embed biosecurity in their policies and in their day-to-day activities.

Keynote Presentations

Tuesday, October 29, 2019



Daniel Simberloff, Nancy Gore Hunger Professor of Environmental Studies, University of Tennessee - Knoxville, USA

Dr. Daniel Simberloff is the senior editor of the Encyclopedia of Biological Invasions and author of *Invasive Species: What Everyone Needs to Know*. Much of his research focuses on causes, consequences, and management of biological invasions. His research projects are on insects, plants, fungi, birds, and mammals. He is a member of the U.S. National Academy of Sciences and the American Academy of Arts and Sciences.

8:45 AM to 9:30 AM

Managing Invasions on Land and in Water: What's Worked and What Hasn't

Daniel Simberloff¹, ¹University of Tennessee - Knoxville, USA

Freshwater and, especially, marine invaders are perceived as vastly harder than terrestrial ones to manage. A major problem is early detection, facilitated by several innovations on land. In water, eDNA helps redress the imbalance. Populations of many animal species and some plant species have been eradicated on land, and technologies to do so are rapidly improving. Invasive populations in small freshwater bodies have often been eradicated. The possibility of eradication in lakes is enhanced by their insular nature, just as islands have been the locus of a disproportionate number of successful terrestrial eradication projects because of their limited extent and isolation. Conversely, eradication of marine populations is particularly challenging. Many terrestrial invaders have been maintained at low levels, even after widespread establishment, by various means. A number of freshwater invaders have similarly been controlled long-term. For aquatic plants, biological control and chemical control have been the main methods, and for aquatic animals, chemical control has been the dominant approach. As for terrestrial invaders, non-target impacts have been a persistent problem with both approaches. Idiosyncratic techniques sometimes permit both eradication and maintenance management not only of terrestrial species but also of freshwater and marine ones.



Shelley Arnott, Department of Biology, Queen's University, Canada

Dr. Shelley Arnott is a professor in the Department of Biology, Queen's University who uses a combination of field experiments, laboratory bioassays, and field surveys to advance our understanding of factors that regulate aquatic biodiversity. She has spent the past 2 decades investigating the effect of non-native species on plankton communities in Ontario lakes. A major focus of her ongoing work is to understand the interactive effects of multiple stressors, including non-native species.

11:30 AM to 12:15 PM

Multiple Environmental Stressors Shape Community Response to Non-Native Species

Shelley Arnott¹, ¹Department of Biology, Queen's University, Canada

Local biotic and abiotic context can influence the impact of non-native species on invaded communities. Local context is increasingly driven by human activities, resulting in native communities that are challenged by multiple environmental stressors, including invasive species. This variation in local context can impede our ability to successfully predict when and where strong impacts of non-native species will occur. A framework for testing the effects of multiple stressors can be used to categorize responses as additive, synergistic, or antagonistic but few studies have considered interactions between invasive species and other stressors, such as climate, nutrient loading, pollution, and habitat alteration. Despite this complexity, I will show how factorial experiments that compare individual and combined effects of stressors can be used to predict the impact of non-native species in a multiple stressor context.

Keynote Presentations

Wednesday, October 30, 2019



Emma Johnston, *University of New South Wales, Australia*

Dr. Emma Johnston is the Dean of Science and Professor of Marine Ecology and Ecotoxicology. Having published more than 140 peer-reviewed articles and supervised more than 20 PhD graduates. She consults with industry through the development and implementation of new biomonitoring techniques and environmental monitoring programs. Professor Johnston is also a science communicator and television presenter for Coast Australia.

8:45 AM to 9:30 AM

The Many Ways in which Humans Assist Biological Invaders Post-Arrival

Emma Johnston¹, *¹School of Biological, Earth & Environmental Sciences, University of New South Wales, Australia*

In this plenary I present evidence for how four drivers of global change are acting in concert to create environments that favour aquatic pest species. Global warming, organic enrichment, disturbance, and species additions are increasing biological and ecological rates, favouring weedy communities and causing pervasive impacts. Using experimental and mensurative approaches, I explore how rate drivers interact and the role of rapid evolution to environmental stresses in facilitating bioinvasion. I discuss our recent latitudinal gradient studies spanning 20 degrees of latitude and 10 degrees of water temperature, giving us a glimpse into the future of biodiversity for our nearshore coastal systems. Finally, I discuss how the 'speeding up' of marine ecosystems necessitates changes to the way we do bioinvasion research, attempt conservation, and use ecosystem services.



Cascade Sorte, *Department of Ecology and Evolutionary Biology, University of California Irvine, USA*

In 2014, Dr. Sorte joined the faculty at the University of California, Irvine in the Department of Ecology and Evolutionary Biology, and was elected an Early Career Fellow of the Ecological Society of America in 2017. As an integrative marine ecologist, Dr. Sorte's research spans ecological scales from physiology to biogeography to investigate the impacts of global change, particularly the interaction between climate change and species invasions.

11:30 AM to 12:15 PM

Impacts of Species Invasions in a Changing World

Cascade Sorte¹, *¹Department of Ecology and Evolutionary Biology, University of California Irvine, USA*

Species invasions and climate change are two primary drivers of biodiversity and economic loss and prominent threats to human well-being. Here, I discuss findings showing that these threats are not independent but instead, interact, leading to a "double whammy" for natural systems. Climate change can increase invasion success as well as the impacts (via changes in abundances and per capita effects) of invasive species. Furthermore, climate change is driving native species to shift their ranges and in some cases impact communities to a similar extent as invasive species. In my talk, I will synthesize findings from case studies and meta-analyses conducted as part of international, cross-ecosystem working groups and collaborations that help to shed light on the likely impacts of species invasions in a changing world.

Keynote Presentation

Thursday, October 31, 2019



Julie Lockwood, Department of Ecology, Evolution and Natural Resources, Rutgers University, USA

Dr. Julie Lockwood is a professor at Rutgers University in the Department of Ecology, Evolution, and Natural Resources. Her research is a cross-section of conservation biology, biogeography and invasion ecology. Her lab group currently focuses on developing technological and decision-support tools for invasion science. She has co-written or edited four books on biological invasions and coastal conservation, and currently serves as a Senior Editor for Conservation Letters.

8:45 AM to 9:30 AM

Colonization Pressure and the Insights of Supply-Side Invasion Ecology

Julie Lockwood¹, ¹Department of Ecology, Evolution and Natural Resources, Rutgers University, USA

Colonization pressure is defined as the number of species introduced into a single location, some of which will go on to establish self-sustaining populations while others will not. In past invasion literature, this concept has been confusingly termed 'propagule pressure'. However, the two are distinguished by the biological level of mechanism where propagule pressure works to increase establishment success at the population level and colonization at the species level. In general, the role that colonization pressure plays in determining spatial and temporal differences in the number of non-native, and invasive, species has received limited attention. Nevertheless, there is sound theoretical and empirical evidence that colonization pressure serves as a 'null model' in explanation of spatial and temporal differences in non-native species richness. This null is succinctly expressed by Lonsdale's equation published in 1999. The key insight of this equation is that the supply of non-native species into a location sets a limit to the number of species that can establish there. Differences in this supply (or introduction) rate will drive differences in non-native species richness across time and space in the absence of any other ecological mechanisms. Empirical tests of, and computational elaborations on, Lonsdale's model elucidate under what circumstances colonization pressure will be the dominant explanation for richness differences, and when ecological or environmental factors will play a large role. Recognizing colonization pressure as a null model places more emphasis on careful recording of all introduction events, including those that are seemingly unsuccessful, and on the spatial and temporal dynamics of introduction pathways as these directly determine colonization pressure.

Monday, October 28, 2019

Session A1: Impacts on Biodiversity and Ecosystems

Villains in a Half-Shell: Assessing the Impacts and Risks of Emerging and Future Invasive Alien Species

James W.E. Dickey¹, Ross N. Cuthbert¹, Jaimie T.A. Dick¹

¹School of Biological Sciences, Queen's University Belfast

Invasive alien species (IAS) cause many negative impacts, from ecosystem disruption, health issues, economic damage, and species extinctions. One major source of emerging and future IAS is the poorly regulated international pet trade, and, importantly, these species often have little or no informative invasion history. In this study we develop the Relative Impact Potential (RIP) metric, a novel measure of ecological impact that incorporates functional responses (FR: a *per capita* measure of resource consumption) alongside proxies for numerical responses (NR: life history traits in this context). Further, with propagule pressure a known determinant of invasion risk, we combine this with RIP to arrive at another metric, Relative Invasion Risk (RIR). In this talk I will outline the application of these metrics to assess the impacts and risks of four commonly traded turtles: *Trachemys scripta scripta*, the yellow-bellied slider; *T. s. troostii*, the Cumberland slider; *Sternotherus odoratus*, the common musk turtle; and *Kinosternon subrubrum*, the Eastern mud turtle. With the two *Trachemys scripta* subspecies scoring highly in terms of FR and life history traits, it is the high availability of *T. s. scripta* and *S. odoratus* that warrants their focus as species of high risk. We propose that the RIP and RIR metrics offer two universally applicable methods to assess potential impacts and risks associated with emerging and future invaders in the pet trade and other sources of future IAS. With these metrics highlighting *T. s. scripta* as having high impact and invasion risk, corroborating its position on the EU list of 49 IAS of Union Concern. This suggests our methodology and metrics have great potential to direct future IAS policy decisions and management. This, however, relies on collation and generation of new data on alien species functional responses, numerical responses and their proxies, and imaginative measures of propagule pressure.

Invasive Wetland Grass Influences Secondary Productivity and Aerial Insectivore Birds

Courtney D. Robichaud¹, Rebecca C. Rooney¹

¹University of Waterloo

Aerial insectivores (i.e. swallows) are experiencing steep population declines in North America. The drivers of this decline are unclear, though suggestions include a decrease in foraging habitat or insect abundance. The coastal marshes of Long Point, ON provide foraging habitat for many swallow species. This habitat is compromised, however, by the invasive wetland grass *Phragmites australis* (European Common Reed) which is spreading throughout North American wetlands. In 2016, a large-scale *P. australis* control project was implemented, representing the first time a glyphosate-based herbicide has been applied to control invasive *P. australis* over water in Canada. Herbicide application is a best management practice for controlling *P. australis*, though it may affect species at risk and invertebrate communities. Therefore, it is critical to understand how invasion and control actions affect vulnerable aerial insectivore communities and invertebrate prey.

Our research identified how invertebrate prey density (number of individuals) and aerial insectivore foraging activity were influenced by *P. australis* invasion and herbicide-based control actions. Using emergence traps and paired point-count surveys during the breeding season in 2017 and 2018, we compared these response variables in invaded (*P. australis*), uninvaded (meadow and emergent marsh), and recently herbicide treated marsh. We conclude that aerial insectivore birds forage less often over invasive *P. australis*. Herbicide-based control of *P. australis* increased the quantity of invertebrate prey, resulting in certain avian species preferring to forage over treated habitat. Herbicide-based control particularly benefited the endangered Barn Swallow (*Hirundo rustica*). Thus, controlling populations of *P. australis* in marshes may provide benefits to at-risk aerial insectivore species.

***Egeria densa* (Brazilian Waterweed): An Ecosystem Engineer and "Blue Carbon" Sink**

Judith Z. Drexler¹, Shruti Khanna², Jessica Lacy³

¹U.S. Geological Survey, California Water Science Center; ²California Department of Fish and Wildlife; ³U.S. Geological Survey, Pacific Coastal and Marine Science Center

Invasive submerged aquatic vegetation (ISAV), which borders marshes and is dominated by *Egeria densa*, acts as an ecosystem engineer in the Sacramento-San Joaquin Delta of California. One of its impacts is trapping sediment from the water column. We hypothesize that widespread Delta infestation of ISAV, which began in ~1990, is obstructing inorganic sediment deposition on marshes, reducing their resilience to sea-level rise. To test this hypothesis, we measured the impact of ISAV on sediment deposition in three sites with differing energy dynamics. At each site we collected five surficial push cores under ISAV and in the unvegetated channel and two ~50 cm cores in the marsh and under ISAV patches. We measured bulk density (BD), % organic carbon (OC), and loss on ignition in all cores and ²¹⁰Pb and ¹³⁷Cs in marsh and ISAV cores only. BD of the top 2 cm of push cores was significantly greater and % OC was significantly less in the unvegetated channel than in sediments under ISAV ($U = 256.00$, $p = 0.001$; $U = 310.50$, $p = 0.001$). BD was greater and %OC was lower in ISAV cores than in marsh cores ($F_{1,6} = 65.261$, $p < 0.001$; $F_{1,6} = 198.52$, $p < 0.001$). Inorganic sedimentation rates were greater in ISAV cores than marsh cores (Student's t-test, $p < 0.01$). In the marsh cores, inorganic sedimentation rates were lower from 1990 to present than pre-1990 at the most quiescent site (Student's t-test, $p < 0.001$), suggesting that ISAV is trapping sediment that was previously deposited in marshes. OC accumulation rates in ISAV cores were not significantly different from marsh cores (range: 60 – 240 g C m⁻² yr⁻¹, Student's t-test, $p > 0.05$). Carbon storage in estuarine patches of ISAV is a novel "blue carbon" (coastal carbon) sink in the landscape.

Non-Native Chain Pickerel and Smallmouth Bass Integration and Impacts in Maritimes Freshwater Food Webs

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Chain pickerel (*Esox niger*) and smallmouth bass (*Micropterus dolomieu*) were introduced to a few Nova Scotia lakes in the 1940s for recreational fishing. Since then, the number of waterbodies throughout the Maritimes Provinces with those species have increased significantly, including those containing COSEWIC-listed vulnerable species. Chain pickerel and smallmouth bass are prolific predators which can impact native species and food web structures in a short time. While anecdotal information and stomach content analyses have indicated that native species (e.g., amphibians, small fish, large invertebrates) are rapidly declining in impacted watersheds, there has been no quantitative food web analyses to date to support those observations. Stable isotopes of nitrogen ($\delta^{15}\text{N}$) and carbon ($\delta^{13}\text{C}$) are a long-established tool to quantitatively assess food web connections and model dietary shifts within lakes. Mercury analyses provide information on food web connectivity since mercury consistently biomagnifies in food chains. We sampled fish and invertebrates from over 15 lakes across Nova Scotia plus a lake in New Brunswick. In addition, we have collected unpublished datasets for several lakes. Two lakes in this dataset have been sampled at least twice, providing an opportunity to include temporal comparisons in addition to spatial comparisons. Our stable isotope data confirm that chain pickerel and smallmouth bass are integrated into food webs. This is cause for concern for several Species at Risk, including yellow lampmussel (*Lampsilis cariosa*), small-bodied Lake Utopia rainbow smelt (*Osmerus mordax*), as well as cyprinid communities, white perch (*Morone americana*) and brook trout (*Salvelinus fontinalis*). Furthermore, there are implications for contaminant transfer in food webs which may impact mercury advisories for the public.

Barring the Way to Asian Carp Invasion of Quebec's Inland River Systems

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The capture of a large egg-laden grass carp (diploid) in May 2016 and the positive eDNA detections observed throughout the St. Lawrence River in every yearly survey since 2015 suggest that this species is now present in Quebec. Risks of dispersal from the St. Lawrence River in tributaries is now highly likely and quantifying such threat became a central objective of Quebec's Asian Carp Program.

Natural and man-made obstacles in the St. Lawrence River tributaries were mapped and described for their potential in restraining fish movement and preventing Asian carp dispersal. The upstream permeability of 231 barriers was evaluated according to their formal specifications and to the physical capabilities of the four Asian carps. Of all barriers evaluated, 77% were dams, 18% waterfalls and 8% locks. Twenty-five percent would fail to restrain carp dispersal while 41% needed further field investigations. Then, during summer 2018, 102 of the 231 barriers, mainly the one located at the most downstream position, were visited under two hydrological conditions (high and low water). Barrier specifications were validated on-site (e.g. barrier width, length, height) and other variables were quantified under natural conditions (e.g. slope, water velocity, water depth and temperature). These variables were weighted and used to develop an evaluation grid quantifying the barrier potential to restrain Asian carp dispersal. Results of this evaluation are presented as well as how they allowed mapping tributaries at risk of being invaded by Asian carps in the St. Lawrence River valley. The potential for our evaluation grid to quantify upstream permeability of barriers for other aquatic invasive species (e.g., Eurasian tench) is presented. So far, the number of potential barriers theoretically capable of blocking Asian carps invasion in inland water appears significant, major tributaries were to some extent protected from the species' ability to disperse through the hydrologic connectivity.

Grass Carp Incident Command Exercise: Two Levels of Government Coming Together

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After credible evidence of potential Grass Carp in a small lake within a national park in the Province of Quebec, it was decided to use the opportunity to search for this species using the Incident Command System (ICS). This would allow for cross-training from the federal Fisheries and Oceans Canada's Asian Carp Program, which had a developed ICS protocol, to the Provincial Ministère des Forêts, de la Faune et des Parcs. The on-the-ground exercise also allowed for testing of the established protocol to refine it. The exercise took two weeks of pre-planning and training and the activities were conducted over a 5 day period. Several staff from both levels of government participated. While no Grass Carp were detected during the exercise, the lessons learned proved extremely valuable to both organizations. It also now allows for a stronger ability to work together in the event of future invasive species responses. An overview of the ICS exercise will be presented along with suggestions for best practices will be presented.

Experimental eDNA Studies in Two Complex Riverine Systems to Improve Invasive Species Detection

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Given its high specificity and sensitivity, detection of environmental DNA (eDNA) is increasingly used as a tool for detection of invasive aquatic species. There is growing evidence that eDNA methods are substantially more sensitive than traditional sampling. However, factors influencing eDNA detection remain to be better understood, such downstream transport that may cause detection of molecule away from their source of emission in river systems. Few studies have analyzed factors influencing physical transport and detection probability of eDNA in large and complex riverine systems. Thus, we conducted in situ experiments to evaluate the spatiotemporal scale of dispersion of eDNA in two complex hydrologic systems, the St. Lawrence and Richelieu rivers (both in Québec, Canada). As punctual source of eDNA, known biomass and number of Brown Trout, *Salmo trutta*, and Rainbow Trout, *Oncorhynchus mykiss* (two species known to be absent in the area) were caged in both riverine systems. Detection assays by quantitative PCR were tried in sampling stations at 10, 100, 500, 1000 and 5000 meters downstream from the cages. Amount of detected eDNA molecules were higher close to the cages, but detected up to 5000 m downstream. We observed a significant effect of the distance on the amount of DNA molecules for brown trout only. For the same biomass, number of caged individuals increased species' detection probability. Finally, we observed low lateral dispersion along the river. Those results provide insights on the factors influencing detection of eDNA as a detection tool in fluvial systems. We detect eDNA molecules at long distance from their sources of emission and observed a laminar pattern of dispersion. Additional investigations remain necessary to understand the complete factors influencing eDNA distance of dispersion and detection probabilities in complex riverine systems.

Bridging Science and Enforcement – An Invasive Species Management Approach in British Columbia

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Since 2004, the British Columbia Inter-Ministry Invasive Species Working Group (IMISWG) has provided policy direction, coordination and collaborative delivery of invasive species programs for the Province of BC. The IMISWG functions to bring together provincial ministries and agencies, each with unique mandates, program goals and technical expertise, to work collaboratively in a "one government" approach on invasive species. The IMISWG has published two Early Detection and Rapid Response Plans for BC, a Provincial Invasive Species Strategic Plan, and has piloted and implemented new and innovative approaches to on-the-ground prevention and management of invasive species.

The BC IMDP is an example of an innovative, public-private partnership focused on invasive mussel prevention. The program was launched in 2015 with efforts focused on inspecting boats, monitoring lakes, educating the public and coordinating actions with neighboring jurisdictions. This Program is a unique blend of science, education and enforcement through the partnership with the BC Conservation Officer Service to operate 12 watercraft inspection stations across the province staffed by 64 auxiliary conservation officers. The Program is supported by annual funding from our partners BC Hydro, Columbia Basin Trust, Columbia Power Cooperation, and Fortis BC. The Program continues to implement and improve the perimeter defense plan for zebra and quagga mussels with neighboring jurisdictions including Washington, Oregon, Idaho, Montana, Alberta, Manitoba, Yukon and Saskatchewan. Research partnerships are also an important component of the Program and help to inform the optimization of watercraft inspection stations and lake monitoring efforts. As one example, the data collected through the provincial watercraft inspection stations is the foundation of a research collaboration with the University of Alberta to develop a boater movement model for BC. This model will further assist in fine-tuning inspection efforts.

Dreissenid Prevention across the Pacific Northwest, USA

Stephen Phillips¹

¹Pacific States Marine Fisheries Commission

Zebra mussels and quagga mussels have been the most costly aquatic invaders in U.S. history as tens of millions of dollars are spent each year in managing zebra mussel infestations in the Great Lakes, Mississippi and now Colorado River drainages. The introduction of zebra and quagga mussels into the Columbia River Basin could not only threaten native species, but also industrial, agricultural, recreational, navigation, and subsistence use of the infested waters.

Dreissenid mussel transfer between basins in the western United States is most likely to occur through the movement of trailered watercraft. Government agencies and organizations in the western US have implemented watercraft interception programs designed to prevent contaminated watercraft from being launched in unaffected waterways. Hundreds of thousands of boats are inspected each year in the western U.S.

An overview will be provided an overview of western watercraft inspection programs, data on number of boats inspected and source waters of infested boats. This talk will also highlight challenges and successes of watercraft interception programs and future direction of interjurisdictional cooperative planning, prevention and management amongst state, federal and provincial agencies.

Watercraft Inspection and Decontamination Programs in the Western Region of the United States

D. Davis¹, Stephen Phillips¹

¹Pacific States Marine Fisheries Commission

The expansion of inspection programs has increased the need to have trained inspection and decontamination program staff and managers regionally adopt protocols and standards to guide uniformity to the procedures and language amongst the state/agency programs.

To serve these needs, Pacific States Marine Fisheries Commission began the Watercraft Inspection Training (WIT) program in 2006. To date, over 100 WIT Level I and Level II training classes have been conducted in 19 Western states (and British Columbia) involving thousands of participants. The program has expanded since inception. Trainer Training (WIT III) began April 2015. These individuals have trained thousand more in their respective programs. Advanced Decontamination was added in 2017. These trainings cover advanced skills and knowledge, triggers for decontamination and the importance of standardizing protocols.

The purpose is to teach natural resource personnel watercraft inspection and decontamination techniques and methods utilizing the "Uniform Minimum Protocols and Standards for Watercraft Interception Programs for Dreissenid Mussels in the Western United States."

The trainings utilized WIT training manuals by the Western Regional Panel (WRP) on Aquatic Invasive Species' WIDT committee. These trainings have proven critical, as properly decontaminating fouled watercraft using current standards is an arduous task, and resource agencies need to be able to trust the decontaminations and inspections conducted by other jurisdictions.

Aquatic Invasive Species Outreach – Zebra Quagga Mussel Prevention in Columbia Shuswap, British Columbia Canada

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The Columbia Shuswap Invasive Species Society (CSISS) is a non-profit organization with a mandate to prevent the spread of invasive species through education, partnership building, and direct management and treatment of invasive species in the Columbia Shuswap region of BC. The Shuswap Watershed Council (SWC) is a collaborative partnership of three regional districts, two municipalities, the Secwepemc Nation, and two provincial government agencies. Its mandate is to enhance, protect, and advocate for water quality in the Shuswap watershed. Since both organizations' formations, we have become increasingly informed about the seriousness of the threat of invasive mussels and the risks to our aquatic ecosystems and economy. Our water quality, fish habitat (resident species and anadromous Pacific salmon, for which the Shuswap watershed provides critical migration, spawning and rearing habitat), infrastructure, water utilities, beaches, and property value are at risk. If zebra and quagga mussels establish here, it's conservatively estimated that it will cost \$43M to British Columbians, and \$500M to the Pacific Northwest Economic Region to deal with the impacts. These numbers surely do not represent the social and cultural losses should invasive mussels impact Pacific salmon stocks. In light of our concern, together in 2018 the SWC and CSISS expanded their programs to include increased regional education, outreach, and monitoring for zebra and quagga mussels in the Shuswap. Both organizations worked closely to deliver these programs within the Shuswap watershed, using a variety of communication mediums, in-person boat launch outreach, marina outreach, lake monitoring, and advocating for policy changes at the federal and provincial level. The objective of the presentation at ICAIS is to share the successes and challenges of their collaborative, regional, on-the-ground aquatic invasive species prevention strategies for zebra quagga mussels.

Testing the Use of Metaphor and Message Framing on Audience Engagement with Advertising to Prevent the Spread of Aquatic Invasive Species

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The prevention of aquatic invasive species (AIS) to reduce societal and environmental impact requires strategic outreach informed by social science. One idea that is relevant to strategic outreach designed to prevent the spread of AIS is message framing, which relates to how the composition of a message influences how individuals process and respond to a message by making certain parts of an idea more salient.

Using a paid messaging test on Facebook focused on learning more about preventing the spread of zebra mussels, this study compared five commonly used message frames and metaphors to determine which frames people were most likely to click on to learn more and to engage with in terms of reactions, comments, sharing and page likes. We targeted people who had shown previous interest in boating or fishing. The five message frames and metaphors tested included: 1) Militaristic; 2) Nativist; 3) Hitchhiker 4) Protective; 5) Science. Art and textual framing were combined to capture the essence of the message frame.

More than 270,000 people were reached by our social media advertising message test. Science was the most cost-effective frame in terms of cost per click, though other frames elicited more engagement in the form of comments, page likes, shares and reactions. The Militaristic and Nativist frames generated more comments, page likes, and reactions, but not all of the engagement these frames received was deemed constructive. The Hitchhiker frame was more likely to be shared. Differences between men and women existed for most of the tracked engagement metrics.

We believe these results suggest that different message frames lead to different audience outcomes, and that more intentional use of metaphor can help lead to behaviors that help prevent the spread of AIS.

The Eurasian Tench (*Tinca tinca*): A Globally Invasive Fish Arrives in the Great Lakes

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A globally invasive Eurasian fish, the Tench (*Tinca tinca*), is spreading through the St. Lawrence River and poses an imminent invasion threat to the Great Lakes. The species was introduced to a tributary of the St. Lawrence River in the early 1990s. In recent years, it has rapidly expanded its abundance and distribution in the river, spreading toward Lake Ontario. Monitoring surveys in the St. Lawrence River indicate that at sites with favourable habitat Tench abundance is growing exponentially. In September 2018, the species was detected in Lake Ontario for the first time.

The Tench is a generalist benthic consumer with largely undocumented ecological impacts in North America. Reports from other invaded regions indicate that it can compete with other benthic fishes, host a diverse assemblage of parasites and pathogens, degrade water clarity in shallow lakes, limit submerged macrophyte growth, reduce gastropod populations, and promote benthic algal growth through top-down effects. There are several potential pathways of spread of Tench into the Great Lakes: intentional introduction by anglers, illegal stocking of farm ponds within drainage areas, accidental introduction through baitfish release, live fish trade including accidental releases en route to food markets, and natural dispersal from sites where Tench are at elevated densities. Risk assessments and climate-match models indicate that the Great Lakes are vulnerable to Tench invasion. They signal the need for immediate comprehensive actions such as monitoring and rapid-response protocols – including the prevention or slowing of the Tench's natural dispersal through canals.

Population Dynamics and Distribution of Tench (*Tinca tinca*) in the St. Lawrence River: Managing a Problematic Invader

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Eurasian Tench (*Tinca tinca*) is an invasive freshwater fish that is undergoing a rapid population expansion in the St. Lawrence River (SLR). Introduced to Quebec through the release of live fish into the Richelieu River watershed, it established self-sustaining populations throughout the SLR and Lake Champlain and has recently been reported in Ontario. Tench is a highly opportunistic fish, which may reduce biodiversity, while simultaneously increasing inorganic nitrogen cycling and sediment resuspension, thus compromising water quality and submerged macrophyte beds. A potential competitor with native cyprinids for food and space, it is of additional concern in Quebec, where it may adversely affect the endangered Copper Redhorse (*Moxostoma hubbsi*). Despite confirmed establishment, little is known about SLR Tench populations, aside from increases in reported catches by fisherman. As successful mitigation and management of aquatic invasive species requires a clear understanding of establishment, distribution and spread, this study aims to elucidate the scale of the SLR Tench invasion and, if possible, provide a mitigation strategy based on fishery exploitation models.

The population dynamics (abundance, size and structure) of Tench at multiple sites in the St. Lawrence and Richelieu rivers were investigated using fyke nets, beach seines and electrofishing. Behaviour, distribution, and movement patterns, and its capacity to use locks as pathways of introduction, were investigated using acoustic telemetry (150 adult fish tagged over 2 years). Preliminary results on both population characteristics and movement via telemetry will be presented and considered for the development of exploitation models to provoke a fishery-induced collapse of Tench in Canadian waters. Results from this project aim to elucidate the scale of invasion, inform mitigation strategies, and improve management and control techniques of Tench in the St. Lawrence ecosystem.

Habitat Utilization and Recruitment Sources of Eurasian Tench in the St. Lawrence River by Otolith Microchemistry

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Quantification of trace elements incorporated within fish calcium carbonate hard structures (i.e., scales, vertebrae or otoliths) are increasingly used to investigate life-history and population dynamics and recruitment. Otolith microchemistry is commonly used to study migratory fish species of high economic and social importance. However, it represents also a promising tool for assessment of dynamics of invasive fish species. We evaluated the use of otolith microchemistry for life-history assessment of a growing, wide-spread invader of the St. Lawrence River; the Eurasian Tench (*Tinca tinca*). Trace element concentration along otolith growth axis were acquired using laser-ablation inductively-coupled plasma mass spectrometry (LA-ICP-MS).

Elemental fingerprint of otoliths' edge varied substantially among broad St. Lawrence River water masses along a 150 km portion of the river (north-south and upstream-downstream gradients). Tench showed important seasonal movement between different habitats (i.e., water masses). Otoliths' core microchemistry, which is indicative of spawning sites, showed several distinct elemental fingerprints, including some exhibiting high Sr values that were not detected in the otolith edges.

This study showed the potential of using otolith microchemistry for assessing invasive fish dynamics. However, unidentified, atypical elemental fingerprints emphasized the importance of an extensive characterization of trace element concentrations along the St. Lawrence River and its tributaries. Other potential applications and upcoming research will be discussed.

Zebra Mussels in Lake Winnipeg: Elucidating Invasion Pathways using Population Genetics

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Zebra mussels are listed as one of the world's 100 worst invasive species. They cause economic harm by fouling manmade structures and significant ecological changes by out-competing other species for space and resources. Zebra mussels first arrived in North America via the Laurentian Great Lakes in the mid-1980s. Since then, they have spread steadily outward and can now be found in 20 US States, and three Canadian provinces. In 2013, the zebra mussel was first reported in the southern basin of Lake Winnipeg, Manitoba. Potential sources of introduction to Lake Winnipeg include veliger advection down the Red River, or overland transport on/in boats of veligers or attached adults from the United States or Ontario, Canada. However, the true source of the invasion is unknown. To differentiate among these invasion sources, we sampled adult zebra mussels at 22 locations, including the Red River, Lake Superior and Lake Michigan, and inland lakes in Minnesota, Wisconsin, and Ontario. We are currently using population genetic analyses based on 14 microsatellite markers to differentiate among these potential source populations and to better understand the invasion pathway to this large and important lake system. Because zebra mussels (like many other invaders) often cannot be controlled once populations are established, understanding the invasion pathways of previous invasions may help to identify risk factors for future invasions. Prevention of invasions is likely our best hope of avoiding the spread of both ecological and economic harm that accompanies these unwelcome but wildly successful species.

Eradication of Invasive Roach (*Rutilus rutilus*). Rotenone Distribution and Degradation in Three Norwegian Lakes

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Roach (*Rutilus rutilus*) is an alien species in middle and northern parts of Norway. Roach has a great potential to alter the ecosystem when introduced to new locations. Dense roach populations will result in significantly reduced zooplankton community and contribute to increased circulation of organic matter. This results in larger phytoplankton biomass, with reduced light penetration in the water masses and increased oxygen consumption.

In Trondheim municipality, the third largest city in Norway, roach was introduced in 1881. The further spread to other lakes in the area occurred in the 1970s and 1980s, and in the past 20 years, increasingly to lakes outside the municipality. This has led the roach to the doorstep of the city's drinking water supply. In fear of poorer water quality, Trondheim municipality applied for permission to remove the blacklisted roach using the rotenone formulation CFT-Legumine.

The treatment area consisted of seven lakes with a surface area of 5-11.1 hectares. Maximum depth ranged from nine to 16 meters. In order to ensure a homogenous mix of rotenone and water, the rotenone was distributed throughout the water in accordance with the amount of water in different depth layers. Olex software, combining an echosounder and GPS was used to control the placement of a perforated submerged hose distributing the rotenone. In addition, rotenone was distributed on the surfaced and on the lake banks using powerful boat mounted pumps. The treatment was performed in September 2016 and no roach has been detected in biodiversity survey after the treatment.

A rotenone-monitoring program was performed, and in three of the lakes, the rotenone concentration was monitored at different depths from completed distribution until below detection limit. A description and discussion of these results will be given.

Glyphosate Effects and Accumulation in Wetland Macrophytes Grown in Outdoor Microcosms

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Glyphosate-based herbicides provide one effective option for controlling invasive plants in wetlands, but glyphosate is toxic to all plants. Land managers therefore must weigh the benefits of glyphosate-based management of invasive plants against the risk to nearby non-target plants. This decision requires an understanding of variation in glyphosate sensitivity and bioaccumulation in target and non-target plants. We assessed glyphosate effects and accumulation in two invasive macrophytes commonly targeted by chemical control, *Phragmites australis* (Cav.) Trin. ex Steud. and *Typha x glauca* Godr., compared to a native plant of similar growth, *Typha latifolia* L., in an experimental outdoor microcosm concentration-response study. Plants were sprayed with a range of glyphosate concentrations (0.1 – 8% solutions of the formulated product, corresponding to 0.5 – 43.2 g/L glyphosate) that included the currently used rate (5% solution, 27 g/L glyphosate). Macrophytes sprayed with 5% and 8% glyphosate solutions were harvested 27-days post-exposure to quantify glyphosate and AMPA (degradation product) concentrations retained in above-ground plant tissues. Invasive *P. australis* exhibited higher glyphosate sensitivity and accumulated more glyphosate and AMPA in above-ground tissues than both of the *Typha* taxa. Invasive *T. x glauca* and native *T. latifolia* showed similar glyphosate sensitivity and accumulation to one another, although individual sensitivity varied within both taxa. Our results illustrate that glyphosate sensitivity and retention varies even among and within structurally similar plant taxa. Understanding this variation can improve the accuracy of predicted responses of emergent wetland plants to glyphosate. These predictions can inform wetland management plans that effectively reduce invasive plants while minimizing risks to non-target plants. Additionally, glyphosate accumulation in above-ground plant tissues suggests managers may consider removing treated macrophytes to eliminate the possibility that glyphosate leaching out of decaying tissues will impact native biota.

The Distribution and Impact of *Eccritotarsus catarinensis* and *Eccritotarsus eichhorniae* on Water Hyacinth in South Africa

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Water hyacinth is the most problematic aquatic weed in South Africa and has been a target for biological control since the 1970s. To date, nine species of natural enemies have been released against water hyacinth in South Africa. Amongst these are two morphologically similar species of mirid from the genus *Eccritotarsus*, which were collected in geographically separate localities in South America, one from Brazil [*Eccritotarsus catarinensis* (Carvalho) (Heteroptera: Miridae)] and the other from Peru [*E. eichhorniae* (Henry)]. The latter was imported into South Africa to increase the genetic diversity of *E. catarinensis* as it was assumed to be the same species, until recently when it was found to be a reproductively isolated cryptic species. This study aimed to investigate the distribution of these two species, and their efficacy on water hyacinth in the field. Nationwide field surveys were conducted to ascertain the current distribution the two species of mirid on water hyacinth. The surveys showed that the mirids are established in six of the nine provinces of South Africa. Because the species are cryptic, molecular analysis was used to identify each species in order to map their current distribution across South Africa. There was significantly more insect damage caused by *E. catarinensis* in Gauteng compared to *E. eichhorniae* in the Eastern Cape, KwaZulu-Natal and Western Cape (Kruskal-Wallis: $H_{(4)} = 20.215$, $P < 0.001$). Although cumulative plant biomass was similar across provinces (ANOVA: $F_{(4, 28)} = 1.011$, $P = 0.419$), sites in KwaZulu-Natal and Western Cape recorded significantly less biomass compared to sites in other provinces (ANOVA: $F_{(10, 22)} = 4.623$, $P < 0.01$). In KwaZulu-Natal, plants produced significantly more ramets (Kruskal-Wallis: $H_{(4)} = 27.827$, $P < 0.0001$), showing a higher reproductive output. This study will therefore help make informed decisions towards future releases of the two species in South Africa to achieve the desired level of control of water hyacinth.

Fighting an Invasive Fish Parasite in Complex Subarctic Norwegian Rivers. The End of a Long Story?

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The introduced salmon fluke *Gyrodactylus salaris* has almost eradicated the Atlantic salmon populations in the Skibotn and Signaldalen Rivers in northern Norway. The parasite was introduced to the Skibotn River in 1976, probably by a truck-transport of infested salmon smolts from Sweden.

G. salaris survives maximum a few days without its host. Rotenone treatments are performed to eradicate all hosts in the river systems. After two failed eradication attempts in 1988 and 1995, the parasite spread further to the neighboring Signaldal and Kitdal Rivers, probably by infested fish migrating in the brackish surface waters of the fjord. This, along with several other failed rotenone treatments in Norway resulted in severe criticism of the national eradication strategy of *G. salaris*. Instead of terminating the eradication program, new scientific programs on the parasite and hosts were founded and the failed attempts were analyzed to find possible improvements.

Arctic char has proved to be a long-term host for the parasite, and its use of small, groundwater-fed tributaries was possibly a reason for host and parasite survival through the first two eradication attempts in the Skibotn River. Underestimating the dilution effect of groundwater intrusion, combined with too low maximum rotenone concentrations allowed by the pollution control authorities might also be the reason.

A third attempt of eradicating the parasite from the region was made in 2015 and 2016, making use of new knowledge about the parasite and its hosts, renewed strategies to deal with dilution from groundwater intrusion, and an acceptance to use sufficient concentrations of rotenone.

The rivers of the region are still under surveillance and not yet declared free from the parasite, but this story along with recent successful eradications of *G. salaris* in other regions of Norway shows the potential in large-scale measures if based on science, experience and determination.

Using Knowledge Surveys to Inform Education and Outreach Initiatives on Asian Carps in Canada

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Invasive species threaten Canada's terrestrial and aquatic ecosystems, economy, and society. Prevention and early detection are key to protect our ecosystems however, lack of public awareness often contributes to invasive species spread through human facilitated pathways. To understand the current state of public knowledge and awareness of invasive species, the Invasive Species Centre, in partnership with Fisheries and Oceans Canada, conducts digital knowledge surveys with the Canadian public. In Ontario, we first conducted a baseline survey in 2015 to gauge public invasive species knowledge, with a specific focus on Asian carps. This was followed by a 2017 follow-up survey to determine if perceptions had changed after two years of active outreach programs. Sample results indicate a 25% increase in Ontarians who believe Asian carps are present in Lake Erie, and a 6.5% increase in Ontarians who believe Canada should be spending more on prevention efforts. This presentation will review the results of each survey and discuss how this information is being used to inform the Asian Carp Canada outreach program.

Using Mock Scenarios to Improve Rapid Response in Pennsylvania

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When aquatic invasive species (AIS) prevention efforts fail, it is critical that a structure be in place to quickly and effectively address new infestations before they have an opportunity to establish and spread. The development of the Pennsylvania AIS rapid response plan was led by Pennsylvania Sea Grant and was approved by the Governor's Invasive Species Council of Pennsylvania in September, 2014. Since that time, the plan has been used to conduct mock exercises on species such as starry stonewort, Hydrilla, New Zealand mudsnail, and Didymo. Pennsylvania Sea Grant is a non-regulatory entity that has used these mock exercises as a tool to increase training on, and acceptance for rapid response efforts by state agencies in Pennsylvania. Mock exercises provide a platform for practicing each step in the rapid response process while identifying existing gaps and challenges, ensuring response actions are coordinated, prompt, and effective. Mock rapid response exercises provide benefits such as increasing general knowledge of the rapid response process, promoting communication and the interconnectedness of agencies, organizations, and stakeholders during the process, and preparing all entities involved for the roles they may play in an actual response. This presentation will provide an overview of the rapid response process in Pennsylvania and will highlight key recommendations and lessons learned from the mock exercises that have helped shape the current response framework. The information presented may be transferable to other regions to inform their own rapid response efforts and support the development of additional mock rapid response exercises.

Novel Educational Tools and Best Practices for Increasing Awareness and Knowledge on Prevention and Management of Invasive Alien Species

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Effective prevention, eradication and impact mitigation of Invasive Alien Species (IAS) requires sufficient knowledge on their pathways, effects and potential management options. Educational programs targeting students and professionals at different levels can be a great help in achieving this goal. However, the topic of IAS is not always part of school curricula and can be difficult to communicate to an audience with limited knowledge on concepts and principles from invasion biology. In the last ten years, several initiatives have started the important, but also challenging, task of teaching about IAS at different levels (e.g. elementary, secondary, vocational or university education). The aim of this presentation is to highlight examples of novel tools and methods used in IAS educational programs globally and to share best practices and lessons learned on how to address specific challenges in raising awareness about IAS. For this exercise, we draw on examples from Europe, North America and New Zealand including: AlterIAS (Belgium), ECOSIM and LINVEXO (The Netherlands), the Florida Invasive Plant Education Initiative & Curriculum (United States), Winning the War against Weeds and The Great Weeds Hunt Aotearoa (New Zealand), KORINA (Germany) and Invasoras.pt (Portugal). While these examples serve as a general source of inspiration for future developers of educational materials, we also critically reflect upon our experiences during the development, implementation and evaluation of different tools and teaching materials.

An Assessment of the Buddhist Practice of Life Release in the Mississippi River Basin

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The Buddhist practice of life release consists of freeing animals condemned to die in order to obtain merit. While it is known invasion pathway in some Asian counties, little is known about the status of this practice in the United States. With funding from the Mississippi River Basin Aquatic Nuisance Species Panel, we interviewed Buddhists within the Mississippi River Basin who have practiced life release. These interviews, along with the results of a Chinese and English language literature review, allowed us to develop a better understanding when the practice occurs, what organisms are released, what the motivations behind the practice are, and how these communities would welcome engagement from natural resource managers.

Additionally, we surveyed natural resources managers across the United States to determine what practices that meet the intent of life release they would be comfortable with, and to learn more on how they think they could engage life release practitioners.

Using the combined results, we will recommend an engagement strategy that can help life release practitioners meet the intent of their practice while minimizing the risk of aquatic invasive species introduction.

Characterizing the Distribution Network of Aquatic Species-in-Trade: Towards a Pathway-level Risk Assessment

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Thousands of live aquatic organisms are imported to Canada each year through the aquarium, water garden, and live food trades. While most of these species remain in captivity or are consumed, some are deliberately or unintentionally released into Canadian aquatic ecosystems by end users (i.e. aquarists, hobbyists, and live food consumers). Some species-in-trade (e.g. Goldfish, *Carassius auratus*) have established in Canadian ecosystems with significant negative ecological impacts. Consequently, screening-level risk assessments have been conducted to evaluate the invasion risk posed by live organisms imported to Canada. However, significant uncertainties remain about the scope and scale of species-in-trade distribution networks, including: 1) the spatial distribution of primary entry points, distribution hubs, retailers, and end users; and, 2) the connections among network components. Movement and release behavior of end users is particularly poorly understood, confounding our ability to estimate propagule pressure of these pathways. We aim to address these knowledge gaps by characterizing the aquatic species-in-trade distribution network in Canada. Specifically, trade data and regression models will be used to estimate the number and spatial distribution of critical network components. Additionally, we will quantify the movement and release behavior of end users using questionnaire results. Preliminary results for the aquarium trade suggest that import volume, the number of network components, and self-reported release rates of live organisms varied by region. Observed spatial patterns may be related to the spatial variation in human population density where imports and releases are higher in urban areas, reflecting purchase demand. Characterizing network components will allow spatially explicit, statistical estimates of propagule pressure to be developed for each pathway in future studies. Results of the pathway-level risk assessment will inform management and policy at regional and national levels by identifying key control points, establishing communication strategies for high-risk components, developing monitoring programs, and informing future research priorities.

Freshwater Snails and Mussels for Sale: The Ornamental Pet Trade as Pathway for Introduction of Invasive Alien Molluscs

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The ornamental pet trade is one of the major pathways for unintentional and deliberate introduction of invasive alien species. Especially introduction of invasive freshwater molluscs can have profound ecological and socioeconomic effects when unintentionally or deliberately introduced into the wild and are widely sold in the Dutch ornamental trade. Though, quantitative data regarding the species being sold is lacking limiting monitoring and prevention efforts. Therefore, the risks of alien freshwater molluscs in the Dutch aquarium and ornamental pond trade were assessed. Species inventories were made for 35 regular retail stores and/or webshops. Based on these inventories species accumulation curves (SACs) were derived to assess the representativeness of visited stores and completeness of the species list. Subsequently, risks of alien species were determined using two criteria: 1) the match between temperature tolerance of the species with the temperature ranges of aquatic ecosystems in the Atlantic bioregion of the European Union, and 2) ecological and socioeconomic risk classifications of species. In total 42 alien gastropod and 6 alien bivalve species were sold in the Netherlands. Webshops had more species for sale than regular retail stores. The SACs showed that the species list based on the visited stores gave a good indication of the available species in the ornamental trade. Of the 48 alien mollusc species 21 species were found to have a minimum temperature tolerance that matched the temperature ranges of aquatic ecosystems in the Atlantic bioregion. Eight of these species were assessed as being potentially invasive including two species that have not been reported as introduced. Information on risks was lacking for eight species revealing a knowledge gap that should be resolved. Implications of the outcomes of this study for risk management will be discussed.

Silent Invaders – Ornamental Fish as a Leading Invader of Australian Freshwaters

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As an island nation, Australia has been well protected from invasions of freshwater fish that have plagued other parts of the world. With a suite of endemic fish species, 74 of these being threatened or endangered, invasion for some could push them to the brink. With an estimated population of 8.7 million pet fish and 1025 aquarium stores, Australia harbours a considerably large population of non-native species. Releases of a small number of these could lead to non-native ornamental species establishing and directly impacting our endemic fauna. Additionally, even the presence of a single non-native individual may impact native fish via the spread of disease and parasites.

A 2010 Australian government report indicated a critical vulnerability in our protection against ornamental fish, stating: “there is little understanding of what species are traded in Australia. Similarly, there is little understanding of the level of prohibited or noxious fish bred and traded within the industry”.

The presence of lists of permitted and inadmissible species do restrict the inflow of freshwater fish into Australia; however, our online monitoring on popular auction and sales groups has found unregulated and illegal trade of prohibited species, confirming government fears. Many species have also not been assessed for their invasive threat, and those that were initially identified as potentially harmful were deferred for further assessment due to their value to industries. Evidence of inadmissible species as pets is also acknowledged, furthering the need for an investigation of potential threats.

This lack of understanding of the threats from ornamental fish is a long-overdue issue in Australia the science community has failed to address. With their continued presence in our natural waterways, such as peacock bass and parasite-infested goldfish, now is the time to start investigating and discerning what risk the pet fish population holds for our aquatic ecosystems.

Horizon Scan of Invasive Alien Species – Predicting the Next Invasions for the Island of Ireland

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A Horizon scanning workshop for potential invasive alien species establishment on the island of Ireland was held in April 2017, using a consensus-based approach and involving experts on invasive species and biodiversity. The main aim of the workshop was to come up with an ordinated list of species most likely to arrive, establish and cause impacts to biodiversity in terrestrial, freshwater and marine biomes on the island of Ireland within the decade 2017-2027.

Freshwater species dominated the top ten species (six out of ten), with crayfish (*Pacifastacus leniusculus*) highlighted as the most likely species to arrive, establish and create impacts on biodiversity in Ireland's freshwater systems. The list of 40 included eighteen freshwater invaders, fifteen terrestrial IAS and seven marine species. Crustacean species (freshwater and marine) were taxonomically dominant (ten out of forty); this relates to multiple pathways of introduction, their ability to adapt as ecosystem engineers and the resulting high impacts on biodiversity.

This evidence-based list provides key information to the competent agencies in both jurisdictions to prioritise the prevention of the most likely invaders and fulfil commitments to their respective legislation and to the EU Regulation on Invasive Species (EU1143/2014). Particular consideration on managing pathways of arrival by introducing targeted biosecurity in both jurisdictions is vital to maintaining native biodiversity on the island of Ireland.

Utilizing an Adaptive Management Approach for Invasive Species Management: Lessons Learned from Implementing the Phragmites Adaptive Management Framework

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Effectively managing invasive species is a significant challenge that requires constant learning and adaptation, as well as meaningful engagement of the management community. Non-native *Phragmites australis* is a serious invader that has colonized over 60,000 acres of Great Lakes coastline and many inland areas. Control efforts are widespread, yet effectiveness may vary due to infestation level, application methods, environmental conditions, and other factors. A survey distributed by the Great Lakes *Phragmites Collaborative* (<https://www.greatlakesphragmites.net/>) identified the need for standardized monitoring protocols, decision support tools, and a central repository of *Phragmites* management data to improve control efficacy. Thus, the *Phragmites* Adaptive Management Framework (PAMF) was developed as a program designed to reduce uncertainty in *Phragmites* control using adaptive management. Through a systematic approach, PAMF partners with *Phragmites* managers across the basin to refine best management practices and provide site-specific management guidance. More than 300 acres of *Phragmites* across four states and one province were enrolled in PAMF in 2018. The program is supported by a core team that provides administrative support to participants whose involvement in data collection is critical in driving this collective learning process. This presentation will focus on benefits and lessons learned from implementing an adaptive management approach to invasive *Phragmites* management.

Developing Practical Biosecurity Recommendations for the use of High-Pressure Hot Water Spray Machines

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The primary introduction and secondary spread of invasive alien species (IAS) in the environment is of growing global concern. Prevention is considered the most cost-effective way of managing these environmental, economic and social threats, and biosecurity is a key part of prevention. An array of vectors have been identified that in the absence of adequate biosecurity measures pose a risk of spreading IAS. To reduce IAS spread, national biosecurity guidance(s) (e.g. in USA and UK) recommend cleaning small equipment (e.g. nets) by submersion in hot water. However, research on the effectiveness of protocols suitable for large equipment (e.g. boats and vehicles) is somewhat limited and needs to be developed to improve national biosecurity guidance. High-pressure hot water spray machines are widely used to clean equipment, yet specific guidelines with known effectiveness to remove and/or kill a range of IAS are lacking. This study tests the effectiveness of high-pressure hot water spray machines (1600PSI) to induce mortality in two invasive aquatic plants: floating pennywort (*Hydrocotyle ranunculoides*) and Australian swamp-stonecrop (*Crassula helmsii*); and two invasive invertebrates: killer shrimp (*Dikerogammarus villosus*) and zebra mussel (*Dreissena polymorpha*) in field conditions. We exposed organisms to 90°C spray for three exposure durations (5, 10 and 15 seconds) applied from three distances (10, 20 and 30cm) measured mortality at four time-points following exposure. Water temperature was programmed into the machine (90°C) and measured on contact every second using a fast-reacting probe. As expected, shorter distances and longer spray exposures resulted in higher mortality of organisms with clear differences in species survival to treatments. We present biosecurity recommendations for hot water spray protocols that take into account effectiveness as well as health and safety and time constraints.

The Use of TAED Derived Peracetic Acid as a Novel Agent for the Control of Zebra Mussels

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TAED (tetra acetyl ethylenediamine) is a bleach activator that has been used extensively in domestic applications such as laundry detergent powders and automatic dishwasher formulations for well over 20 years. It reacts with a source of hydrogen peroxide in solution to produce peracetic acid, and as such provides a means of generating a powerful disinfecting agent in situ. TAED is safe to store, transport and handle, even in hot weather. TAED is also non-toxic and non-sensitising and degrades to water, carbon dioxide, nitrate and ammonia.

The biocidal properties of peracetic acid generated from TAED have been investigated for the ability to control *Dreissena polymorpha* (zebra mussel) at different life stages. PAA is a disinfectant that, once in water, degrades quickly to form acetic acid which has a low toxicity to most organisms, with final by-products of water and oxygen. Therefore, this chemistry has exciting potential to be used in industrial facilities to tackle invasive zebra and quagga mussels.

Research has been conducted on the use of TAED as a method of control of zebra mussels in lake water from Lough Arrow, Ireland. Initial results indicate:

- At 20°C, the LC90 (8 hours) of peracetic acid derived from TAED in adult *Dreissena polymorpha* has been determined to be 60 ppm peracid.
- A treatment concentration of 20 ppm peracetic acid derived from TAED for 8 hours at 20°C resulted in a reduction in settlement of 97.8 % of veligers.
- In all 8-hour treatments, the residual concentration of peracetic acid in the water had fallen below 2 ppm within 48 hours.

Preventing Dreissenid Mussel Settlement in a Flow-Through System: Is Carbon Dioxide a Sustainable Option?

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Carbon dioxide (CO₂) is an advantageous alternative to currently registered molluscicides for control of dreissenid mussels due to low cost, lack of harmful chemical residues, and minimal risk to human health. Previous studies demonstrated the toxicity of CO₂ to adult zebra mussels in controlled laboratory trials; the next step is to determine CO₂ treatments that will prevent larval (veliger) settlement and biofouling in a semi-field setting. We conducted an experimental trial of continuous CO₂ infusion to determine its efficacy at two levels (~45 mg/L and 90 mg/L CO₂) for preventing settlement and inducing mortality of zebra mussels. A raw water intake system supplied veligers from a naturally-infested water body (Mississippi River) to a continuous flow-through test system housed in a mobile laboratory. Carbon dioxide treatments and a control were applied to four replicate tanks that discharged to effluent tanks from each treatment. Veliger density and juvenile mussel settlement were monitored from May through August in the source water, test tanks and effluent tanks. The effects of elevated CO₂ on water quality, algal and macroinvertebrate communities, native unionid mussel and macrophyte growth were also monitored. Preliminary results suggest that 45 mg/L of CO₂ was effective at preventing settlement of veligers in the test system. Additional information will be presented regarding CO₂ use and recapture in the system as well as community changes during the study period.

Great Lakes Aquatic Nonindigenous Species Gap Analysis

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The Great Lakes Aquatic Nonindigenous Species Information System (GLANSIS) is a robust inter-agency database funded by the Great Lakes Restoration Initiative featuring comprehensive information on identification, ecology, management, and distributions of aquatic nonindigenous species throughout the Great Lakes region. The system also includes impact assessments for established species and risk assessments for a set of more than 60 watch-list species. GLANSIS information holdings are based on comprehensive review of the scientific literature, agency reports and personal communications from regional experts. Our gap analysis looks at which types of information (taxa, geographic, vectors, risk components, etc.) are under-represented in the literature and in our holdings. With notable exceptions, distribution data is especially lacking for micro-organisms, particularly for parasites. Uncertainties associated with impact assessment (for both established and high risk species) are much higher for the environmental components of the assessments than for socio-economic components.

Community Science to Capture the Leading Edge of an Invasion: European Green Crab on Washington State's Inland Shorelines

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The ongoing spread of the globally-damaging invasive European green crab, *Carcinus maenas*, along the west coast of North America has been viewed with concern by managers. Though green crab has been present on the outer coast of Oregon, Washington, and British Columbia since the late 1990s, the Salish Sea might have distinct dynamics. Initial establishment of these inland waters was most likely human-mediated, as prevailing oceanographic conditions are not expected to favor import of larvae.

Following the detection, in 2012, of an established population of green crab in Sooke Basin, B.C., Washington Sea Grant (WSG) launched Crab Team, a volunteer-based monitoring program in 2015. Crab Team currently engages 250 volunteer, tribal, and agency monitors in surveying a network of 54 sites along Washington's inland shorelines. This multi-stakeholder approach has enabled a much broader scope of early detection than would otherwise be possible. In addition, close advisory partnerships with management entities, including tribes, US federal and state agencies, facilitate communication and coordination of response and assessment efforts.

Since 2016, 188 individual European green crab have been captured at five monitoring sites along Washington's inland shorelines, the majority at a single site. Based on size, these are believed to be initial colonizing individuals, arrived via larval dispersal in 2015 and/or 2016. Though most of these populations are not yet fully established, there is potential for rapid growth without intervention. Yet the low numbers and apparent isolation of current populations indicate that the invasion is still in its early stages, providing a unique opportunity for effective early intervention. While physical oceanographic modeling and genomic research are ongoing in an attempt to better understand the dispersal dynamics of green crab in the Salish Sea, continued monitoring efforts and cross boundary collaboration are imperative to protect ecosystems and natural resources.

Revisiting Classrooms and School Science Projects as Pathways for Invasive Species

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Ten years ago, a collaborative study was initiated across North America in the USA and Canada to assess classrooms and science projects as a critical pathway for the introduction of aquatic nuisance species. The study involving teachers, curriculum developers, biological supply companies and natural resources agencies revealed the broad extent of this previously neglected pathway and shed light on solutions that must also include a more nuanced understanding of the role of live organisms in classrooms.

The consequences of releasing invasive species from school activities are profound. For example, a corollary study revealed that over an ~ 10 year span since its first observation west of the USA continental divide, the rusty crayfish (*Orconectes rusticus*) in the John Day River Basin of Oregon Basin likely established due to releases from a nearby school, have dispersed and impacted the ecology over 200km downstream. This session reviews and sheds new findings, revisits solutions in context of better understanding the human and learning dimensions of live organisms in classrooms. We highlight model cases of collaboration implementing findings and lessons learned with biological supply companies, curriculum developers, educators, zoos/aquariums and managers/policy makers taking action to mitigate this pathway. Although much progress has been made understanding the “schools” pathway, we conclude with key lessons learned ten years hence and considerations for more effective avenues moving forward institutionalizing awareness and prevention of the schools pathway.

Crises and Risks: the *Sargassum* Invasion in the Caribbean Islands

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On most Caribbean and Mexican Gulf shores, species of brown pelagic seaweeds, *Sargassum fluitans* and *Sargassum natans*, have been massively and irregularly washing ashore since 2011. They come from off the coast of Brazil and of West Africa and form an Atlantic sargassum belt. Due to their decomposition on the intertidal zones and the emanation of hydrogen sulfide (H₂S) and ammonia (NH₃), these seaweeds are causing not only sanitation and ecological issues, but also economical, political and social problems. In the French Caribbean islands, we can notice a number of diverging perceptions and speeches aiming at thinking, categorizing, building and overcoming these crises. The postcolonial, historical and geographical overseas context partly determines the position of social players in the public arena to tackle the biological invasion. The building and communication of expert and public knowledge on the potential risks of these crises are fuelled by controversies among (re)configurations of a variety of players in the local political life and civil society. The management of the crisis will be dealt with in two parts:

- (1) Discursive strategies of adaptation, appropriation and diversion develop among local communities, generally on the coast, in the creation of groups of citizen mobilizations. They play the role of watchdogs and whistle-blowers and usually look for allegations of liabilities. In response to the concerns of residents expressed in part on social networks.
- (2) The government is responding by describing it as “Sargassum crises”, “[a] plague”, and “a phenomenon that goes beyond us all,” (as Nicolas Hulot, the ex-French Minister of Ecology, put it in a speech, June 2018).

The conclusion of this presentation shows the representations of the crises and potential risks, including sanitation risks, and the emergence of a public problem with various actors and norms in interactions.

Effectiveness of EarthTec QZ®, a Copper-Based Product, for Adult and Larval Dreissenid Mussel Control

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The Great Lakes faced an unprecedented challenge in the late 1980s due to the introduction of invasive zebra and quagga mussels (dreissenids). Drinking water treatment plants were particularly affected because of the species' ability to attach to practically any surface, including water intake pipes, where they could restrict influent flow. Drinking water utilities counteracted this threat primarily through chlorination at the front of the intake pipes. Although inexpensive and effective, chlorine has disadvantages such as disinfection by-product (DBP) formation and chemical decay. The first is of concern as some DBPs are believed to be carcinogenic, while the second implies a requirement for an almost-continuous dosage to achieve control. EarthTec QZ®, a copper-based product, emerges as an alternative because of its ability to induce mortality to dreissenids via toxicity, while being persistent and avoiding chlorinated DBP formation.

Raw Lake Ontario water from a water treatment facility's sampling line was diverted towards a custom-built pilot system that continuously supplied fresh water to flow-through devices. Both adult and larval (veliger) individuals were exposed to varying concentrations of the product and tested in triplicate. Experiments on adults revealed that the product was effective for eradicating 100% of the individuals using 30 µg/L as copper after 28 days, with decreasing time when increasing doses, while 1 mg/L of total residual chlorine required 41 days to achieve 100% mortality. Veligers showed higher sensitivity than adults, exhibiting 55%, 84%, and 94% mortalities after 4, 4, and 6 days of exposure to 30, 60, and 120 µg/L as copper respectively; whereas adults did not reach even 10% mortality in the same period. Additionally, veliger behaviour was qualitatively assessed. Apparently, individuals showed no behavioural changes when exposed to the product, suggesting no changes in filtering activity, necessary for the product to cause intoxication.

Can a Small-bodied Non-native Fish Impact upon Native Fish Communities in Temperate Ponds?

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Introducing non-native fish can have adverse effects on native fish communities, but the substantive evidence is often limited. Assessing trophic relationships between species can provide great insight into the potential impacts of invasion on native species, which can be easily detected by stable isotope analysis (SIA). Here, trophic consequences of introducing a small-bodied cyprinid fish for the temperate fish communities were investigated. Sunbleak *Leuciscus delineatus* was chosen as a model non-native species due to its ability to integrate into native fish shoals and similarity in diet with young cyprinids. The field-based experiment was done in artificial ponds in southern England in summer 2015, and it consisted of three controls ponds with native fishes (rudd *Scardinius erythrophthalmus*, gudgeon *Gobio gobio*, tench *Tinca tinca*) and three treatment ponds with the same native community, but with the addition of *L. delineatus*. The stable isotope analysis of fish tissue samples revealed that isotopic niches (proxy for trophic niches) of native fishes were reduced in the presence of *L. delineatus*, but this did not affect their body sizes or conditions. This indicated that the response of native fishes to invasion was trophic specialisation, which allowed them to maintain their growth rates. The implications of these outcomes for invaded pond communities are discussed.

Natural and Anthropogenic Drivers Facilitate Invasion of Riparian areas by *Hedychium coronarium*

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Subtropical ecosystems are characterized by a lack of information on many introduced species. *Hedychium coronarium* (König) is an invasive plant widespread in the Atlantic Forest biome of Brazil, especially in riparian corridors. We aim at investigating whether natural and anthropogenic drivers facilitate the establishment of *H. coronarium*. We randomly chose 148 riparian sites – each containing two plots – in a subtropical basin and we recorded the presence/absence of the plant and local environmental variables; we extracted other variables using GIS software. We performed a GLMM with presence/absence as response variable, riparian site as a random factor and six predictors: a) proximity to urban area, b) local area's degradation, and c) type of surrounding vegetation, according to which the presence of trees -especially exotic ones - favors the invader; d) size of stream's substrate and f) Strahler's stream order, both of which had a positive relationship with the plant's presence probability. Our results point out to the influence of local human presence for the occurrence of *H. coronarium*, possibly due to competition removal, facilitation by other exotic plants and propagule supply; the latter is also possible through hydrochory, as shown by the greater presence probability in higher-order rivers. Disruptive action from a large substrate during floods can also create establishment opportunities for *H. coronarium*. If fine-scale assessments are not possible, management should focus on areas closer to urban centers, as they are more exposed to human disturbance.

Assessing Risk of Competition Between Invasive and Native Fishes: Eurasian Tench (*Tinca tinca*) Versus Redhorses (*Moxostoma* spp.)

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A globally invasive Eurasian cyprinid fish, the Tench (*Tinca tinca*), is increasing in abundance exponentially in the St. Lawrence River and will likely become established in the Great Lakes in the near future. The Tench is a generalist benthivore with a broad tolerance to environmental conditions including temperature. It occurs in calm shallow waters of lakes and large rivers, and feeds primarily on benthic macroinvertebrates. It overlaps in diet and habitat with several functionally-similar native species including a group of catostomid fishes, redhorses (*Moxostoma* spp.), which contain species-at-risk in Canada. To experimentally assess the potential for resource competition, we designed an array of 30 outdoor mesocosms containing Tench and Shorthead Redhorse (*Moxostoma macrolepidotum*). We will compare growth rates and glycogen levels of Shorthead Redhorse and Tench in conspecific and heterospecific treatments. In a pilot experiment conducted last summer, abnormally high mesocosm water temperature (>35°C) revealed a drastic difference in the survival rates of Silver Redhorse (*Moxostoma anisurum*) and Tench under natural thermal stress. All Silver Redhorse died during the episodic event, whereas no mortality or long-term loss of growth was observed for Tench. These results suggest a competitive advantage under climate warming that must be considered when interpreting the implications of resource competition between Tench and redhorses. Higher summer maximum temperatures might drive redhorses away from habitat tolerable to Tench.

Recent Aquatic Introductions in the United States

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Introductions of aquatic species continue to occur in water bodies of the United States. By definition, introductions primarily occur with the aid of human intervention as a species enters a water body for the first time. In general terms of introductions, these species are not native to the United States. If a population becomes established, secondary introductions of these species can occur as either natural range extensions or again through human-aided overland transport into previously uninhabited locations. At the same time, many introductions in the United States are intracontinental where indigenous species are moved within the country's borders but beyond their natural ranges. Over the past five years, nearly forty foreign or native transplanted species have been introduced for the first time within the United States that include fishes, reptiles, mollusks, crustaceans, annelids, and plants. Continents of origin of foreign species newly introduced include Africa, Asia, Eurasia, South America as well as marine waters of the Indo-Pacific region. Species of concern currently present and established in the United States that continue to extend their ranges are represented by several carp species, round goby, northern snakehead, zebra and quagga mussels, Asian clam, rusty crayfish, curly-leaf pondweed, Eurasian watermilfoil, and flowering rush.

Invasion Genomics of the Next Great Lakes Invader Fish Species, Eurasian Tench (*Tinca tinca*)

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Understanding how introduced species can successfully establish and spread in novel environments is critical to prevent biological invasions and reduce their impacts. We propose to use genomic approaches to evaluate the colonization dynamics of the Eurasian Tench (*Tinca tinca*), a globally invasive fish species that has spread throughout the St Lawrence River since its introduction in 1991 and is now threatening to invade the Great Lakes. Specifically, we will use restriction site-associated DNA sequencing (RAD-seq), phenotypic, and environmental data to characterize population structure, compare patterns of genomic and phenotypic variation across the distribution, and assess putative footprints of selection along an environmental gradient. Preliminary *col* haplotype data indicate that existing North American invasive populations were founded by individuals drawn from two European clades (i.e. Eastern and Western). We anticipate that our analyses will inform management policies by revealing demographic, ecological, and evolutionary processes facilitating invasion, as well as population structure and gene flow for this invasive species.

State of Maine Lake Vulnerability to Invasive Aquatic Plants: A Lake Vulnerability Analysis and Predictive Model

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The first version of the Lake Vulnerability Analysis to Invasive Aquatic Plants was developed in 2004 by the Maine Department of Environmental Protection (DEP) and the Maine Natural Areas Program. The purpose of this analysis was to assess the risk to Maine lakes of infestation by invasive aquatic plants. Geographic Information System (GIS) analysis was used to assign each lake a risk score using nine parameters grouped into three categories: volume of use, proximity to infested waters, and potential for colonization. A 2017 update to this analysis included up-to-date data and statistical evaluation on each parameter used. Lakes were categorized as high, moderate and low risk based on score. In total, data from 2,664 Maine lakes of 10 acres or larger were used in the analysis.

In addition to the Lake Vulnerability Analysis, Maine DEP developed a statistical model to predict the probability of a lake being infested with an invasive aquatic plant. The model provides an additional tool to assess a lake's risk to invasive aquatic plants. The model accurately predicted 85% of Maine's known aquatic plant infestations.

When comparing the model results with the lake vulnerability scores. We found that a significant number of model lakes also had high risk scores. Analyzing a lake's risk of colonization by invasive aquatic plants allows the Maine DEP and its partners to effectively use limited resources to protect lakes and target those at highest risk and needing additional evaluation.

Variation in Legislative Powers Related to Aquatic Invasive Species in Canada

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Canadian legislation related to aquatic invasive species varies by federal, provincial and territorial jurisdiction. Understanding this variation is important to better national coordination and management of aquatic invasive species.

We inventoried and compared the laws and regulations of each jurisdiction that target aquatic invasive species according to 23 categories related to prohibitions and enabling actions. We interviewed representatives from the various jurisdictions to validate our findings. This poster will illustrate the similarities and differences, and outline gaps among the jurisdictions.

In general, we found that all provinces, territories, and the federal government have legislation that address most of the categories, although some jurisdictions (e.g., Ontario, Manitoba, and Parks Canada Agency) currently have more comprehensive legal authorities than others (e.g., Nova Scotia, PEI, and the three territories). Provinces and territories with fewer provisions targeting aquatic invasive species rely more on federal legislation. Potential areas for legislative improvement include: inter-provincial movement of AIS; regulated lists of species; regulation of commerce; inclusion of plant species; and coordination with industry-based regulations (e.g., aquaculture).

Evaluating the Impact of a Removal Program for the Invasive European Green Crab (*Carcinus maenas*) in Placentia Bay, Newfoundland

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Populations of invasive green crab have become established on much of North America's east coast. By competing and preying on native species, green crabs significantly impact local biodiversity and habitats, including beds of bivalves and eelgrass beds. Green crabs were first observed in Newfoundland in North Harbor in 2007 and have since spread throughout Placentia Bay, damaging eelgrass beds and subsequently reducing local fish densities. A five-year removal program is aiming to reduce abundance of green crab in Placentia Bay. More than 150 metric tons of crabs were removed in the first two years and the average catch per unit of effort (CPUE) decreased from 2 to 1.09 kg/trap between 2017 and 2018. However, CPUE can be a biased measure of abundance trends due to being influenced by factors other than abundance. The objective of this research is to develop a generalized linear mixed model to standardize the CPUE of green crab in Placentia Bay. Temperature, depth, and salinity sensors were placed on traps to record environmental factors. This model will help inform on the efficacy of the green crab control fishery in Placentia Bay and the capacity of large efforts to control established populations of aquatic invasive species.

Potential Trophic Competition between Native and Non-Indigenous Bivalve Species: Complementary Approaches to Estimate Clearance Rates

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Clearance rates (CR) measurements are a crucial tool to assess the impacts of non-indigenous species on native species based on trophic competition, particularly on suspension-feeding bivalves. Although there are several studies measuring CR on bivalves, most of them focus only one species and/or technique, hampering comparisons and interpretations. Furthermore, environmental parameters such as water temperature, salinity and concentration of particulate matter can greatly influence CR. This study aimed at using a pioneer complementary approach to determine the CR of three bivalve species: the non-indigenous Manila clam (*Ruditapes philippinarum*) and the native Portuguese oyster (*Magallana angulata*) and cockle (*Cerastoderma glaucum*). The experiment was performed *in situ* at the Sado estuary, by using two methods: the clearance method and the biodeposition method. The first method consisted on the use of two different techniques: (1) a chlorophyll fluorometer, to estimate the phytoplankton biomass reduction and (2) a particle counter system, to determine the number of particles in suspension. Additionally, during these experiments the valve-gaping of each individual was also measured using valvometry sensors, in order to verify if there is a direct relationship between valve-gaping and CR. The second method consisted on comparing the Total Particulate Matter (TPM) and the Particulate Organic Matter (POM) of the seawater with the TPM and the POM of faeces and pseudo-faeces deposited by the organisms. Water temperature and salinity were recorded during the experiment. Preliminary results indicated that different CR were obtained for different species, highlighting the importance of determining the carrying capacity of aquatic systems before expanding aquaculture activities, particularly when non-indigenous bivalve species are introduced for production. Results obtained with the different methods also indicated that the use of complementary techniques for CR measurements is a promising approach, providing cumulative information on potential trophic overlap between native and non-indigenous species.

The Microalgae *Didymosphenia geminata* in Southern Hemisphere: Elucidating Potential Invasion Pathways by Population Genetics Analysis

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Microalgae are one of the most abundant microorganisms in aquatic systems, and several works have shown that invasive microalgae may be highly recurrent in aquatic environments producing in some cases intense blooms with significant impact on biodiversity and economic activities. In contrast to expectations, recent research using molecular techniques, suggest that microalgae have limited dispersal capacities. In this context, the ongoing invasions of aquatic microorganisms offer not only a big challenge, but also the opportunity to explore ecological, genetics and evolutionary questions that are favoring invasion success. Among invaders of freshwater ecosystems, *Didymosphenia geminata*, commonly named "Rock snot" is an invasive freshwater benthic diatom native to rivers of the circumboreal region of the Northern Hemisphere. The species has been able to establish in rivers and lakes of North America, Europe, and Asia, as well as the Southern Hemisphere. In the Southern Hemisphere, Didymo was first detected in New Zealand and more recently, it has been found in Argentina and Chile. The invasion of Didymo in the Southern Hemisphere has been characterized as one of the most aggressive with potentially severe ecological and economic impacts because of the rate of expansion and the number of rivers affected. Here we present a global spatial analysis of the genetic diversity in *D. geminata* populations around the world in order to determine if the evolutionary lineages (i.e. metapopulation lineages through time) of *D. geminata* collected from Chilean rivers are independent of Didymo from other geographic regions of the world. The results show evidence of two highly differentiated genetic lineages of *D. geminata* around the world and suggest that the expansion to the southern hemisphere occur from North America. Fondecyt 1170591.

Distribution and Abundance of Invasive Octocoral *Carijoa riisei* in Ecuadorian Coast

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This study reports the distribution and abundance of the invasive octocoral *Carijoa riisei* (Alcyonacea: Clavulariidae) in Ecuadorian continental coast. *C. riisei* is native from the Indo-Pacific region where it is an aggressive competitor. One of the major effects is the monopolization of resources (food and the space). The identification of the specie was confirmed genetically. Distribution and abundance of *C. riisei* was measured over quadrants located randomly at a 50 m transect positioned parallel to the coast in subtidal zone. *Carijoa* was found between February 2015 to February 2016 in three coastal provinces (Esmeraldas, Manabí and Santa Elena), including two marine protected areas (Galera San Francisco Marine Reserve in the north of Ecuador and El Pelado Marine Reserve in South Central Ecuadorian coast) and one area influenced by estuarine ecosystems (Jama). The highest relative abundance of *Carijoa* colonies were found in Jama (44.57%). This octocoral was found as an epibiont on corals (e.g. *Pocillopora damicornis*) and other macroinvertebrates (i.e. *Pinctada mazatlanica*, *Muricea appresa*, and *Aplysina* sp.). Our investigation suggests that *Carijoa riisei* is in advanced status from colonization in the coastal area and it is an imminent danger for autochthonous autochthonous sessile macroinvertebrates biodiversity and even greater risk for the Galapagos Islands.

Using Aquatic Invasive Species as Biomonitors of Microplastic Pollution

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Despite burgeoning research efforts, scientists still strive to obtain a clear understanding of the abundance, distribution and fate of microplastics in freshwater environments. Current technology does not facilitate efficient sampling of copious amounts of water and sediment sufficient to detect the presence of plastic particles of <300µm in size; consequently, a potentially enormous fraction of microplastics are omitted from estimates of contamination in aquatic systems. In addition, mapping microplastic distribution across aquatic systems requires exhaustive sampling and long hours in the laboratory for particle separation and analysis. Microplastics have been found to be ingested by organisms across all major taxa, some of which preferentially take up particles well below 300µm. Widely distributed aquatic animals adapted to consuming small particles could serve as valuable biomonitors of microplastic pollution.

We are examining a model trio of species that are abundant and widely distributed across the Great Lakes basin: the quagga mussel *Dreissena bugensis*, gammarid amphipods, and the round goby *Neogobius melanostomus*. We used these species to test the dose-dependent relationship in the uptake of microplastics via three environmental vectors: suspension in the water column, sedimentation, and transfer through consumption of prey. Animals were exposed to five concentrations of polyethylene microbeads (0.1 to 100 ml⁻¹) for 24-hrs, prior to being dissected and having the contents of their gastrointestinal tract examined to enumerate particles ingested at each concentration and from each vector. Dose-relationships differed between species. Our experiments demonstrate that *D. bugensis* can serve as a biomonitor of microplastic pollution, and the use of food web modules can offer new insights into the extent and impact of microplastic contamination in aquatic ecosystems. Furthermore, results show that this model trio of trophically interacting species can facilitate the transfer of microplastics through food chains, indicating another potential ecological consequence of joint invasions by dreissenid mussels and the round goby.

Dreissenids' Need for Speed

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Both the quagga mussel or *Dreissena rostriformis bugensis* (Andrusov, 1897) and the zebra mussel or *Dreissena polymorpha* (Pallas, 1771) are notorious for dominating hard freshwater substrates throughout most of the Northern hemisphere. There have been widespread observations of a dominance shift favouring *D. r. bugensis* where both Ponto-Caspian dreissenids co-occur. The mechanisms driving this shift are still largely unknown. The present study assessed the role of species mobility as a possible driver of the dominance shift from *D. polymorpha* to *D. r. bugensis*. Higher mobility may promote the avoidance of unfavourable environmental conditions such as low oxygen and desiccation during water level drawdown. To accomplish this, adult dreissenids may detach from substrates by removal of their byssus threads. The mobility of dreissenids was assessed during a mobility experiment. A total of 120 adult individuals of each dreissenid species were collected in the Rhine-Meuse river delta, the waterbody where *D. r. bugensis* was first recorded in Western Europe. The setup consisted of 4 polyethylene tanks containing 60-litre non-aerated fresh tap water, subdivided into 152 six by six cm squares and eight concentric circles, indicating the location of the dreissenids at any time. All individuals were marked with a unique number and were individually monitored on movement duration, distance, pattern and speed, and the effect of light and dark conditions on the dreissenids' mobility. On average, *D. r. bugensis* moved around for longer periods before settling than *D. polymorpha* individuals. During this mobility experiment, dreissenids were able to reach speeds of half a meter per hour. Our results suggest that *D. r. bugensis* are at a competitive benefit over *D. polymorpha* because of its higher mobility, possibly explaining the shift in dominance where both species co-occur.

Two-way Engagement with Stakeholders to Improve Biosecurity in the Workplace

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Biodiversity in Ireland, like the rest of the world, is threatened by Invasive Alien Species (IAS). Being an island means that our biodiversity is particularly vulnerable to this threat. However, islands also offer greater opportunities for protection from IAS than individual states in a continental land mass. Promoting good biosecurity and a strong sense of biosecure citizenship must become a priority among the various stakeholder groups whose activities risk facilitating the spread of IAS.

In April 2017, a daylong workshop took place at the Institute of Technology, Sligo. This workshop drew together a broad range of stakeholders, from state-sponsored competent authorities, to consultants, members of community groups and recreational water-users. The measureable outcomes from the workshop were a survey, repeated before and after the workshop, plus the collated outputs from an elicitation session. Rather than identifying any specific species, the emphasis for the workshop was on practicing good generic biosecurity. With a small amount of guidance towards reliable sources of information, participants still reported an increased confidence in identification skills. The most significant change after the workshop was in participants' confidence in designing good biosecurity plans and carrying out effective biosecurity measures in the field. 93.8% reported that their behaviour would change as a result of the workshop.

The facilitated elicitation process identified some of the existing obstacles to practicing good biosecurity in the workplace, drawn from participants' experience on the ground. During the elicitation process, extensive information was gathered in the form of a prioritised range of obstacles affecting participants' ability to engage in effective biosecurity, and a list of opportunities that these stakeholders perceived as open to promoting good biosecurity.

This information is now available to managers and policy-makers to inform future biosecurity measures on the island of Ireland, and is potentially transferrable to other jurisdictions.

Development of Molecular Approaches for the Monitoring of Marine Non-indigenous Species in Irish Waters: Supporting National Strategies and International Law

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In response to international law set to address issues related to Non-Indigenous Species (NIS), the Irish government has transposed EU regulations into national legislative instruments and strategies. However, the effectiveness of policy and management implementation depends on reliable and accessible data collected in a coordinated and systematic fashion. This is difficult to achieve using conventional monitoring approaches mostly due to time and resources constraints. This is particularly true in the marine environment, where knowledge gaps exist and baseline information can be limited to localized and/or few selected areas.

Thanks to recent technological advances, a suite of molecular tools is being developed and applied to aid monitoring of aquatic organisms. In particular, the ability to isolate nucleic acids from environmental samples (environmental DNA/RNA) followed by downstream molecular detection of target DNA sequence data has unlocked the possibility of implementing fast and cost-effective monitoring tools, such as highly sensitive quantitative and digital Polymerase Chain Reaction assays (qPCR/dPCR), and environmental DNA metabarcoding. However, limitations to the prompt implementation of such tools include the lack of comprehensive reference data as well as poor understanding of factors affecting distribution and persistence of nucleic acids in the marine environment.

This presentation will provide insights on the development and initial application of molecular approaches for the detection of NIS in a range of marine environments in high-priority sites around the Irish coast. In particular, this project aims to (i) establish a national reference database containing an inventory of information, including genetic data, of NIS that are present or could invade Irish marine waters; (ii) develop a molecular toolkit for systematic monitoring of marine NIS at a national scale; and (iii) generate maps and metadata to aid the implementation of national and international legislation in preventing the loss of native biodiversity and mitigating the impact of invasive marine species.

Interinstitutional and Scientific Networks to Prevent and Manage the Spread of Invasive Alien Species in the Corsican Wetlands

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The management of invasive alien species and the commitment to protect biodiversity in the Corsican Region has become more and more important over the course of time. Introduced species, when they are invasive, cause multiple impacts, direct or indirect, affecting native species, natural habitats and ecosystem services, but also economic activities and human health.

The Environmental Agency of Corsica conscious of the importance of this problematic and working for the protection and the conservation of the species and the natural spaces, has equipped itself with several networks: Network Alien Corsica (RAC) and Action to limit the spread of invasive species introduced into the Mediterranean (European Project – ALIEM). These networks were designed to (1) detected, document new invasions and assessed initial risk (2) sensitized to invasions through different tools and (3) provide the cross-institutional coordination needed to successfully implement regional management plans.

Our establishment, by way of the Regional Observatory of Wetlands of Corsica – ORZHC (one year of existence), works for the preservation and the restauration of wetlands in respect of their functionalities. In this observatory various topics are studied including IAS. Wetlands are transitional environments of great ecological richness that seem to be particularly sensitive to invasions. The presence of IAS in Corsican wetlands areas was assessed using a compilation of scientific publications and observations within the two networks; 145 species have been listed. Monitoring of IAS, performed by our two networks, provide a valuable opportunity for delving further into the knowledge of introduced species in this habitats.

However, apart these indispensable networks, a regional strategy must be developed (European Project – INVALIDIS). The drafting of specific action plans should be based outline specific proposals and on how to improve the policy instruments (e.g. regulations). It's the objective of INVALIDIS project to increase public administrations' capacity on IAS policies.

Context-dependent Differences in the Functional Responses of Conspecific Native and Non-native Crayfishes

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Experimentally derived estimates of per capita effects (e.g. functional responses) have been advocated as predictors of field impacts of potential invaders. However, risk assessments based on estimates from single populations can be misleading if *per capita* effects vary greatly across space and time. Here, we present a large-scale, multi-population comparison of *per capita* effects of the American spinycheek crayfish, *Faxonius (Orconectes) limosus* – a species with an extensive invasion history in eastern North America and Europe. Functional responses were measured on individuals from six geographically disparate populations of *F. limosus* in its native and invaded ranges on two continents. These revealed inter-population differences in both the maximum feeding rate and functional response type that could not be explained by the biogeographic origin of the population nor by time since invasion. We propose that other differences in source communities (including the presence of competitors) impose selective pressures for phenotypic traits that result in dissimilar *per capita* effects. We also compared functional responses of the congeners *F. limosus* and *F. virilis* in the presence and absence of potential competitors to examine indirect effects. The maximum feeding rate of *F. limosus*, but not *F. virilis*, was suppressed in the presence of heterospecific and conspecific competitors, demonstrating how the *per capita* effects of these species can differ across biotic contexts. In the competitor-presence experiments, individuals from the invasive population of *F. limosus* consistently had a higher maximum feeding rate than those of the native *F. virilis*, regardless of treatment. Our results caution against invasion risk assessments that use information from only one (or a few) populations or that do not consider the biotic context of target habitats.

Arctic Marine Shipping and Non Indigenous Species: A Canadian Perspective

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The Canadian Arctic is experiencing environmental shifts in response to climate change and in turn economic expansions throughout the region (Dawson et al. 2018). While the development of new Arctic shipping routes provides opportunities it also poses new risks to this previously untouched environment. One such risk is the potential introduction of non-indigenous species (NIS) (Niimi 2004).

The biological and socio-economic impacts of NIS can be immense, in their ability to out-compete native species, alter food webs, and directly or indirectly contribute to economic losses. Marine organisms enter a host region through three broad mechanisms: importing of goods, transportation vectors, and natural spread from neighboring regions. Within the scope of the Canadian Arctic, all three mechanisms are at play with ship mediated NIS dispersions.

In order to manage a threat of NIS introductions one needs to determine the associated risk of introduction. One management strategy for consideration is a vector based approach, in which an entire assemblage of potential species introductions can be managed, in this case, by managing the transportation vectors of ships.

This research aims to determine ballast mediated invasion risk by characterized the individual probabilities of successful arrival, survival and establishment using ballast water discharge data and environmental similarity between ports. The potential magnitude of consequence of each introduction event will be evaluated based on the number of high impact NIS recorded for each source port. Understanding the invasion process of NIS is essential for adapting management strategies and plans to mitigate arrivals and establishment of harmful organisms.

Selective Management of Exotic Watermilfoils and other North American Invasive Aquatic Plants with ProcellaCOR®, a Novel, Reduced-risk Aquatic Herbicide

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In early 2018, the US Environmental Protection Agency approved the reduced-risk aquatic herbicide ProcellaCOR® (a.i. florpiauxifen-benzyl). ProcellaCOR has excellent activity on a variety of North American (NA) aquatic invasive plants including Eurasian watermilfoil (*Myriophyllum spicatum*) and hybrid Eurasian accessions. The new arylpicolinate herbicide reduces use rates by several orders of magnitude versus older spot herbicide strategies for invasive watermilfoil management without restrictions on water use for drinking, swimming, and fishing. Efforts are underway to register the new herbicide for use in Canada and several other countries. Research studies prior to registration and initial use since its US approval have confirmed excellent, short-exposure (as little as 6 – 12 hours) activity on invasive watermilfoils with little or no impact to most common NA native aquatic plant species such as pondweeds (*Potamogeton* spp.), naiads (*Najas* spp.), tapegrass (*Vallisneria americana*), and bulrush (*Schoenoplectus* spp.). In this paper, results from multiple field projects with ProcellaCOR for invasive watermilfoil management will be reviewed including pre- and post-treatment quantitative point-intercept vegetation surveys and herbicide dissipation monitoring. Additional information on ProcellaCOR selective activity on other NA invasive plants such as water soldier (*Stratiotes aloides*) and yellow floating heart (*Nymphoides peltata*) will also be highlighted.

Known Occurrences and Potential Distribution of Invasive American Bullfrog (*Lithobates catesbeianus*) Populations in Ecuador: Risk Analysis and a Management Protocol

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The American bullfrog (*Lithobates catesbeianus* Shaw, 1802), a North American native amphibian, is considered one of the 100 most harmful invasive species in the world. This aquatic anuran lives mainly in shallow water bodies and has high tolerance to polluted environments. The American bullfrog was introduced in the south of Ecuador in 1985 for farming production. Previous studies about the potential distribution of the species, show that most of the continental territory of Ecuador has suitable climate conditions for its establishment. In this study, we recorded known and novel occurrences (based on fieldwork, collection records and literature) and, estimated the potential distribution for *L. catesbeianus*. We recorded feral populations in eight separate localities covering the three regions (Andes, Coast and Amazon) of continental Ecuador. We also quantified the invasion risk using the I3N protocol. The risk analysis and distribution model revealed that the species presents a high risk of being invasive, with the greatest vulnerability located in the protected areas of the Ecuadorian Andes. With these results, we proposed a protocol for the detection and management of *L. catesbeianus* in protected areas. The proposed management protocol was based on four variables: i) species presence ii) species occurrence probability, iii) presence of farmed-American bullfrog and, iv) expansion pattern if the species has been introduced. In conclusion, the probably expanding distribution of feral *L. catesbeianus* populations in Ecuador is a major conservation concern for native fauna. American bullfrog management in Ecuador should be considered a priority action because the species represents a current threat for protected areas due to its widely geographical distribution across of contrasting ecosystems, and a future threat for the Galapagos National Park. Our protocol is the first step for the management of this species at a country scale, and a base line to improve biosecurity tools in Ecuador.

U.S. Habitattitude™ Program Revitalized - Educating Consumers to Make Wise Pet Choices

Joshua Jones¹

¹Pet Industry Joint Advisory Council

The Habitattitude campaign—with its centerpiece website Habitattitude.net—has recently received a comprehensive update to address current environmental concerns and modern audiences from its original format which was rolled out over a decade ago. It was re-launched during the Reduce Risks from Invasive Species Coalition's agency fair on Capitol Hill in Washington, D.C., in June. The updated program addresses the policy and public outreach topic category for ICAIS 2019.

Habitattitude is an innovative, non-regulatory education campaign designed to increase awareness of the risks posed by non-native species in the environment and to positively impact consumer attitudes and practices. A public-private collaboration between industry groups and government agencies, it is sponsored by the Pet Industry Joint Advisory Council (PIJAC), the U.S. Fish and Wildlife Service (USFWS) and the National Oceanic and Atmospheric Administration (NOAA).

Well-meaning pet owners that find they are unable to care for their animal sometimes make an uninformed decision to release their pet to the outdoors—unaware of the potential impacts. The potential risks of released pets can be mitigated or avoided entirely if the public better understands certain information, like what is needed to care for a certain species, before choosing a pet.

Thanks to the input from the pet care community, agencies, and invasive species experts, the revitalized Habitattitude.net addresses this with guidance on choosing a pet, new information on aquarium fish and water gardening, and 2 new sections on reptiles/amphibians and animals and plants in the classroom in response to concerns about the potential for classroom pets to be released at the end of a school year. The new site is a springboard for beginners before moving on to more detailed resources. Information is provided on the variety of species as well as on basic considerations for habitat, diet, humidity, lighting requirements and health concerns. The content and layout were designed with younger generations in mind including their appetite for visually engaging media platforms.

Citizen Science Utilized to Report an Aquatic Invasive Species, the Chinese Mystery Snail (*Cipangopaludina chinensis*), in Atlantic Canada

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The Chinese mystery snail, *Cipangopaludina chinensis*, is an aquatic, potentially, invasive species native to Eastern Asia that has spread throughout the United States of America, Canada, Belgium, and the Netherlands. *C. chinensis* may be a potential risk to biodiversity because of its high reproductive rates (females are reported to produce up to 100 offspring per brood), relatively large size, and ability to be more resistant to predators compared to native snail species. We undertook a national review of reports of Chinese mystery snails across Canada and identified probable areas of concern and gaps in data. One area identified with low reported occurrence, despite the presence of established populations in large, inter-connected water systems, is Atlantic Canada. In order to increase reporting and public awareness of *C. chinensis*, a citizen science methodology, in conjunction with more traditional biologist-led surveys, was adopted to further assess this species' presence and distribution in the Canadian Maritime provinces (New Brunswick, Nova Scotia, Prince Edward Island). Citizen science approaches, where the public, interested groups, and communities collaborate with researchers to provide information, appear to be under-utilized in surveying aquatic invasive species. For many aquatic invasive species, public education is the best option to minimize the spread of these species. To engage citizens and interest groups in the project, an interactive website for reporting was created and public presentations were given. Additionally, informative household refrigerator magnets and fact sheets were sent out to groups that were interested in surveying lakes for *C. chinensis*. We plan to report the findings from our citizen science and research surveys, examine how those compare and complement each other, and describe a citizen science method which could be implemented in other Canadian provinces to survey aquatic invasive species.

Goldfish: Friend or Foe...

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The goldfish (*Carrasius auratus*) is one of the most common fish in the aquarium trade but also unfortunately one of the most widespread released-in-the-wild species. Its impacts on native species are reviewed in the context of the various temperate ecosystems in which they may be released. Survey of goldfish populations in Québec revealed disparities in the relative success to invade distinct water systems and their potential impacts on native species. Habitat variables and landscape descriptors were used to identify through multifactorial analyses key features explaining how goldfish could successfully colonize water bodies.

Anthropized ecosystems and man-made artificial structures appeared as suitable habitats where goldfish may thrive, but not necessarily establish feral population. On the other hand, some remote habitats where potential predators were absent or extirpated were home to self-perpetuating populations. A decision tree is proposed to modify the provincial strategy aimed at removing unwanted species in the context of maximizing the positive impacts of native ecosystems while minimizing costs and indirect negative impacts (e.g. ecosystem disturbance, indirect native species mortality, etc.).

Despite the potential connectivity between the aquatic ecosystems found in Quebec, multifactorial analyses revealed that human vector is the most important factor explaining local abundance and success in establishing self-perpetuating populations. Such an observation stresses the importance of developing outreach activities and other actions aimed at raising public awareness about the fate of their beloved (or once beloved!) pet fish after their release in the wild.

Engaging Stakeholders through the Great Lakes Aquatic Nonindigenous Species Information System

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The Great Lakes Aquatic Nonindigenous Species Information System (GLANSIS) is an inter-agency database funded by the Great Lakes Restoration Initiative that serves as a "one-stop shop" for information about aquatic invaders in the Great Lakes region. The database features comprehensive and cutting-edge scientific information on identification, ecology, management, and distribution of aquatic nonindigenous species throughout the Great Lakes basin, and is freely accessible to both environmental professionals and the public. The GLANSIS site has recently undergone a number of updates and improvements based on user feedback solicited from scientific and environmental management stakeholder groups. This presentation will focus on results of an initial survey of scientists launched in June 2018, an in-depth user-testing project conducted with environmental managers since December 2018, and the changes that have been made to the site so far based on this user feedback. Major updates and new functions of the site will be highlighted, including an improved user interface, a new comparative risk assessment tool, frequently asked questions, and feedback forms to encourage environmental professionals and other stakeholders to contribute ongoing peer review of the information on the site.

For Once, We Can be Positive: The Subsidiary Role Played by an Invasive Rockweed on Native Sandy Beach Organisms and Systems

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Fucus serratus is an invasive rockweed that colonized the Canadian Maritimes in the 1800s. However, contrary to the usual perception that invaders are detrimental to native species, this rockweed may have a positive effect on part of its invaded habitat: Dislodged rockweeds drift and end up stranded on sandy beaches, a habitat naturally denuded of primary producers, potentially becoming food subsidies for native sand hoppers (*Americorchestia longicornis*). To assess this, we compared the nutritional quality of invasive rockweeds with that of the native eelgrass (*Zostera marina*), the other main plant constituting the wrack in Prince Edward Island sandy beaches. Then, we compared sand hopper's grazing rates on both types of plant, and assessed the value of this rockweed as a habitat. We found that tissues of rockweed contained more protein, carbohydrates and lipid concentrations than those of eelgrass tissues. As a response, sand hoppers consumed 40% more rockweed than eelgrass on laboratory trials. A field survey also showed that the number of sand hoppers colonizing clumps of rockweed was higher than those colonizing eelgrass or bare sediments, a result that was consistent with a field manipulation showing higher colonization rates on artificially-made rockweeds than eelgrass. We conclude that sand hopper's preferences for rockweeds were related to food subsidies and habitat amelioration. These results highlight the positive role played by this invasive rockweed on native sand hoppers, and indirectly, on the role played by these amphipods on sandy beach systems.

A Refuge against Invasive Predators: Not Every Habitat Protects Native Decapod Species the Same

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Clumps of mussels, seaweeds and a combination of them are prominent features of sedimentary habitats of Atlantic Canada. For small native decapods such as the mud crab (*Dyspanopeus sayi*), such clumps are often perceived as refuges against larger predators. However, it is unclear whether they will be effective against highly skilled predators such as the European green crab (*Carcinus maenas*) an invasive species currently spreading across the region. This study used 24 hour laboratory and field manipulations to quantify green crab feeding rates on native mud crabs inhabiting distinct types of clumps. Bare sediment habitats were compared against standard-size clumps made of blue mussels (*Mytilus edulis*), giant Irish moss (*Chondrus crispus*), and a combination of mussels and seaweeds. For comparison, cannibalism on small green crabs was used as a reference measure of the level of predation large green crabs can exert on small mobile species. Results from the laboratory and the field showed that green crabs caused consistently high levels of mortality ($\geq 60\%$) among mud crabs placed on bare sediments and on clumps made with mussels or giant Irish moss. However, mortality was 2-5 times lower in the habitat that combined mussels and giant Irish moss. Rates of cannibalism did also change across treatments but were less consistent, and also generally lower than rates of native mud crab mortality. Altogether, these results suggest that the complexity provided by the association between seaweeds and mussels represent the most effective refuge against these and potentially other invasive predators.

Systematic Review on the Efficacy of Recreational Watercraft Decontamination Measures to Reduce the Overland Dispersal of Aquatic Invasive Species

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Decontaminating recreational watercraft, and fishing, sailing or watersports equipment after use can reduce the overland dispersal of aquatic invasive species (AIS) among lakes. Recommended measures include pressure-washing, rinsing with hot water, or air-drying, but their efficacy is unknown. The aim of this review is to assess the effectiveness of current decontamination methods against various AIS. Web of Science, Greenfile, Environment Complete and Geobase were searched in October 2018 for articles published till 2018. Studies on preventing overland AIS spread, and plant and invertebrate AIS response to heat, pressure-washing, desiccation or cleaning agents, were selected. Of 31 studies included in the review, 71% assessed air exposure. Age or size was proportional to intraspecific desiccation tolerance among invertebrates. In summer-like conditions, 100% of adults from three mussel species died within 2-7 days of air-drying, compared to 3h among larvae. Conversely, aquatic snails did not reach 50% or 100% mortality despite air-drying for one week. Among aquatic plants, water loss was inversely associated with fragment survival or growth, and short or single fragments were less resistant than larger or clustered fragments. Overall, 95%-100% of small fragments (hydrilla, Eurasian watermilfoil and fanwort) died after 5h of desiccation. Seven studies (23%) assessed how hot water affects AIS survival. Immersion of two mussel species, bloody-red shrimp, spiny waterflea, killer shrimp, and four macrophytes, at a minimum of 50°C for 15 minutes resulted in 100% mortality. Hot water sprays at 60°C also produced 100% mortality among zebra and quagga mussels after 5- and 10-seconds exposure, respectively. Only one study assessed pressure-washing; high pressure eliminated significantly more entangled plants, and small organisms or plant material than low pressure-washing, regardless of duration. This review reveals vast differences in treatments and response among AIS. Further studies are necessary to evaluate practical and effective catch-all decontamination protocols targeting several AIS simultaneously.

Mechanisms of Displacement of Native *Myriophyllum sibiricum* by Invasive *M. spicatum* in Northeastern United States

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Native *Myriophyllum sibiricum* was a common aquatic plant across New England in the past. Recent surveys suggest that the species went locally extinct in southern parts of the region. Local extinction is often linked to the presence of closely related invasive *M. spicatum*. However, the mechanisms by which the displacement of the native species occurs are unclear. Hybridization between *M. spicatum* and *M. sibiricum* is considered a driving force of *M. spicatum* adaptation to local environments in the Midwest of the United States, where hybrids have higher fitness than both parental lineages, as well as increased herbicide resistance. However, it is not known if this hybridization also drives the local extinction of *M. sibiricum* or if direct competition may be more important. Moreover, hybrids between *M. sibiricum* and *M. spicatum* have not been documented in New England, to the best of our knowledge.

The goal of the project is to answer the following questions:

- 1) Are there *M. spicatum* × *M. sibiricum* hybrid populations in New England?
- 2) What drives local extinction of *M. sibiricum*: competition with *M. spicatum*, genetic swamping through hybridization or some other factors (such as climate change)?

Locations that have present and past records of *M. sibiricum* have been visited across New England. Samples of both *M. spicatum* and *M. sibiricum* were collected, whenever present. Taxonomic and genetic identity of the samples was determined with a combination of fragment analysis of microsatellite markers and deep sequencing of ITS region.

Most of *M. spicatum* populations are represented by a single genotype (clone). In all locations, but one, where *M. spicatum* and *M. sibiricum* coexist, hybridization takes place. Thus both direct competition (by the single clone) and hybridization with *M. spicatum* are possible factors of local extinction of *M. sibiricum* in New England. Climatic data analysis will follow.

The NAS Alert System: Monitoring and Reporting the Leading Edge of Aquatic Invasions

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The Nonindigenous Aquatic Species (NAS) database (<http://nas.er.usgs.gov>) functions as a repository and clearinghouse for occurrence information on nonindigenous aquatic species from across the United States. It contains locality information on more than 1,280 species introduced since 1800, including both foreign species and North American natives transported outside of their natural range. The NAS web site provides immediate access to new occurrence records through a real-time interface with the NAS database. Fact sheets, distribution maps, and information on new occurrences are continually posted and updated. Dynamically generated species distribution maps show spatial accuracy of the locations reported, population status, and provide links to the full specimen record.

Awareness of, and timely response to, novel species introductions by those involved in nonindigenous aquatic species management and research requires a framework for rapid dissemination of occurrence data as it is incorporated into the NAS database. In May 2004, the NAS program developed an alert system to notify registered users of new introductions as part of a national early detection/rapid response system. Here we summarize information on system users and dispatched alerts from the system's inception through the end of 2018. The NAS alert system has registered over 2,100 users throughout its lifetime, with ~950 current subscribers. A total of 2,357 alerts have been transmitted through 2018. More alerts were sent for Florida (254 alerts) than for any other state. Fishes comprise the largest taxonomic group of alerts (851), with mollusks, plants, and crustaceans each containing over 200 alerts. Most alerts were for organisms that were intentionally released (779 alerts), with shipping, escape from captivity, and hitchhiking also representing major vectors (>100 alerts). To explore the archive of sent alerts and to register, the search and sign-up page for the alert system can be found at <http://nas.er.usgs.gov/AlertSystem/default.aspx>.

Planning for Genetic Biocontrol of Invasive Species at the State of Minnesota

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Genetic biocontrol technologies are being developed to target invasive species. Minnesota's invasive species program, part of the state's Department of Natural Resources (DNR), with funding from the Great Lakes Restoration Initiative, is beginning to explore these technologies. The DNR worked with university and U.S. federal agency partners to plan a three-day working group meeting in June 2019 with state and U.S. federal regulators, managers and researchers to learn about and discuss these emerging technologies. Based on the presentations and discussion at that meeting, we will review key points related to: current research on different applications of genetic biocontrol technologies for invasive species, including common carp, nonnative *Phragmites*, and spotted-wing drosophila; the U.S. federal regulatory framework; a preliminary analysis of relevant state authorities in Minnesota; public engagement; and other scales and jurisdictions that may be involved in governance of these technologies. We will present a summary of the key outcomes and next steps that were identified by participants at the June working group meeting. We will also share information about the tools that we used to prepare for the meeting, including a novel "workbook" that could be adapted for similar meetings and hypothetical case studies to facilitate discussions within state agencies about scenarios that may be years in the future.

Biological Traits that Discriminate between Native and Invasive Benthic Invertebrates

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There is increased pressure to accurately predict species likely to become invasive in order to provide targeted surveillance and proactive management against the growing threat of biological invasions. Currently no consensus exists regarding the key traits that determine invasiveness in marine species, the extent to which invasive and indigenous species differ in their trait compositions, or the ability to predict species with invasive potential on the basis of biological traits. Here we propose a method based on trait profiles which can predict invasive species likely to cause the greatest impact and native species with a proclivity for invasion. We compiled a database of 12 key biological and life history traits of 85 invasive and 181 native benthic invertebrate species from Western Europe. These traits allow us to position species according to life history strategies, in particular the opportunistic strategy hypothesised to be prevalent in invasive species. Using multivariate methods, biological traits were able to discriminate between native and invasive species with an accuracy of 89% with the five key traits of feeding method, mobility, fecundity, offspring type and pelagic stage duration being most important. The analysis reveals that the typical invasive benthic invertebrate is a suspension feeding, attached-sessile species which produces a large number of eggs or larvae typically pelagic for 1-15 days. Biological traits were also able to predict native European species with known invasion histories (i.e. those invasive elsewhere) with an accuracy of 75%. Given the increasing rate of marine invasions to Western Europe in recent decades, studies addressing the central questions of invasion biology (i.e. what allows an invader to be successful and which species are likely to become invasive?) are of increasing importance. Our findings add to the growing evidence that invasives represent a particular subset of species which possess a greater affinity for certain traits.

Responses of Invasive Round Goby Populations to Elevated Temperatures in the Great Lakes-St. Lawrence River System

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Freshwater lakes and rivers worldwide are subject to burgeoning effects of both biological invasion and climate change; interactions between these overlapping stressors should therefore be considered in risk assessments. Increasing temperatures of surface water in the Great Lakes-St. Lawrence River system will likely cause changes to the distributions, abundances and impacts of non-native species in the system. The Eurasian round goby (*Neogobius melanostomus*) has successfully established populations throughout the Great Lakes and their tributaries, and impact studies generally focus on its species-level interactions with native fishes and invertebrates. However, population-level differences in the invasion ecology of the round goby and its responses to climate warming remain largely unexplored. Through lab experiments, we will measure the feeding efficiencies and CT_{max} for round gobies acclimated to current or future projected mean summer temperatures. Experimental subjects will be collected from three separate populations distributed along a latitudinal gradient within the round goby's introduced range, from the western basin of Lake Erie north to Hamilton Harbour and the upper St. Lawrence River near Montreal. We will test two hypotheses: 1) individuals from more southerly populations will have higher maximum feeding rates at increased temperatures than those from northern populations; and 2) feeding rates will increase with temperatures that approach the round goby's thermal optimum, but sharply decline at temperatures approaching CT_{max} . Information on how climate warming can affect the feeding ecology and physiology of different populations can inform risk assessment and provide insight on the capacity for local adaptation of the round goby within its North American range.

Validation of an Automated Cell Imaging System to Enumerate Living Microorganisms

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Verification testing of Ballast Water Management Systems (BWMS) requires the characterization of samples to determine the number of living organisms. Currently, the method required in the U.S. Type Approval (TA) process is based on manual microscope counts for organisms in the ≥ 10 and $< 50 \mu m$ size class. Living organisms are labeled with two fluorescent markers (5-chloromethylfluorescein diacetate – CMFDA, and Fluorescein diacetate – FDA), and counted via epifluorescence microscopy. This procedure requires a trained analyst to enumerate living organisms based on visual interpretations of movement and the fluorescent emission of the cells. This process can be laborious given that numerous samples must be analyzed soon after collection for TA testing. Bias between analysts can also occur due to differing interpretations of the fluorescent label signature of the analyzed cells. The objective of this work was to validate an automated cell imaging system (LionHeart™ FX, BioTek®), used to quantify organisms in the ≥ 10 and $< 50 \mu m$ size class following the U.S. TA procedure. Protocols with imaging routines were developed for live and ultraviolet (UV)-treated samples using the instrumentation software (Gen5™, BioTek®). For each protocol, multiple images of a Sedgewick Rafter Counting Chamber were collected in brightfield and epifluorescence modes. Images were stitched together to create a single montage image. Living and treated organisms were identified using cellular image processing, where cell regions were defined based on pre-determined threshold values for color intensity (fluorescence emission). This automated method was compared to the U.S. TA manual microscopy method performed by a trained analyst using algal monocultures. Live and UV-treated samples were tested and results were analyzed with comparative statistics. Initial results demonstrate a strong correlation between manual microscopy and automated analyses using the cell imaging system. Improved automated cell counting techniques could reduce cell-counting error and reduce the potential discrepancies between trained analysts.

UV-C as a Freshwater Treatment Option against Microalgae

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Aquatic invasions are an issue that dramatically affects the quality of freshwater ecosystems. Species, like zebra mussels and round goby, can be easily introduced if proper techniques are not followed. Water treatment is an essential processes required to protect our aquatic resources from these invasions. While water treatment is essential for preventing non-native and invasive introductions it is also essential for controlling micro-organism concentrations. Microorganisms, like microalgae and bacteria, pose critical challenges to the freshwater environments just like invasive species. For instance, microalgae can cause issues like toxin release and blooms. Microalgae, however, are not effectively targeted using traditional treatment methods. Chlorination, a widely used treatment method, has disadvantages as it creates hazardous by-products and relies on cell lysis. Cell lysis is risky because it can release cell components into the water. Filtration is another method for treating freshwater environments. Filtration, however, does not properly target microalgal cells as they are smaller than the typical membranes. A method that could efficiently treat freshwater environments while targeting microalgal cells is Ultraviolet Type C (UV-C). However, there is little information on the response of microalgae species to UV-C treatments. UV-C targets the DNA, which kills cells by stopping reproduction. Here we tested the effectiveness of UV-C in reducing the viability of different microalgae taxa. For this assessment, we use the method plate-based Most Probable Number (MPN) to look at the effects of different treatments of UV-C on microalgal cells. We look specifically at the inability for cells to replicate/reproduce by analyzing the reduction of cells after UV-C is administered. Our tests on green algae and diatoms reveal that UV-C is a useful tool for reducing the viability of microalgae. This work has implications for improving treatments in freshwater environments and potentially protecting these ecosystems from invasions and blooms.

The Baltic Sea as Recipient and Donor of Non-indigenous Fish Species

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The Baltic Sea is the youngest and one of the largest brackish water areas in the world. Baltic is semi isolated from other seas. A mixture of salt water from the North Sea and fresh water from numerous rivers creates unique hydrological conditions.

Geologically, the Baltic Sea area has gone via a series of various salinity stages, including both freshwater and marine/brackish water phases.

In the Baltic marine and freshwater species live side by side. Most of the marine species are relicts from the times when the sea was saltier, freshwater species arrive from rivers and lakes. The brackish water could impose physiological stress for both marine and freshwater organisms.

The most probable vectors of invasions, for non-indigenous fishes, into the Baltic Sea are aquaculture and shipping. Fish run away from fish farms (pacific salmon, Asian sturgeons, Asian cyprinids) or are transported in ballast waters (round goby). Fish of some species were intently stocking for commercial or recreational purposes, at least partially (rainbow trout).

Connection of various river systems by creating canals has opened a new route, form many Ponto-Caspian species, into the Baltic Sea (round goby).

There are about 20 non-indigenous fish species, in the Baltic Sea. But only two species can be treated as invasive ones. Only round goby and crucian carp are ecologically important and they, have changed significantly the food web, in occupied areas. Fish from other non-indigenous species are noticed, sometimes in big number, but no ecological importance of those was reported.

Is the Baltic Sea potential donor area of non-indigenous fish species, for European water bodies? History of round goby spreading (starting from the Baltic Sea) shows that such possibility is highly probable.

A Wisconsin Aquatic Invasive Species Pathways Priority: Outreach to Waterfowl Hunters

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Recreational boaters on Wisconsin lakes and rivers are the primary vector of secondary spread for aquatic invasive species (AIS). Outreach programs (e.g., Stop Aquatic Hitchhikers!, Clean Boats, Clean Waters) are designed to educate boaters about their role in preventing the spread of AIS. These programs have effectively raised awareness and inspired boaters to take preventative actions, such as removing all plants from their boats and trailers before leaving a launch site. As Wisconsin refocuses on the pathways taken by AIS into the state, more targeted efforts are being developed. Wisconsin has an estimated 70,000 waterfowl hunters. Waterfowl hunters use their watercraft outside of the Memorial Day to Labor Day boating season to access lakes, rivers and wetlands and may not have been exposed to the Stop Aquatic Hitchhikers! message or realize its applicability to their sport. By adapting existing outreach methods, the Wisconsin Aquatic Invasive Species Partnership began reaching out to waterfowlers in 2016. The Clean Boats, Clean Waters survey, used by boat inspectors during the summer to evaluate boater behavior, was repurposed for the 2017 Waterfowl Hunter AIS Campaign with questions and conversational prompts to evaluate hunters' movement between waterbodies and their understanding of the AIS Law and how it applies to them. Approximately 1200 in-person contacts were made by boat inspectors and law enforcement during hunting opening weekends in 2017 and 2018. At least, 12,000 were reached through multiple media and events. Waterfowl hunters indicated that they welcome contacts at their access points and the campaign's hunter-related focus. Since the campaigns inception, outreach has expanded from five main locations to sites in fourteen counties as members of the statewide AIS partnership become more involved. Ongoing training and planning going forward will help inspectors be even more successful in their outreach efforts to waterfowl hunters in the future.

Wisconsin's Aquatic Invasive Species Partnership: Partners as the Key to Prevention

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Wisconsin's aquatic invasive species (AIS) outreach program is largely implemented by the broader Wisconsin Aquatic Invasive Species Partnership. The Wisconsin AIS Partnership is a broad group of professionals representing federal, state, and local government, universities, and nongovernmental organizations that all work on AIS issues. Led by the University of Wisconsin-Extension and the WDNR, the Wisconsin AIS Partnership implements AIS outreach programs statewide. Programs include the Clean Boats Clean Waters education-based watercraft inspectors' program, two special summer campaigns targeting anglers and boaters, and three statewide citizen science monitoring programs. The partnership communicates regularly through a listserv, one on one contacts for support, two in-person meetings per year, the Wisconsin Lakes Convention and multiple online meetings. The Partnership is currently piloting a new funding method to support the partners working out of counties and NGOs in order to broaden statewide coverage by partners. Many Wisconsin AIS Partnership members are currently funded through a yearly competitive WDNR grants program that awards ~\$600,000 yearly to entities that hire positions that participate in the Wisconsin AIS Partnership. However, this funding model has led to coverage gaps by partners and uneven implementation of AIS outreach programs across the state. Because of this, Wisconsin will be moving away from a competitive grants program to fund partners and to a contract model that will allow for a base-level of core AIS outreach services to be implemented. This new model will be called the Wisconsin AIS Prevention Network and it is scheduled to be implemented in 2020. This will hopefully lead to more consistent implementation of AIS prevention programs across Wisconsin and more long-term members of the Wisconsin AIS Partnership.

Amplifying Digital Reach Through Strategic Partnerships: Examples from Asian Carp Canada

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The Invasive Species Centre (ISC) uses social media and web tactics as a major method of outreach to fill gaps in knowledge about invasive species, and highlight news, research and current events in the field. We utilize a targeted approach across various social media platforms and websites to connect with a broad audience and increase awareness about invasive species and their associated risks. This poster will highlight examples of successful social media campaigns the ISC has run, including Asian carp awareness in Ontario. Content will include recommendations for successful invasive species digital communications and audience engagement through social media and web tactics; and tips for evaluating success.

Dutch Harbor Invasive Species Bioblitz

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Dutch Harbor is the nation's top fishing port and was also found to be the Bering Sea port at the highest risk to marine invasive species infestation. The National Marine Fisheries Service Alaska Region teamed up with the Smithsonian Environmental Research Center (SERC), Alaska Sea Grant, Aleutian and Bering Sea Islands Landscape Conservation Cooperative and Alaska Department of Fish and Game to sponsor a community marine invasive species bioblitz event on September 8, 2018. The event coincided with a week-long survey by SERC to assess the marine invertebrate biodiversity of Dutch Harbor and compare it to a 2002 survey. The bioblitz raised awareness of both the research and threat of invasion to Dutch Harbor and the Bering Sea. About 40 participants from the community participated in a presentation on invasive species, field collection to a local harbor, and a laboratory session. In addition, high school students visited with SERC scientists earlier in the week to learn about their research and view specimens.

The Neglected Pathway for Marine Alien Species: Biofouling

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Although biofouling is one of the main transport vectors around the world, invasive alien species legislation tends to focus on ballast water and aquaculture related vectors. The Netherlands assessed the risk of biofouling as a pathway. This study focussed on recreational crafts. It was based on citizen science, fouling plates, port surveys and students projects. The results show that more alien species were found on floating objects in harbours than in any other habitat surveyed along the coastline of the Netherlands, including soft sediments, shellfish beds and on the dikes. The study furthermore illustrated that 59% of all pleasure crafts in marinas have fouling on their hulls. About a third of the crafts visiting a marina on the North Sea came from other countries and continents including America, Asia and Australia. At present biofouling is therefore considered to be the main pathway of marine alien distribution within the NE Atlantic Ocean whereby harbours and ports function as important stepping stones for biofouling species. Biofouling is therefore the main primary pathway and harbours are important stepping stones. In 2019/2020 the Netherlands will start a baseline study on biofouling on commercial ships as part of the IMO hull fouling guidelines evaluations. Furthermore we show some results on biofouling on naval ships. The poster shows a pattern of biofouling in the various sea (naval) ports along the North Sea coast, Wadden Sea and Delta areas of the Netherlands.

Developing a National Clean Drain Dry Program – a BC Pilot Project

Nicholas Wong¹

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The Invasive Species Council of BC established the first Clean Drain Dry (CDD) program in Canada in 2012 that incorporated innovative Behaviour Change tools and approaches. This Clean Drain Dry program researched messaging, barriers, commitment tools and braiding all aimed at supporting the public and water recreationists needed to take actions to reduce the spread of aquatic invasive species. Since then, the CDD program has evolved and expanded considerably than the ISCBC is now delivering a three-year national pilot CDD program funded by Fisheries and Oceans Canada in partnership with the Canadian Council on Invasive Species. Engaging both provincial and national advisors, this pilot will test, refine and deliver resources including signage, community partnerships, commitment tools, outreach resources and an extensive digital campaign that will be applied with partners consistently across Canada. Working together with consistent messaging and tools, will help engage Canadians across the country to take actions that prevent the spread of aquatic invasive species.

Mind the Gap: Using a Gap Analysis to Identify Elements Missing from an Outreach Program

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The four species of Asian carps have been identified as a major threat to the Canadian waters of the Great Lakes. In response to this threat, Fisheries and Oceans Canada (DFO) created the Asian Carp Program (the Program) in 2012, which is based on four pillars: Prevention, Early Warning, Response, and Management.

As Asian carps are not yet established in the Canadian waters of the Great Lakes, a significant part of the Program's efforts are put towards prevention, including public outreach. The goals of this outreach are to educate the public on: how to identify the four species of Asian carps and the threats that they pose; how to report sightings; and, to encourage them to do so.

In December 2017, the Program hosted a workshop with its partners (provincial staff, key Indigenous communities, non-governmental organizations, and academic institutions) to brainstorm and share ideas with the ultimate objective of developing a five-year action plan. One of the outcomes of the workshop was that a "Gap Analysis" was needed to determine and effectively steer the Program's future outreach activities.

The intent of this Gap Analysis is to identify: key target audiences of the Program (including those being reached and those being missed); messages needed to improve understanding and behaviour change in key audiences; whether competing messages or audiences exist that may hinder outreach efforts; and, to identify additional outreach methods that could be used to reach target audiences. Finally, the analysis will identify organizations and Indigenous communities with similar goals, interests, and audiences who have expertise in changing behaviours, with whom we could potentially partner.

The results of the Gap Analysis will inform the Program's, as well as those of our partners, outreach activities with respect to aquatic invasive species, especially Asian carps.

Functional Responses of Invasive Goldfishes under Warming Temperatures

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The impacts and competitiveness of non-native aquatic species are expected to be altered by climate warming, particularly in north temperate regions. We examined the effect of warming on the feeding efficiencies and growth rates of two closely-related goldfishes with global invasion histories: Common Goldfish (*Carassius auratus*) and Prussian Carp (*Carassius gibelio*). Common Goldfish has an extensive invasion history in North America and it has formed dense populations in the western basin of Lake Erie and in Hamilton Harbour, Lake Ontario, whereas Prussian Carp has recently invaded Alberta and has not been reported from the Great Lakes basin but is a future invasion threat. Although the species are closely-related and morphologically similar, we hypothesize that they have distinct physiologies that affect their response to changing temperatures. Common Goldfish is a warmwater species, and there is concern that climate change is causing it to become increasingly abundant in the Great Lakes and elsewhere in North America, with concomitant increasing impacts. The thermal guild of Prussian Carp is unknown, but the species appears able to thrive in a variety of climates throughout its global range. Using individuals collected from established wild populations in Lac des Battures, Nun's Island (for Common Goldfish) and Blood Indian Creek Reservoir, Alberta (Prussian Carp), we experimentally measured the maximum feeding rate and specific growth rate of both species to compare their feeding efficiencies at temperatures ranging from 18°C to 28°C. The results of these experiments were used to compare the potential per capita effects of these species under future temperatures projected for nearshore areas of the lower Great Lakes.

The Bait That Keeps on Wiggling: Vectors and Outreach for the Asian Jumping Worm

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Invasive earthworms are typically associated with impacts on terrestrial soils and plant communities. However, earthworms in riparian environments have the potential to negatively affect freshwater ecosystems. Litter-feeding species such as the Asian Jumping Worm (*Amyntas* spp.) can increase runoff and bioaccumulate hazardous levels of heavy metals which can affect both aquatic and terrestrial food webs. Two species of Asian jumping worms were found in Oregon in the summer of 2016 and additional worms have been found since the initial discovery. These worms can live in a wide variety of habitats and are unusual in their behavior: they jump and thrash when disturbed and slither much like snakes. While early introductions of jumping worms in North America were for fishing bait, there are numerous additional vectors for their spread. These can include online worm retailers, gardening stores, nurseries, and landscape supply retailers. We explore these vectors in western Oregon to assess the relative risk of each for the introduction of Asian jumping worms as well as identify targets for outreach activities aimed at preventing the spread of these invasive earthworms. Our findings can also help natural resource managers better understand how invasive species move both within and across political borders.

How Well Do We Understand the Impacts of Invasive Alien Species on Cultural Ecosystem Services? Results from a Literature Review

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Aquatic invasive alien species (IAS) can alter ecosystems and ecosystem functioning, which in turn may affect the benefits or services these aquatic environments provide for people. Studying impacts on ecosystem services is a complex task given the need for a broad range of indicators and the sometimes conflicting outcomes. Often, assessments include only a subset of ecosystem services, with a main focus on provisioning, regulating and/or supporting services. In particular, the absence of data on the impacts of aquatic IAS on cultural ecosystem services is a matter of concern. According to the Millennium Ecosystem Assessment, cultural ecosystem services are "the nonmaterial benefits people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experiences". A common characteristic of these nonmaterial benefits (such as providing a sense of place) is that they are considered as intangible, and can thus not be quantified or described in simple terms. This creates challenges for including them in formal assessment frameworks such as IAS risk assessments. This poster presents the results of a literature review undertaken to determine our current understanding of the complex relations between IAS and the social and cultural values associated with freshwater ecosystems (i.e. rivers and lakes). The aim of this review is not to provide a definite answer to the question of how IAS affect cultural ecosystem services (either positively or negatively) but in fact to explore relevant questions and avenues for future research. By providing an overview of the research on this topic, the results provide a basis for discussing (1) gaps in knowledge and future directions for research and (2) possible ways to account for social and cultural values in formalized impact assessments of IAS.

Pioneering in Chinese Mitten Crab (*Eriocheir sinensis*) Management in Flanders

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The invasive Chinese mitten crab is widespread throughout NW Europe and occurs in some bays in Northern America. This migratory species reproduces in saline or brackish waters, and migrates upstream to freshwater streams to feed and grow. Although the exact impact of the species on the aquatic ecosystem has not been studied thoroughly in Flanders, the very high population density during the annual migration undoubtedly affects the ecosystem in which these crabs mature. This has led to the search for a method to reduce or even prevent influx of crabs into the most sensitive upstream watercourses.

The Flemish Environment Agency developed a submerged physical barrier as a pilot project. This system is made up of a river-wide gutter on the stream bed that does not block any waterflow, is passable for all fish species but is almost unsurpassable for the benthic mitten crabs that crawl into the gutter and are unable to get out. They can only follow the gutter out of the water, into large containers positioned on the banks, from which they can be removed to be euthanised.

This crab barrier has passively caught over 360 000 crabs during 2018's and over 700.000 crabs during 2019's spring migration. In a catch – recapture experiment, 2 batches of 100 marked crabs were released at 2 different distances downstream from the trap. Up to 75% of the crabs were recaptured. The trap appears to be a promising and durable solution for efficiently limiting the numbers of Chinese mitten crabs in watercourses.

New Ammonia Based Piscicides: Getting from Science to Useable Management Tools

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Management and removal of invasive aquatic species is often difficult because problems are typically large in scale with few effective tools available. Ammonia has many qualities that make it an effective candidate piscicide, such as its specific toxicity to gill breathing organisms, its high solubility, and its natural ability to detoxify via the nitrification cycle. Several studies have demonstrated the effectiveness of ammonia as a fisheries management tool in small-scale experimental settings but transitioning from small-scale experiments to large-scale eradication efforts on wild fish populations has been challenging. Large-scale management efforts to demonstrate effectiveness are hindered by regulatory requirements because ammonia is generally considered an aquatic contaminant with extensive laws preventing its discharge into natural environments. These regulations, while justified in terms of limiting detrimental effects of treated wastewater, impede the ability of scientists to gather the data that is required for licensing and registration of new ammonia-based piscicides. Without regulatory support progress on development of new tools for control of invasive aquatic species may be limited.

A Non-Native Freshwater Prawn's (*Macrobrachium nipponense*) Impact on Tropical Forest Stream Macroinvertebrate Communities

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Empirical evidence for the specific impacts of potentially invasive species is often lacking. This can hinder efforts to understand the invasive risk posed or to control and manage the invasive species and their impacts. We assessed the impact of a non-native freshwater prawn, *Macrobrachium nipponense*, in relation to a common native species, *M. malayanum*, on macroinvertebrate assemblages from forest streams in Singapore via a laboratory experiment. Responses in macroinvertebrate assemblage diversity and community composition were evaluated from macroinvertebrate-colonised leaf litter that were exposed to different prawn treatments, viz., *M. nipponense* only, *M. malayanum* only, and *M. nipponense*-*M. malayanum*, and no prawns. *Macrobrachium nipponense* consumed a greater abundance and diversity of macroinvertebrates, reducing the community complexity of the assemblage compared to its native counterpart. This asymmetric predatory effect contributes direct evidence of one form of potential ecological impact that *M. nipponense* may have on tropical forest stream macroinvertebrate communities.

Risks and Management of Invasive Alien Crayfish Species in the Rhine-Meuse River Delta

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Since the 1950s, ten alien crayfish species have been introduced in the Rhine-Meuse river delta. Eight species originate from North America, one from South-east Europe and one from Asia. Currently, at least six species have well established populations.

Recently, five species have been listed as invasive alien species of European Union concern (i.e. *Faxonius limosus*, *Faxonius virilis*, *Pacifastacus leniusculus*, *Procambarus clarkii* and *Procambarus fallax f. virginalis*). All crayfish species of EU concern are subject to restrictions on keeping, transportation, importing, selling and breeding. Member States are required to take action on pathways of unintentional introduction, to take measures for early detection and rapid eradication of these species, and to manage species that are already widely spread in their territory. The impact of these species on biodiversity, water quality and functioning of ecosystems mainly results from predation on macroinvertebrates, amphibians and fish and from fragmentation and consumption of aquatic macrophytes. Moreover, burrowing activities of some species cause bank instability, increase risk of dyke breaches in peatland areas and result in higher sedimentation rates in ditches and canals.

The introduction of Northern American crayfish species is also associated with the spread of the crayfish plague (*Aphanomyces astaci*). This disease caused, in addition to water pollution and habitat destruction, a rapid decline of the critically endangered European crayfish (*Astacus astacus*). Moreover, the presence of infested alien species limits the success of restocking programmes of native crayfish.

Our presentation will focus on pathways for introduction, spread, dispersal rates, climate match, establishment and environmental impacts of invasive alien crayfish in the Rhine-Meuse river delta. Threshold densities for significant adverse effects and scenarios for cost-effective management of invasive crayfish species will be discussed with special attention to options for enhancing ecosystem resilience.

Tackling Unintentional Pathways of Introduction and Spread of Invasive Alien Freshwater Species in Belgium

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In Belgium, competences with regards to IAS are scattered across the regions (Flanders, Wallonia and Brussels Capital Region) and the federal level. To support the implementation of the EU IAS Regulation (1143/2014), a cooperation agreement was set up. This agreement provides the legal basis for several new entities: the National Scientific Secretariat on IAS which coordinates scientific activities, the National Scientific Council on IAS as an advisory body and the National Committee on IAS which finalizes decisions and prepares policies. These three entities worked together to prioritize pathways of unintentional introduction and spread of the IAS of Union concern and to draft action plans for priority pathways. First, a complete pathway inventory was set up. Second, the relevance of the pathways for the country was scored. A prioritization protocol was then applied, taking into account species impact, establishment potential and the frequency of introduction.

For the freshwater species, three pathways related to freshwater recreation were identified: transportation via angling equipment, hitchhiking on boats and fish stocking. Additionally, hitchhiking on machinery and disposal of aquatic species in the environment by private individuals, were also identified as important pathways. With consultation of administrations, sectors and stakeholders to ensure support for action plans and assess feasibility, we identified potential actions to tackle these "freshwater" pathways. These included measures in broad categories: legislative action, biosecurity, inspection, awareness raising and research. The exercise showed: the need for baseline data on anglers and boaters habits, knowledge and attitude towards IAS, the difference in biosecurity in fish stocking between the regions, the absence of a mechanism in the tenures of maintenance companies to decrease the spread of IAS, and the need for awareness raising targeting pond owners and aquarists' communities. Future work will focus on the drafting of concrete action plans to tackle freshwater invasion pathways.

Mosquito Larvae Associated with the Water Lettuce "*Pistia stratiotes*" in a Lagoon of the Magdalena River, Barranquilla, Colombia

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The water lettuce, *Pistia stratiotes*, is an invasive plant in tropical and subtropical wetland ecosystems, worldwide. This macrophyte constitutes a suitable breeding habitat for mosquito larvae (Culicidae), hence its development is thought to produce negative impacts on human health due to mosquito-borne illnesses. We evaluated the vegetation coverage of *P. stratiotes* and associated mosquito species composition in a shallow lagoon, located in the low watershed of the Magdalena River, Colombia. Four sampling stations and two zones (north and south) were established to monitor macrophytes and mosquitoes during a flood-drought season. Vegetation cover for *P. stratiotes* was estimated using transects of up to 10 m², while dipping and root rinsing with 5% NaCl were used to gather immature stages of mosquitoes. Abiotic parameters such as pH, dissolved oxygen, electric conductivity, temperature, transparency, water deepness and nutrient content were measured using standard methodologies. Canonical Correspondence Analysis, (CCA) and Spearman correlation test statistics were used to investigate a likely link between *P. stratiotes*, mosquito larvae and water abiotic parameters. Coverage for the water lettuce was higher than 12% in the southern region and correlated positively with water transparency. Mosquito production reached more than six thousand larvae, with *Culex* (Mel) *erraticus*, *Uranotaenia lowi* and *Mansonia indubitans* being the most prevalent species. *Mansonia indubitans*, a bridge vector of lymphatic filariasis in Colombia, depicted a positive association with *P. stratiotes* (r coefficient = 0.64). Furthermore, CCA analysis suggested that the presence of *M. indubitans* is a function of *P. stratiotes* vegetation cover. Our findings highlight the importance of *P. stratiotes* when evaluating risk of mosquito-borne diseases in Neotropical wetlands.

Invasive Freshwater Mosquitoes as Emerging Disease Vectors Along a Caribbean Basin–Appalachian Plateau Transect

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Since 2013, two separate unprecedented invasions of the Western Hemisphere by human-infectious Chikungunya virus and Zika viruses have stunned the global health community. Both of these highly pathogenic viruses are transmitted to humans almost exclusively by exotic invasive mosquitoes that colonized the Americas from Africa centuries ago (*Aedes aegypti*), and from Asia within the last few decades (*Aedes albopictus*). In North America, another invader from Asia is currently spreading (*Aedes japonicus*). All three invasive mosquito species live in various freshwater systems and are also invasive across Europe and other regions, but differ from each other in habitat and climate preferences. Much of the movement of mosquito-borne pathogens between South America and North America occurs through the Caribbean Basin corridor, crossing numerous island countries. We are examining variations in invasive and native mosquito populations across this diverse corridor, and their potential for vectoring other diseases (e.g., dirofilariasis, West Nile virus, LaCrosse virus, dengue, yellow fever, malaria). Our new biosurveillance program encompasses a broad transect from the southern end of the Caribbean Basin through the high elevation of the Cumberland Plateau. From 2017-2019, we performed extensive surveys of mosquito populations from the transect's northernmost point in Tennessee (eight sites) through intermediate points in northwestern Georgia (ten sites) and southwestern Florida (seven sites). In 2018 and 2019, we performed limited locality surveys at eight sites in the central (Haiti, Puerto Rico, St. Thomas, St. Maarten, St. Kitts) and southern (Aruba, Bonaire, Curaçao) Caribbean Archipelago, extending to the transect's southernmost point near the South America mainland. We collected *Ae. aegypti* only in the Caribbean and Florida, while collecting *Ae. albopictus* and *Ae. japonicus* only in Georgia and Tennessee, where our reports include new distribution records. We also identified more than 30 native mosquito species and are examining their diverse relationships with the invasive mosquito species.

Recovery of a South African Native Fish Population after the Eradication of an Invasive Fish

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The eradication of invasive species is a management strategy implemented to eliminate negative impacts of invaders on native species communities. After attempted eradications, follow-up studies are done to confirm eradication of the invader and the short-term recovery of the native species, but long-term monitoring to confirm full population recovery and stability is often not completed. In this study, long-term monitoring of three native fishes was carried out over five years after the application of rotenone to remove Smallmouth Bass from the Rondegat River, South Africa. Forty-six sites distributed along four river sections were sampled for presence/absence using underwater cameras and snorkel surveys. Using multi-season occupancy models, the annual probability of colonization and local extinction of the native fishes along the river sections and annual rate of change in occupancy were estimated. Changes in native fish densities across time and across the control and treatment section of the river were. Probability of colonization and local extinction differed for each native fish species and may have been affected by both extrinsic factors, such as rainfall, and intrinsic density-dependent factors, hypothesized from the trends in the density data. The estimated occupancy rates of change along the river reveal that the two native fish species listed as Near Threatened by IUCN have reached population equilibrium while the native fish species listed as Endangered has not, suggesting that other conservation efforts, such as habitat restoration, may be needed. The long-term monitoring of native fish populations after an eradication program has confirmed not only the successful removal of the invader but also the recovery and stability of the native community. This study shows that a successful eradication of an invader was not itself sufficient for recovery; additional conservation management strategies are needed to ensure the population stability and persistence of endangered fishes.

Structured Decision Making and Adaptive Management for AIS Responses: An Application to Grass Carp in Lake Erie

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Introductions of aquatic invasive species (AIS) can result in diverse and complex social, ecological, and economic effects. Structured decision making (SDM) can provide an objectives-based strategy to explicitly address the complexities of AIS prevention and control. When paired with an iterative adaptive management framework, response actions can be used to reduce uncertainties in the decision making process to inform future decisions. Invasive carp prevention and control in the Great Lakes present an ideal scenario to implement SDM, due to the involvement of multi-jurisdictional stakeholders and the diversity of predicted effects on the Great Lakes' social-ecological system. Evidence of Grass Carp *Ctenopharyngodon idella* reproduction in Lake Erie has been documented since 2015, emphasizing an urgent need to develop coordinated response actions. A structured decision making process was initiated in 2016 among regional stakeholders and subject experts to establish management objectives, identify areas of uncertainty, and evaluate response action alternatives within an adaptive management framework. Beginning in 2018, an adaptive management strategy was implemented to reduce uncertainties while simultaneously executing control actions. Information that is gathered and shared across user groups continues to guide future research efforts and is used to develop more effective response actions. The Grass Carp strategy provides a framework for using SDM and adaptive management to address the complexity of current and future AIS issues.

A New Approach to Manage Common Carp: Citizen-aided Carp Management

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Common carp (*Cyprinus carpio*) is a large invasive fish that has wide-ranging impacts on water quality, biodiversity and ecosystem function in North America. Historically, carp populations have been managed using indiscriminate lake poisoning, large non species-specific seine nets, and lake de-watering (water drawdowns). We have developed a new management method by exploiting carp's unique diet (their preference to consume grains) and the cognitive aspects of their foraging behavior. We used corn to train carp to form dense feeding aggregations in seven lakes in Minnesota. Underwater cameras and passive integrated transponder tags were used to monitor the diel dynamics of carp aggregations at the bait. Once the fish were conditioned to aggregate at the bait, they were removed with specially-designed stationary traps deployed at the baited sites. This process was repeated multiple times in each lake. Citizens and lake residents played a key part in this strategy by systematically deploying bait, and monitoring bait consumption. In each lake, we removed between 17% and 55% of carp populations within one season. Carp comprised over 99% of all captured fish, even though the lakes were inhabited by relatively diverse communities of native species. Overall, it appears that significant numbers of carp can be selectively removed from lakes using the strategy we developed. Further, our strategy engages local citizens and volunteers and uses relatively simple protocol and techniques, which increases its applicability and cost-effectiveness.

A Non-structural Fish Deterrent: Variation in Avoidance Responses across Species, and within Invasive Common Carp

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Non-physical deterrents can be used in conservation to limit the dispersal of invasive fishes without altering the hydrological conditions of a watershed. To determine how native and non-native species interact with non-physical deterrents, acoustic and stroboscopic stimuli were deployed alongside a physical Common Carp-exclusion barrier (Royal Botanical Gardens, May - July 2018). Adult fishes migrating into a wetland habitat (Cootes Paradise, Hamilton, Lake Ontario) were blocked by the Common Carp-exclusion barrier and guided towards a series of traps. Two underwater speakers and five strobe-lights were installed over two traps and activated on alternating days for a period of 24 hours. Over 10,000 fish were captured including Brown Bullhead, Common Carp, Gizzard Shad, Goldfish, White Sucker, and Channel Catfish. Preliminary general linear models indicate that the trapping rates of adult fish varied according to species and stimulus activation.

A subset (n=40) of invasive Common Carp that had interacted with the acoustic and stroboscopic stimuli were then collected for physiological and behavioural testing. Inter-individual variation in Common Carp physiology (basal metabolic rate) and behaviour (boldness, activity, sociability) will be quantified to determine how variation between individuals will influence their response to deterrent stimuli placed in the field. This research will help inform management decisions regarding invasive fish exclusion efforts.

Engaging High School Students as Collaborators in Ecological Investigation of the Columbia River Estuary: Lessons from a Transdisciplinary University-High School Partnership

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Estuaries are under increasing threat from anthropogenic stressors such as eutrophication, invasive species and habitat degradation. Understanding the linkages between human activity and the transfer of materials and organisms through estuaries to the coastal ocean requires coordinated investigation into the structure and function of estuarine ecosystems as well as the dynamics of human systems in the watershed. The Columbia River Estuary Science Education and Outreach (CRESCENDO) project was a university-high school partnership between scientists and science education researchers from Washington State University and science teachers and their students from five high schools located in southwest Washington and adjacent to the Columbia River Estuary (CRE). The CRESCENDO project explicitly integrated ecological research with science education research that assessed how high school students' participation in the scientific research impacted their knowledge of CRE ecology and their attitudes about science and stewardship. On a monthly basis from September 2016 to October 2018, CRESCENDO teachers and their students measured water quality and conducted plankton tows from a dock near each of their schools. Each May, the data were compiled from the five schools and all of the CRESCENDO participants (WSU scientists, science educators, high school teachers and up to 30 students from each school) convened a Research Symposium to review, discuss and interpret the results. In this presentation we will describe the project design and highlight preliminary results related to the distribution of the invasive copepod *Pseudodiaptomus forbesi* in the CRE, in order to illustrate the "lessons learned" from CRESCENDO, and provide a set of recommendations for developing future university-high school partnerships focused on locally-relevant environmental problems.

Fisheries and Oceans Canada's Role with Aquatic Invasive Species in the Prairies

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Ongoing funding for the Aquatic Invasive Species Program (AISP) under Fisheries and Oceans Canada (DFO) allows for federal support for aquatic invasive species (AIS) related issues in Alberta, Saskatchewan, and Manitoba on behalf of the Government of Canada (GoC). Regional AIS priorities are determined by these in-land provinces as the delegated freshwater AIS authority. The relatively new presence of the federal AISP has led to many challenges for all government agencies involved, such as determining the GoC's role with AIS and how to best achieve a variety of priorities among three Prairie Provinces. The AISP functions as a partner to assist, support, and provide resources for the provinces. The \$80K budget for the freshwaters of central Canada is limited considering the geographic size and the multitude of AIS threats currently being faced (e.g. zebra mussel, Prussian carp, and flowering rush, to name a few). We will detail how the AISP and its provincial partners have come together to address these challenges and how AIS priorities were implemented with examples where the AISP functioned to aid the Province of Alberta. These examples will include the management of flowering rush, the early detection of zebra mussel in Manitoba, and the development of regional-wise Incident Command System (ICS) structure for response.

Regional Operationalize of Canada's Federal Aquatic Invasive Species Regulation

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¹Aquatic Invasive Species Program, Fisheries and Oceans Canada

In 2015, Canada passed the *Aquatic Invasive Species Regulations* (AISR) into law. The objective of this legislation was to create a comprehensive national AIS framework that would complement the patchwork of provincial legislation. The federal AISR create several prohibitions, such as import, transportation, possession, and release, while also allowing for the deposit of control substances that target specific AIS. Prior to these regulations, there was no law covering the interprovincial transfer of AIS or their import into Canada. Furthermore, additional resources were made available to DFO in 2017 for the implementation of the AIS Regulations.

In this presentation, we will highlight and discuss attributes of the federal AISR, including listing of species under the regulations, enhanced enforcement and conservation provisions, and on-going regional and national efforts to further enhance our ability to protect Canada's ecological, economic, and societal resources.

With new resources come new challenges on a complex jurisdictional landscape within central Canada. We will discuss how Fisheries and Oceans' (DFO) AIS Core Program will implement the AIS Regulations through partnerships with existing regulatory programs. Likewise, we will discuss plans to work with other federal stakeholders. We will also highlight the strengths, weaknesses, challenges, and opportunities we face with implementing the AISR across a large landscape with limited resources.

Participants in this talk will leave with knowledge of Canada's federal Aquatic Invasive Species Regulations, Fisheries and Oceans Canada's role in implementing and operationalizing these regulations at the regional level with respect to freshwaters.

Bridging the Gap between Invasive Species Research and Management

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The body of scientific literature surrounding invasive species and their impacts and management has increased dramatically in recent decades. However, despite expanding knowledge and technological advances in the research sphere, a persistent disconnect exists between research and management which hinders real-world application of these new solutions. In an effort to bridge this gap, New York State has established the New York Invasive Species Research Institute (NYISRI), which serves to communicate and coordinate invasive species research to help prevent and manage the impact of invasive species. Through extensive interactions with researchers and managers working with invasive species, NYISRI has identified strategic areas and developed initiatives to promote communication and research that addresses research-management gaps. This presentation will provide an overview of some of NYISRI's current initiatives ranging from advancing classical biological programs for difficult to manage species, to collaborating with computer scientists to develop an invasive species management optimization tool, to integrating information on emerging issues such as climate change and invasive species. Additionally, this talk will examine ways to promote the co-creation of knowledge to improve the scientific basis of invasive species management and policy decisions.

Exotic Parasites in European Freshwater Ecosystems: The Neglected and Forgotten Invaders

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Since the Enemy Release Hypothesis, the most common way in which parasites influence biological invasions is considered to be through their absence. Several reviews have been devoted to most biological compartments of European ecosystems but none have been devoted to exotic parasites, yet parasitism is the most common animal lifestyle and parasites have numerous important ecological, evolutionary and conservation implications. We documented cases of parasite introductions in European fresh waters and analysed the host-parasite list obtained in detail. Exotic parasites are a rising problem over the last two centuries that follow the rhythm of other species introductions. All successful introductions of parasites pass through the encounter filter and the compatibility filter as successive stages of invasion and the pathogenicity of the parasite is a key factor. Spillover (when an introduced host transmits its parasites to susceptible native hosts) is rare in spite of its importance and impact when it has been observed. Trojan introductions (parasites introduced with the successful introduction of an exotic host acting as a reservoir) are the most frequent but this phenomenon implicates a small number of host species. We finally tested the prediction that the most likely parasites to be introduced in new areas would be monoxenous, generalist, weakly pathogenic and highly prevalent in their native range.

The Neglected Pathway for Marine Alien Species: Biofouling

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Although biofouling is one of the main trans—port vectors around the world, invasive alien species legislation tends to focus on ballast water and aquaculture related vectors. The Netherlands assessed the risk of biofouling as a pathway. This study focussed on recreational crafts. It was based on citizen science, fouling plates, port surveys and students projects. The results show that more alien species were found on floating objects in harbours than in any other habitat surveyed along the coastline of the Netherlands, including soft sediments, shellfish beds and on the dikes. The study furthermore illustrated that 59% of all pleasure crafts in marinas have fouling on their hulls. About a third of the crafts visiting a marina on the North Sea came from other countries and continents including America, Asia and Australia. At present biofouling is therefore considered to be the main pathway of marine alien distribution within the NE Atlantic Ocean whereby harbours and ports function as important stepping stones for biofouling species. Biofouling is therefore the main primary pathway and harbours are important stepping stones. In 2019/2020 the Netherlands will start a baseline study on biofouling on commercial ships as part of the IMO hull fouling guidelines evaluations. Furthermore we show some results on biofouling on naval ships. The poster shows a pattern of biofouling in the various sea (naval) ports along the North Sea coast, Wadden Sea and Delta areas of the Netherlands.

Phylogeography and Origin of Invasive Fish *Perccottus glenii* in Europe

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The native range of the fish Chinese (Amur) sleeper *Perccottus glenii* Dybowski, 1877 is in the Far East of the Asia, mainly the Amur River drainage in China and North Korea. This fish was first introduced to Europe in beginning of 20th century, following a numerous secondary re-introductions to various locations in Eurasia with stocking material of Asian cyprinids and farther active dispersal. It is one of the most successful invasive fish species in European waters, recorded in several parts of Russian Federation, and also in Belarus, Ukraine, Latvia, Lithuania, Estonia, Moldova, Poland, Slovakia, Hungary, Serbia, Bulgaria, Germany, Romania and Croatia. Because of the significant negative impact on native fauna, it is desirable to determine current level genetic diversity of Chinese sleeper in Europe.

The material consisted of about 300 individuals (42 localities) collected across the European range of the invaders, was sequenced for the cytochrome *b* (*cyt-b*) mitochondrial marker. Combining our results with literature data we aimed to answer the following questions:

- a) What is the species phylogeography in Europe?
- b) Is there a loss of genetic diversity associated with the colonization process?
- c) What was the source for the populations established in Europe?
- d) Was the introduction of *P. glenii* in Europe a single or multiple event?

Phylogeography of the Invasive Amphipod (Crustacea) *Pontogammarus robustoides* in Native and Colonized Range

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The *Pontogammarus robustoides* is one of the invasive Ponto-Caspian Amphipods in European waters. This species was introduced in the 1950s to dam reservoirs on the Daugava and Nemunas in the Baltic States. Probably, along the coast of the Baltic Sea, it managed to spread to the Vistula Lagoon, Szczecin Lagoon, Vistula, Oder, Mazurian Lakes, Mecklenburg Lake District, as well as to the Gulf of Finland. The main objectives of our studies were: (1) species phylogeography in native and invaded area, (2) historical demography of populations, (3) source population for first introduction in the Baltic States. We amplified ca 650 bp long portion of the mitochondrial cytochrome oxidase I (COI) marker from ca. 560 specimens collected in 85 locations all over Europe, including 43 locations from the native and 42 from invaded area.

The obtained results allowed us to determine the genetic population structure of *Pontogammarus robustoides*. Spatial distribution of clades occurring in the native region is structured geographically. The source population for introductions to Baltic States were populations from the Lower Dnieper, as identical haplotypes were found in both locations. We observed a reduction of genetic diversity connected with the founder effect. In the newly colonized area only three haplotypes were found comparing to seven occurring in native Dnieper clade. The species continues invasion to western Europe and the secondary bottlenecks were detected in its westward progress. In the Baltic States three haplotypes were identified, in Poland two, while in Germany only one. Demographic analysis has shown a stable growth of native population in the 8-28k BP which can be associated with sea level and the salinity fluctuations in this area during the Pleistocene.

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Session E2: New Developments in Management and Control

Analyzing the Decision Basis for Aquatic Invasive Species Management

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We conducted a survey of AIS professionals throughout the US and Canada to determine how they made decisions about AIS management. We received ~250 responses from managers, researchers, and educators spanning jurisdictional levels (local, state, federal) to a range of questions including their experience with AIS management, which species and management actions they have undertaken in their work, and the importance of sources they relied for management decisions including species-specific and state/regional AIS Management Plans. We found a reasonably high rate of familiarity with US Federal AIS Plans, with 72% of respondents having read some or all of the plans relevant to priority AIS in their jurisdiction. The majority of respondents felt federal AIS plans were useful or very useful for guiding management decision making, and most thought that their corresponding intervention efforts were effective (77%). Those involved with containment vs. eradication or suppression were most likely to feel their efforts were effective (~80%). We found that containment was also the most common activity (rather than prevention, suppression, or eradication) when populations were spreading and established. Of a variety of information sources used to design AIS interventions, respondents deemed that expert advice, state management plans, and published research were mostly adequately available to them, while the availability of federal management plans was less adequate. Lastly, we found that data on AIS impacts on native taxa were commonly collected (71%) as well as ecological impacts generally (58%), however data on socio-economic impacts were much less often collected (36%).

Evaluating the Recovery of Native Marsh Communities after Herbicide-based *P. australis* Control

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The rapid expansion of invasive *Phragmites australis* (European Common Reed) in wetlands throughout North America has displaced resident vegetation communities, disrupted ecological processes, and threatens wetland bird and herptiles populations. Reducing established populations of *P. australis* and reinstating displaced native vegetation communities can be costly and difficult. In 2016, a pilot project conducted in the coastal marshes of Lake Erie treated over 500 ha of *P. australis* with a glyphosate herbicide applied by helicopter. In 2017, efforts at herbicide-based *P. australis* control continued, but included both aerial and ground-based application methods.

To evaluate the efficacy of *P. australis* control and the effect that herbicide application has on the marsh ecosystem, we designed a BACI-style monitoring program. Between 2016-2018, we evaluated 1) how effective herbicide was at reducing *P. australis* density across a water depth gradient, 2) any differences in efficacy among aerial and ground-based herbicide application methods, and 3) how the diversity and community composition of vegetation recovered following herbicide application. We determined that both aerial and ground-based herbicide application were highly successful (>95%) at killing *P. australis* regardless of water depth; however, aerial application was significantly more effective than ground-based application. Despite local elimination of *P. australis*, we did not observe dramatic increases in diversity in the two years following treatment. Community composition in treated plots, though distinct from control plots, does not resemble remnant patches of native vegetation. Secondary invasion by *Hydrocharis morsus-ranae* (European Frog-bit) is a major concern in recently treated areas, likely due to historically high lake levels in the last two years. We conclude that the trajectory of native vegetation recovery in coastal marshes depends on the water levels in years following treatment.

Effective Citizen Participation in Eradication of Invasive Alien Plant Species

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The Himalayan balsam (*Impatiens glandulifera*) is an invasive alien species (IAS) that strongly affects biodiversity and ecosystems functioning of various types of aquatic as well as terrestrial ecosystems. This species is already wide spread in several European countries and Northern America. Recently, the European Commission has listed the Himalayan balsam as an IAS of EU concern. Member states must implement appropriate measures to combat this species. Successful eradication and prevention of re-establishment of the Himalayan balsam will require a basin-wide approach with cooperation of all land owners, involvement of all stakeholders and public support. Participation of volunteers can reduce costs of management measures and is indispensable in creating public support for eradication of invasive species because they act as observers, restorers and narrators.

Therefore, a pilot study on eradication of Himalayan balsam with volunteers was performed in the Goffert Park in the municipality of Nijmegen (The Netherlands). This study included a five steps approach: 1) preparing a sound participative eradication campaign; 2) recruitment and instruction of volunteers, 3) inventory of the species distribution in the park and surrounding area, 4) invasive species eradication, and 5) follow-up inspection and removal of remaining plants and new seedlings. Moreover, several tools for citizen participation in eradication of invasive alien plant species were developed (such as knowledge documents, roadmaps, identification guides, instructions for plant surveys, means of communication and evaluation forms). The pilot study also included an experimental sowing of native plant species at areas where Himalayan balsam was removed to suppress regrowth from seed and to increase competition for resources. The native plant species also compensates for the nectar function of Himalayan balsam for insects and increases the amenity value as well. Probability of recolonization by Himalayan balsam was estimated in experimental and control plots.

An comprehensive evaluation of our pilot study reveals following conditions for effective eradication of Himalayan balsam with the help of citizens: 1) availability of an umbrella organization and an inspiring project coordinator, 2) development of a sound eradication strategy, 3) intensive communication with all stakeholders and local residents, 4) clear instructions for surveys and guidance of volunteers during all field activities, 5) involvement of governmental representatives, local stakeholders and input of (practical) knowledge by experts. With limited adaptations, our participative eradication approach and tools for effective involvement of volunteers can also be used to control other invasive plant species.

Invaders Must Die: Mortality of Invasive Macrophytes, Bivalves, and Crustacean Species following Exposure to Aquatic Disinfectants or Steam Treatments

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Aquatic invasive alien species (IAS) negatively impact freshwater ecosystems worldwide. As suppression and eradication techniques for established invader populations are often complex, costly and resource-intensive, the prevention of further invader spread is considered a key aspect of proactive management strategies. However, the application of many proposed spread-prevention practices are frequently inhibited due to low practicality, high expense, undesirable non-target effects and a lack of known efficacy. We have assessed the use of aquatic disinfectants at various concentrations (i.e. Virkon® Aquatic and Virasure® Aquatic; 1, 2 or 4%), and/or innovative direct steam exposure to cause mortality of fragmentary propagule stages for eight invasive macrophyte species, adult Quagga *Dreissena rostriformis bugensis* and Zebra *Dreissena polymorpha* mussels, Asian clam *Corbicula fluminea*, killer shrimp *Dikerogammarus villosus*, and bloody red shrimp *Hemimysis anomala*. Each species was independently exposed to aquatic disinfectants or steam treatments for up to sixty or five minutes, respectively. *D. villosus* and *H. anomala* were also exposed to disinfectant mist sprays. Overall, the examined aquatic disinfectants did not induce complete mortality of the assessed invasive macrophyte or bivalve species. However, both disinfectants efficaciously caused complete mortality of *D. villosus* and *H. anomala*, even following mist spray treatments of 1% solutions. Steam treatments were found to be highly effective, causing the complete mortality of all examined invasive macrophyte, bivalve and crustacean species, even following short exposure times of ≤ 30 seconds. Although aquatic disinfectants will likely have a beneficial role within decontamination protocols, it appears they will not prevent the further spread of many damaging IAS. However, we argue that the innovative, yet simple technique of direct steam exposure can be used to improve biosecurity practices to better prevent the spread of invasive macrophytes, bivalves, and crustacean species.

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Session E3: Ecophysiology and Adaptive Evolution of Invaders

Predicting the Effects of Thermal Stress on Native and Invasive Fishes in Ontario Streams

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The thermal habitat of a species is defined by its thermal preferences and tolerances. Global climate change will alter thermal habitat availability for native and non-native invasive species, leading to changes in distribution and possibly negative impacts on ecosystem function. Synergies with other stressors, such as invasive species, could amplify the effects of climate change on ecosystems and their communities. Native White Sucker (*Catostomus commersonii*) and invasive Round Goby (*Neogobius melanostomus*) were chosen as candidate species to examine how increases in temperature may influence other interactions (e.g., distribution and feeding). The White Sucker is an important energy transfer link between the nearshore and Lake Ontario tributaries and is currently in decline. Round Goby is a recent invasive that has similar environmental requirements and, thus, the opportunity for competition and displacement is a concern. This research examines the response of these native and invasive fishes to increasing water temperature by measuring their agitation temperature and critical thermal maximum (CtMax) using stream-side experiments across seasons to predict their potential future interactions under a warming climate. Preliminary analysis suggests that there is a significant difference in CtMax and agitation temperature between White Sucker and Round Goby. In addition, the location along the river gradient is a significant driver of CtMax, suggesting some level of phenotypical plasticity in thermal tolerance of both species.

Could Water Temperature Stop the Round Goby Invasion

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Round goby is a common Ponto-Caspian species with wide environmental conditions tolerance. In 1990, first round gobies were fished in the Gulf of Gdansk and in the Laurentian Great Lakes. It has been the beginning of the long story of invasion in many localities in Europe and North America. Such successful spread of non-indigenous species involves questions about possible ways of invasion prevention and environmental conditions that could stop the invader. Round goby can survive and reproduce in wide range of salinity, from freshwater to marine. Round goby is present in waters of temperature from zero up to 30°C. Fish during its ontogenesis is the most sensitive in early life stages. Conditions of spawning and embryogenesis could be the most important for species survival.

We have checked the effectiveness of round goby embryogenesis in the water of temperatures: 5, 10, 12, 15, 16, 20, 25°C. Obtained from rape fish eggs and sperm were mixed and then developing embryos were incubated. Each day, embryos were counted and photographed under a stereomicroscope.

In waters colder than 12°C no effective embryos development was observed. Period of embryogenesis varied from 36 days in water of 12 °C to 11 days in water of 25 °C. The survival rate was high (over 90%) for embryos incubated in the water of temperature from 12°C to 20°C. Embryos incubated in the water of 25°C temperature hatched after 11 days but the survival rate was much lower, about 70%.

After our experiment, it can be stated that it is highly possible that waters which temperatures are lower than 12°C during all year are safe form round goby population establishment. In waters of temperature around 12°C, embryogenesis takes over a month. The probability of successful embryos development in environmental conditions seems to be very low. Embryogenesis is most effective in temperatures from 15 to 20°C.

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Session E3: Ecophysiology and Adaptive Evolution of Invaders

Morphological Differentiation in Trophic Traits of Round Goby across Multiple Invasion Events

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Round goby (*Neogobius melanostomus*), a Ponto-Caspian fish species, is one of the most pervasive aquatic invaders in Europe and North America. Through predation, feeding competition, and aggressive behavior it poses a high risk for decline of native biodiversity, including some protected and endangered fish species. The generalist diet of round goby and its tolerance to a broad range of abiotic conditions, such as temperature and salinity, enable this species to survive its initial introduction in widely different aquatic ecosystems, ranging from small ponds to large rivers, and even coastal seas. However, establishment of populations in new locations after initial survival, may involve subsequent specialization to local circumstances, such as the available food sources, which can widely vary in composition and abundance between different ecosystems. Specialization in feeding performance for particular food sources will entail morphological differentiation of feeding-associated functional traits, as feeding capacity is causally linked to morphology. Therefore, it is to be expected that established populations of round goby from diverse aquatic ecosystems will also differ morphologically, and that these morphological differences reflect the gobies' diets. In this study we compared the trophic morphology of round gobies from eight different populations across Europe (The Netherlands, Belgium, Austria, Germany, Czech Republic, Switzerland) and North America (Laurentian Great Lakes). We used an eco-morphological approach (the Food-Fish Model, FFM), which links the functional traits of the predator to the biomechanical, behavioral, and chemical characteristics of prey types. This resulted in a trophic profile of each individual, describing its capacity for feeding on different prey types. Significant differences between some populations (e.g. between the Belgian Berwijn and the German Danube rivers) were recorded, while others overlapped. The mechanisms and role of rapid morphological adjustment in alien invasions will be discussed.

Is Salinity an Obstacle for Biological Invasions?

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Invasions of freshwater habitats by marine species have become increasingly common in recent years, with most of these species originating from Ponto-Caspian region. In contrast, few freshwater species have invaded brackish, but not marine habitats. To determine if species from certain areas can better tolerate transitions from saline to freshwater habitats and vice versa, we explored nonindigenous species (NIS) established in the North and Baltic Seas and Great Lakes–St. Lawrence River regions—two areas intensively studied in concern to NIS, highly invaded by Ponto-Caspian species and with different salinity patterns (marine vs. freshwater). We compared observed numbers of NIS in these two regions to expected numbers of NIS from major donor regions which were calculated based on the available species pool from donor regions, frequency of shipping transit, and an environmental match between donor and recipient regions. Then we conducted salinity tests on eight species native to Northern Europe, the Great Lakes–St. Lawrence River and Ponto-Caspian region, as well as experimental selection experiments on Ponto-Caspian gammarid *Pontogammarus maeoticus* to determine their salinity tolerance and adaptation potential for higher and lower salinity than the tested population was collected from (i.e., 10 ppt), respectively. Our results demonstrated that Ponto-Caspian taxa colonized both types of habitats, marine areas of the North and Baltic Seas and freshwater of the Great Lakes–St. Lawrence River, in much higher numbers than expected. All eight species tolerate wide ranges of salinity, however, different patterns arose among species from different regions. Ponto-Caspian taxa showed lower mortality in fresh water, while Northern European taxa showed higher survival in fully marine conditions. Finally our experimental selection of *P. maeoticus* resulted in successful selection to lower, but not to higher salinity.

Metabarcoding Reveals Deep Diversity in Ballast Water

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Understanding the biodiversity present in a ballast water tank presents significant challenges given the difficulty of representative sampling and the potential taxonomic diversity of organisms present. Here we report results of an attempt to provide a detailed and thorough account of the diversity present in two ballast tanks from a single voyage between LA/Long Beach, California and Valdez, Alaska (USA). We conducted high throughput sequencing on 8 replicate plankton tows from each of two ballast tanks, using four different primer sets (three targeting the nuclear small RNA subunit 18S gene and one targeting the mitochondrial COI gene). As anticipated, different markers revealed distinct but overlapping components of community biodiversity spanning metazoan and protozoan taxa. Nuclear 18S markers captured OTUs representing diatom, dinoflagellate, and fungal taxa that were absent in the COI dataset. Perhaps surprisingly, analysis of COI data did not result in a higher proportion of taxonomic assignments at the genus and species level than did analysis of 18S data. However, COI did provide the highest sequence depth, and that combined with the relatively higher specificity of the marker resulted in the most comprehensive assessment of metazoan taxonomic diversity. OTU accumulation analysis indicates that 15 tows across two tanks is sufficient to account for greater than 95% of OTU diversity at the 18S locus, but that a substantially higher sampling effort (68 tows) would be required to reach the same level of completeness for COI. Analysis of a single tow would be expected to yield over 60% coverage for 18S OTU pools, but only approximately 20% of the COI pool. Additional analysis of ballast water samples drawn from multiple vessels entering Valdez and two other US ports reveals considerable diversity entering these ports over a two-year period; we briefly explore how the geography of source port distributions might shape the accumulation of introduced diversity in these recipient environments.

Testing Ship-borne Species Spread Models with a Global eDNA Metabarcoding Survey Dataset

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The unintentional transport of invasive species through the global shipping network causes substantial environmental and economic harm. Addressing this global challenge requires identification of potentially harmful species and confirmation of their movement along highly frequented shipping routes. As we have previously shown, properly calibrated network models of ballast water and biofouling species transport are able to describe movement of nonindigenous species around the world. These models can be substantially improved when suitable in-situ biological data is available, which is now possible by sequencing of environmental DNA (eDNA) from port waters.

Here we report the results of a global eDNA metabarcoding survey of 28 ports using 18S ribosomal amplicons. We use this dataset to test for the effects of environmental similarity, ecoregion, and various measures of shipping connectivity on between-port community similarity metrics, revealing the relative role of shipping in shaping current port biodiversity patterns. With further port DNA sampling and network model refinements, we will also soon be able to provide accurate global assessments of ship-borne nonindigenous species spread to inform management and policy decision makers.

Evaluation of a DNA Cell Proliferation Assay as a Cell Viability Measurement Technique

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Ultraviolet (UV) light is commonly used in ballast water management systems (BWMS) designed to treat invasive species transported by ships. BWMSs are designed to treat ballast water discharges to meet the standard set by the United States Coast Guard (USCG) and the International Maritime Organization (IMO). USCG-approved BWMSs must demonstrate their treatment efficacy through testing conducted in accordance with the Environmental Technology Verification (ETV) Program Protocol, which describes procedures for the analysis of organisms in the ≥ 10 and < 50 μm size class. To assess fluorescence and movement, the protocol requires labeling with a combination of two fluorescent probes, and counting of organisms via epifluorescent microscopy. When used to treat ballast water, UV does not necessarily kill an organism, but instead is intended to degrade its DNA and render it unable to reproduce making it nonviable. The ETV method that relies on fluorescence and movement may not accurately measure organism viability (ability to reproduce) because nonviable cells may exhibit fluorescence and movement. To address this issue, the applicability of a DNA cell proliferation assay (CyQuant®) to determine viability of organisms following UV treatment was evaluated in comparison to other cell measurement techniques. Other cell measurement techniques included the ETV microscopy method, and automated cell counting. Cell concentrations were measured and compared after treatment at day 0, 1, 5, and 14, and overall method practicality was evaluated. Reduction of aquatic invasive species transported via ships is a global concern and an ongoing regulatory challenge. New and improved cell concentration measurement techniques—especially those that can measure viability—are important for the evaluation of treatment efficacy and compliance with US and international discharge standards.

Predicting Hot Spots for Marine Aquatic Invasions in the Arctic

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The risk of aquatic invasive species (AIS) introductions in the Arctic is expected to increase with ongoing trends of greater shipping activity, resource exploitation, and climate warming in the region. We identified a suite of AIS (benthic invertebrates, zooplankton, macroalgae and phytoplankton) with the greatest likelihood of introduction and impact in the Canadian Arctic, using mainly the Canadian Marine Invasive Screening Tool. The top twenty three riskiest species (mainly benthic) were then modelled to predict the potential spatial distributions (habitat modelling using Maximum Entropy) at an Arctic and global scales. Modelling was conducted under present environmental conditions and under two future global warming scenarios (2050 and 2100). Results show that hotspots or regions where suitable habitat is more densely accumulated for modelled AIS are in the Hudson Complex, Northern Grand Banks/Labrador, Chukchi/Eastern Bering Sea, and Barents/White Sea. Most taxonomic groups showed a trend for a positive pole-ward shift in the future, increasing from the present time to the end of the century. This approach will aid in the identification of present and future high-risk areas for AIS in response to global warming.

Tuesday, October 29, 2019

Session F1 Emerging Vectors, Pathways and Invasion Threats

The Invasive Crayfish Collaborative: Bringing Together Research, Management, Outreach and Industry to Address a Threat to the Laurentian Great Lakes

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Invasion of non-native crayfish, such as the red swamp crayfish (*Procambarus clarkii*), is a relatively new area of focus for resource managers working in the Laurentian Great Lakes. In part because of this novelty, few tools are available to managers wishing to control them. To help facilitate development of science-based management tools, Illinois-Indiana Sea Grant (IISG) formed an Invasive Crayfish Collaborative (ICC) with funding from the Great Lakes Restoration Initiative. ICC membership is varied comprising state, federal and provincial managers; outreach professionals, researchers, industry representatives and non-governmental organizations. To help connect ICC members to the available science, we created a website (invasivecrayfish.org) containing summaries on relevant topics such as natural history and control techniques with links to the corresponding scientific literature, and hosted webinars on ongoing research. We also established an email list (invasive-crayfish-collaborative@googlegroups.com), which is an efficient mechanism for individuals to connect with and request information from a broad network of stakeholders. Through a needs assessment of ICC members, we identified the ICC research and outreach needs, which will help guide future efforts. Additionally, IISG is developing an outreach tool based on ICC member needs, a workshop to train K-12 educators to incorporate crayfish monitoring into their classrooms, and a framework for establishing invasive crayfish best management practices. This presentation will describe our efforts and provide an update on the future of the ICC.

Tuesday, October 29, 2019

Session F3: Ecophysiology and Adaptive Evolution of Invaders

It is Going to be a Stormy Ride: Effect of Airflow on Survival of Dreissenids during Overland Transport

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Introductions of the invasive zebra mussel (*Dreissena polymorpha*) and quagga mussel (*Dreissena rostriformis bugensis*) into hydrologically isolated water bodies have been attributed to overland transport of (recreational) boats, buoys, metal pontoons and floats. However, the attached mussels are exposed to air during the overland transport. Depending on the duration and environmental conditions, overland transport affects their survival. The fraction of surviving individuals depends on air temperature, the relative humidity, travelling duration, travelling speed (viz. exposure to airflow) during the overland transport, and detachment rate by vibrations of the transport vehicle. Effects of several factors have been extensively assessed but the influence of airflow on dreissenid survival remains poorly studied. Therefore, the effect of airflow on the mortality of the quagga mussel was determined to increase the reliability of boat hull-mediated overland dispersal predictions. Airflow exposure experiments were performed at 10 and 20 °C (relative humidity of $81.6 \pm 2.8\%$) using individual mussels and clumps of mussels. These mussels were exposed to low and medium airflows (respectively 10 and 50 km.h⁻¹) for set durations ranging from hours to days. Survival of mussels exposed to airflow was lower compared to exposure without airflow. Clumped individuals showed a higher survival during airflow compared to individual mussels. Weight loss of mussels significantly increased when exposed to airflow. Overall the results show that air movement has a profound effect on the survival of dreissenid mussels and should therefore be included in model predictions of their overland transport potential. Moreover, monitoring efforts and air exposure experiments should also focus on specific parts of boats, buoys, metal pontoons and floats that are shielded from airflow during transport on trailers.

Lygodium microphyllum Spore Viability Collected from Soil samples in Hydric Habitats

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Old World climbing fern (OWCF; *Lygodium microphyllum*) is an invasive plant in southern Florida and the Everglades. Soil samples were collected from natural areas invaded by OWCF and potted ($n = 72$) while sub-sets of soil were allowed to dry at ambient temperatures for 6 ($n = 72$) and 12 months ($n = 72$) before potting. After potting, soils were maintained in the greenhouse, saturated with water daily, and monitored for sporophyte development over six months. Additional soil samples (42 per time period) were collected from six natural areas in southern Florida where OWCF was treated with herbicide at 0, 6, 12, 18, and 24 months and Everglades' tree islands ($n = 52$) treated with herbicide and subsequently burned. OWCF sporophyte production from soils declined ($P < 0.05$) following drying at ambient temperature from 0 (3051 ± 196 sporophytes/m²), 6 months (1811 ± 174 sporophytes/m²), and 12 (1010 ± 83 sporophytes/m²) months. In treated sites, sporophyte production from soils decreased ($P < 0.05$) from 0 to 24 months post-treatment. At 0 months, soils samples with OWCF coverage produced 2692 ± 210 sporophytes/m², while 1732 ± 215 sporophytes/m² were produced in sites without but within 100 m of OWCF infestations. At 24 months, soils from treated sites produced 1405 ± 266 sporophytes/m², while 244 ± 84 sporophytes/m² were produced from soils in uninvaded sites. On Everglades' tree islands, soils treated with herbicide and burned produced 3011 ± 414 sporophytes/m² while 434 ± 98 sporophytes/m² were produced from soils collected on tree islands with no OWCF coverage. OWCF spores exhibited reduced viability over time following drying, but large numbers of sporophytes developed from soils indicating spores are being blown into treated areas. Disturbance from herbicide treatments and burning opens up habitat for wind-blown OWCF spores to invade.

Tuesday, October 29, 2019

Session F3: Ecophysiology and Adaptive Evolution of Invaders

Variation in Traits that Influence Invasion Success in Clones of the New Zealand Mud Snail, *Potamopyrgus antipodarum*

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Genetic variation within an introduced population can be an important reason for invasion success as selection may act to adapt the invader to new habitats. The New Zealand mud snail (*Potamopyrgus antipodarum*) is composed of multiple clonal genotypes in its invaded range in North America. Here we test the hypothesis that there are differences between clonal genotypes and between populations of the same clone in behavior and desiccation tolerance. We exposed various invasive populations of the snail to odor from fish and crayfish predators and examined their geotactic, photokinetic, and dispersal behaviors. We also performed experiments to examine desiccation tolerance of different populations. The results indicate that there is substantial variation in behavior between the different populations of the snail with the most invasive clonal genotypes appearing to respond to predators more strongly. In addition, there exists variation between populations in desiccation tolerance with the population from the driest climate exhibiting the greatest tolerance to desiccation. These results suggest that there is genetic variation within and between clones of the New Zealand mud snail, which may allow it to adapt to new areas as it spreads through North America.

Habitat Degradation Promotes Non-native Fish Occurrences in Tropical Forest Streams

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The highly speciose tropical fresh waters of Southeast Asia face growing numbers of non-native species, and this situation is potentially worsened by ongoing anthropogenic environmental change such as forest conversion and river damming. The urgent need to understand region-specific invasion mechanisms for informing management efforts, however, is hampered by the paucity of relevant baseline ecological data. To address this knowledge gap, we aimed to determine drivers of freshwater fish invasion using data from a forest stream-reservoir system in Singapore. This system comprises diverse communities of both native and non-native fishes, which mirrors forested impoundments in the surrounding region. Using a Bayesian multivariate co-occurrence model, we partitioned species-specific responses to abiotic conditions and biotic interactions, and found that non-native species are more likely to occur in degraded, reservoir-like abiotic conditions. However, predator-prey relationships and trait-based indices of interspecific competition are poor predictors of non-native species co-occurrences within recipient communities. Taken together, our findings show that environmental change is a key driver of freshwater fish invasion in our study area. The prevention of further habitat degradation is therefore a priority for the proactive management of non-native species in Southeast Asia.

Temperature Effects on Exploratory Behaviour and Learning Ability of Invasive Mosquitofish

Kit Magellan¹, Timothy C. Bonebrake¹ and David Dudgeon¹

¹University of Hong Kong

One of the key factors in the success of an invasive behavioural flexibility, which may promote invasions by allowing invaders to exploit novel foods, habitats and shelters. As behaviour can change rapidly it is an ideal first response to environmental change, including introduction and spread into a new habitat. Behaviour can also be modified by learning, thus facilitating adjustment of existing behaviours to accommodate novel or changing environmental conditions. Climate change is also likely to promote the introduction, establishment, and spread of aquatic invasive species, and temperature in particular is vitally important for ectotherms. Temperature directly affects metabolic rates with consequent changes in behaviour. We evaluated the exploration tendency and learning ability of the western mosquitofish, *Gambusia affinis*, after acclimation to warm, medium and cool temperatures. We showed that behaviour is affected by temperature, and overall warm-acclimated fish outperformed lower temperature fish. Mosquitofish showed remarkably rapid learning ability exhibiting a clear change within just three days. However, these effects differed by fish sex and size. In general, larger females and smaller males were quicker to approach a novel object, while smaller females and larger males were quicker to find food. Warm-acclimated fish learned to adjust to a novel object more quickly and warm-acclimated males showed a faster response to food. In contrast, neither males nor females acclimated to warm temperatures appeared to learn to find the food and it was cool-acclimated females who were both faster to find food and showed the greatest improvement over time. Nonetheless, mosquitofishes' rapid learning ability and behavioural flexibility, together with their wide environmental tolerances, is likely to augment their success as invaders in a warming world on both local and global scales.

Do Biological Invasions Mask the Effects of Ecological Restoration? A Case Study on the Old Rhine River (France-Germany)

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The erosion of biodiversity has been driven by the massive loss of natural habitats and the fragmentation of areas, especially those in the aquatic environment. To limit such deficits, large rivers are currently being subjected by ecological restoration measures, aiming the functional return of biocenoses. The reactivation of sediment transport by injection of dredged material or controlled bank erosion was favored within a 50 km natural residual section of the Upper Rhine River (France-Germany), the Old Rhine. Results from a five-years multi-compartment monitoring showed that new fluvial forms have emerged favoring typical alluvial landscapes whose water-river interface has softened as expected. However, the results also highlighted the weight of the exotic species in the evaluation of the effects of the restorations carried out, and in the degree of their achievement. Some invasive species arrived concomitantly with restoration actions and their impact was particularly structuring within the newly created biodiversity. This study comprises several surveys that have been conducted on invasive Rhine species: (i) ecological effects of the current replacement by the Japanese knotweed, (ii) case study of an invasive aquatic plant species, *Elodea Nuttallii*, (iii) the nursery facilities for the amphipod crustacean, *Dikerogammarus villosus* present at 80% in biological stands, and (iv) the impact of predation of a Ponto-Caspian invasive fish, *Neogobius melanostomus*. A wide range of methodological approaches was used, from phytotoxicity tests to stomach content analysis. A question remains about the efficient integration of such issues in restoration measures where hidden cascades yet misunderstood occurred. This approach species by species serves a community-wide understanding in a context where the factors of global change will intensify.

Interactions between Invasive Ponto-Caspian Goby Species and their Impact on Native Fishes in a Large Lowland River System

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Invasive non-native species are an important cause of biodiversity loss and particularly freshwater ecosystems are at risk. Among the fishes, a number of highly invasive Ponto-Caspian gobies were able to spread across Europe in a few decades.

We monitored during 7 consecutive years (2012 – 2018) the fish fauna at six sites in a 60 km river stretch of the Meuse River. Monitoring was performed using electrofishing gear in the riparian zone of the river. All caught fish were identified to species level, and individually measured and weighed. The dataset comprises 10,862 specimens belonging to 36 fish species. Data of the earlier fish fauna structure was available from quadrennial sampling efforts since 1998 (2932 specimens belonging to 25 species). Three Ponto-Caspian gobies are present in the Border Meuse: tubenose goby *Proterorhinus semilunaris* was the first to arrive in 2010, and since 2013 also round goby *Neogobius melanostomus* and bighead goby *Ponticola kessleri* are being found in our samples.

The dataset was analyzed in R (mixed models analysis) to study the effect of the presence of the Ponto-Caspian gobies on each other and on typical indigenous river fishes and to calculate the trend in Fisher's alpha (as a measure of diversity and an estimate of the number of species in the sample with only one individual) and of the actual number of species present.

Initial high densities of tubenose goby declined dramatically after the increase of round goby. Tubenose gobies have now almost disappeared from the main river.

The trend in Fisher's alpha as well as the actual species richness considerably declined after the arrival of the Ponto-Caspian gobies. A drop in Fisher's alpha is considered as an early-warning index for effects of invasive species on the species composition. Also a 'what if' analysis revealed a strong negative effect of the Ponto-Caspian gobies on the number of specimens of typical indigenous river species. An exponential growth in numbers of riverine fish species was to be expected were the invasive gobies not to have exponentially expanded over the years.

Especially small benthic species like bullhead and stone loach seem to respond negatively to the presence of Ponto-Caspian gobies. Predatory species like Eurasian perch and chub, on the other hand, seem to benefit from the presence of the gobies (as food source).

Future monitoring of the fish populations of the Meuse river will further strengthen our dataset and this way we hope to be able to prove in situ effects of these invasive fishes on the native fish fauna.

Plankton Community Change due to *Bythotrephes* Invasion Uncouples Indicators of Water Quality in Eutrophic Lake Mendota

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Invasive species can alter complex species interactions that are important to ecosystem function and the provisioning of ecosystem services. Outbreak of the invasive predatory zooplankton, spiny water flea (*Bythotrephes longimanus*) in Lake Mendota, WI (USA) led to decline in the keystone herbivore *Daphnia pulicaria*, and in turn, water clarity. However, there has been little evidence of increases in the frequency or intensity of harmful algal blooms, another important indicator of water quality in the lake. We use a 20-year dataset for Lake Mendota and adjacent, invaded Lake Monona to quantify the food web interactions that manifested in this invasion-induced trophic cascade. We found that diatom biomass increased with invasion in both lakes, driving lower water clarity. However, cyanobacteria biomass did not change in either lake. Multivariate time series analysis revealed that diatoms are likely limited by *D. pulicaria* grazing while cyanobacteria are more likely limited by nutrients in Lake Mendota. Phosphorus concentrations in Lake Mendota have declined since *Bythotrephes* invasion despite no clear change in phosphorus loading. Accordingly, the number of beach closures in Lake Mendota due to potentially harmful cyanobacteria blooms decreased despite declining water clarity, suggesting a divergent response in water quality to invasion. This uncoupling was mediated by complex interactions within the lake's plankton community, highlighting the importance of understanding invasive species impacts on native communities for managing important ecosystem services.

Biogeography Influences Endolithic Parasitism of Coexisting Invasive and Indigenous Mussel Species

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Biotic stress in concert with physical environmental conditions can have significant effects on competitive interactions between invasive and native species. Here, we assessed the impact and prevalence of endolithic parasitism in competing invasive and indigenous intertidal mussel species. We conducted large-scale surveys along three biogeographic regions along 2500 km of the South African coast: the subtropical east coast dominated by the indigenous *Perna perna*, the warm temperate south coast where indigenous mussels coexist with the invasive *Mytilus galloprovincialis* and the cool temperate west coast dominated by the invasive species.

The prevalence of infestation increased with mussel size and in the case of *M. galloprovincialis*, we found significantly higher infestation in the cool temperate bioregion than the warm temperate region. For *P. perna*, there was no significant difference in prevalence between the warm temperate and subtropical regions. On the south coast, where the two mussels co-occur, no significant difference in infestation prevalence was observed. Endolithic induced mortality rates through shell collapse mirrored the same patterns as prevalence of infestation.

For *P. perna*, identification of endoliths revealed clear grouping by bioregion. The findings show that endolithic cyanobacteria are generalist parasites, affecting indigenous and introduced mussels similarly.

Sea Lamprey Control on the Great Lakes: Process, Status, and Updates

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The Great Lakes are a valuable resource shared by Canada and the United States. More than 40 million people depend on the Great Lakes for food, drinking water, and recreation. The fishery alone generates up to \$7 billion for the region annually, offering recreational angling opportunities for five million people and providing 75,000 jobs. Nevertheless, the health of the Great Lakes fishery is under constant threat from habitat loss, pollution, and invasive species including sea lampreys. Because these valuable resources are multi-jurisdictional, they require a comprehensive collaborative effort to address the issues that threaten them.

By Convention, the binational Sea Lamprey Control Program (SLCP) is supported by the governments of Canada and the United States and is administered by the Great Lakes Fishery Commission (commission). The Department of Fisheries and Oceans in Canada and the U.S. Fish and Wildlife Service serve as the agencies that deploy the SLCP in the Great Lakes. The SLCP is an integrated program that relies on collaborative engagement from fishery management agencies and the public, and uses barriers and lampricides to directly suppress sea lamprey populations, while investigating biological and behavioural methods to further reduce sea lamprey abundance. This presentation will cover the development of the SLCP, control efforts and outcomes, and the place of the SLCP in ongoing fishery management in the Laurentian Great Lakes.

Assessing the Effectiveness of a Passive Size-based Selective Fish passage for Managing Sea Lamprey (*Petromyzon marinus*)

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Habitat fragmentation is often a significant detriment to population stability. Anthropogenic barriers often fragment aquatic habitat by limiting fish movement within stream systems. In particular, habitat fragmented between foraging and spawning sites could decrease the productivity of fishes within the system. This raises the possibility that selective habitat fragmentation could be used to control undesirable species. We evaluate the applicability of this technique for the management of invasive Sea Lamprey (*Petromyzon marinus*) in the Laurentian Great Lakes. We estimated the effectiveness of size-based passive sorting relative to current manual trap-and-sort techniques in current fishways in Lake Ontario, Erie, and Superior. We found that across all three fishway sites there was a positive correlation, however, the relationship indicates the potential passage of non-Sea Lamprey fishes caught within the fishway is significantly lower than the current manual trap-and-sort technique and highly variable (between 10% and 75%). The variability in success is due, in part, to the success of passively separating Sea Lamprey from desirable fishes. The effectiveness of size-based passive sorting is a promising method for selective fragmentation, however the variability within the effectiveness of different fishways demonstrates the need for further research into the causes of that variability.

Getting to a Decision: Using Structured Decision Making to Gain Consensus on Approaches to Invasive Species Control

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One of the great challenges with invasive species is deciding how to act when an invasive species is detected. This is due to a variety of diverse perspectives on the risk perception, desired end-state (objectives), effectiveness of different control methods (control options) and likelihood of success. These differences of opinion are largely due to different perspectives among individuals or agencies, and can be overcome with careful consideration, consensus-building and collective action. We report on a structured decision-making workshop aimed at determining the appropriate course of action to address a problem. Structured decision making is a formal method to identify shared goals and facilitate discussion among diverse participants with an aim to collaboratively achieve an outcome in natural resource management. The problem we address is a recently discovered invasive smallmouth bass population in a British Columbia (BC) lake. Smallmouth bass are invasive to BC, and while they may provide a unique and satisfying experience for recreational fishers, they may also exert high predation rates on young native trout and salmon. We outline the process of structured decision making and its intersection and utilization of decision analysis. The steps of structured decision making were used to quickly build consensus among a diverse group of participants on the primary objective(s) and measures to track. We then evaluated available control options and key uncertainties in the future of the ecosystem. Finally, we used this combination of control options and uncertainties to complete a decision table using the recently developed INVASPVA software, which evaluates scenario outcomes for invasive species using a population viability analysis. We report on early successes and drawbacks to this process and how it fostered collaboration and collective action to begin the process of population control for this invasive population.

Developing a Bilateral Management Plan for European Green Crab in the Salish Sea: Advances and Challenges

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Management of biological invasions in marine environments already is a complex, challenging and costly undertaking so when an invasion spans an international border these complexities and challenges are exacerbated. However, this doesn't have to equate to a "doom and gloom" scenario but rather provides an opportunity to focus limited resources on a common problem with mutually identified priorities that engage managers, researchers, First Nations/Tribes, stakeholders, politicians and the public to develop and implement potential solutions, both shorter- and longer-term. Here we use the recent discovery of European green crab (*Carcinus maenas*) in the Salish Sea as a working example to highlight advances and challenges around developing a truly bilateral management plan for a high risk invader in shared waters. Although researchers have maintained a less formal network to exchange scientific information on green crab invasion dynamics on the west coast of North America since the early days of the invasion (and in fact this network was used to convey the first reports in the Salish Sea) a more formalized network was needed to identify and align management priorities/objectives, including engagement of citizen science through Washington Sea Grant's Crab Team (a model that is being considered for implementation in Canadian waters). Currently, both Canada and the USA don't consider green crab to be widely established in the Salish Sea (they are known to be established in Sooke Basin) so many of the initial management decisions have focused on Early Detection/Rapid Response activities, especially delineating the extent of the incursion, while a European green crab-specific bilateral management plan is developed. Some of the challenges such as identifying the potential source population(s), and the advances that can inform management options including the implementation of novel genetic analyses and modeling larval dispersal, will be discussed.

Predicting Invader Ecological Impacts in a Changing World: Further Development of Key Metrics Based on Relative Impact Potential (RIP) and Comparative Functional Responses (CFR)

Jaimie T.A. Dick¹, James W.E. Dickey¹, Ross N. Cuthbert¹

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Prediction of the ecological impacts of invasive alien species (IAS) has taken major steps forward in recent years, with advances in invasion theory, adaptation of existing ecological theory, and incorporation of these into risk assessment. For example, combining the classic functional response (*per capita* effects) with proxies for the numerical response (e.g., invader abundance) has radically improved impact understanding and prediction. We have further developed the Relative Impact Potential (RIP) metric, and we now demonstrate the use of RIP in the face of climate change, introducing the Resource Reproductive Qualifier (RRQ), which takes account of both changing predator consumption *and* prey reproduction with abiotic factors such as temperature. We then outline the application of RIP to assess biotic resistance by natives against incoming IAS, the effect of evolution on invasive species impacts, application to interspecific competition *via* our novel "Competition Spectrum" argument, changing spatio-temporal patterns of invasion and associated ecological impacts, and how RIP can inform biological control agent efficacy. In addition, we have further developed the Comparative Functional Response (CFR) metric to better focus this on impact prediction and its use to probe critical behavioural aspects of invader impact, such as predator "novel weapons" and native prey "naiveté". We show that utilizing a combination of functional response metrics, principally the attack rate a and handling time h parameters, into a ratio of a/h , or the Functional Response Ratio (FRR), provides a more tailored solution to impact prediction with CFR. For example, FRR solves contradictory information from the use of attack rates *versus* handling times and, across a range of taxa and trophic groups, FRR is consistently higher for damaging invaders compared to trophically analogous natives. We argue strongly that RIP/CFR/FRR thus provide scientists and practitioners with user-friendly, customisable and, crucially, powerful techniques to inform policy and management of IAS.

Does Biosecurity Training Work? Applying the Concept of Hazard Perception to Assess Fieldworkers' Ability to Detect Biosecurity Hazards

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Preventing the spread of invasive species in the environment is imperative to limiting their environmental, economic and social impact. Vectors such as equipment and transport can mediate the accidental spread of invasive species. Biosecurity protocols aim to remove invasives from vectors and therefore reduce the risk of potential spread. However, the question remains, are fieldworkers able to identify these important vectors (here termed 'biosecurity hazards') and does training improve their 'hazard perception'? As a scientific approach, hazard perception is well utilised in driving safety assessments to assess an individual's ability to identify clear hazards and therefore mitigate against the risk. The ability of an individual to identify hazards does not necessarily translate into mitigation action, in this case, employing biosecurity, but the inability to identify hazards is likely to result in no action taken, therefore creating a biosecurity risk. This research aimed to identify the impact of training on participants' ability to identify biosecurity hazards and if certain hazards were less frequently identified than others. University (undergraduate and masters) students whose studies likely involve fieldwork, were recruited and completed a biosecurity hazard assessment before, immediately after and several months after in-person biosecurity training. The biosecurity hazard assessment consisted of still-image environmental scenes with a range of 'biosecurity hazards' present, to be identified by participants. Training enhanced the ability of both groups of participants to detect biosecurity hazards at both time points at training. Certain hazards were frequently not identified by participants, even after training illustrating the need to highlight these potential vectors in stakeholder communications. This approach could be used with a range of stakeholders and can create an informed method of assessing an individual's understanding of biosecurity vectors as well as potentially being transferrable to training itself.

Wednesday, October 30, 2019

Session G3: Predictive Ecology and Risk Assessment

Keep on RIPing in the Free World: New Metrics to Predict and Assess the Ecological Impacts of Aquatic Invaders

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Our increasingly globalised world means invasive alien species (IAS) continue to arrive in new locations with no abatement in rate. As a result, we require greater predictive powers and improved means of quantifying the ecological impacts of new IAS under abiotic and biotic context dependencies. Here, we further develop the novel Relative Impact Potential (RIP) metric, combining the Functional Response (FR: consumer *per capita* effect), with proxies for the Numerical Response (NR: consumer population response), to provide quantification of IAS impact, which we define as measurable changes in the populations of affected species. Relative Impact Potential is comparative in relation to the eco-evolutionary baseline of trophically analogous natives, and also with other IAS and members of the same species from different populations. The metrics can also reveal shifting impacts under context dependencies, both abiotic and biotic. While studies focused solely on FR, like the Comparative Functional Response (CFR) technique, have been effective tools for impact assessment in recent years, RIP retains those advantages while adding crucial elements. RIP can be further tailored depending on the study species or the likely source of spread, with one example being the incorporation of propagule pressure into the metric to allow an assessment of invasion risk. We propose that this facilitates effective management by prioritising invaders not just by potential impacts but also by likelihood of arrival. We also introduce the potential for behavioural measures to be incorporated into the metric, and propose that such studies, which have primarily addressed predator-prey interactions to date, can shed light on other critical inter- and intraspecific interactions of the invader. We argue that RIP thus provides scientists and practitioners with a user-friendly, customizable and, crucially, powerful technique to inform policy and the management of aquatic IAS.

Predicting the Effects of Reintroducing a Native Predator (European eel, *Anguilla anguilla*) into a Freshwater Community Dominated by Alien Species

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Multiple introductions of alien species can lead to the formation of new and diverse communities with diverse interactions, particularly in isolated freshwater ecosystems. In Lake Arréo (located in Basque Country, Northern Spain), the introduction of several North American species (largemouth bass *Micropterus salmoides*, pumpkinseed *Lepomis gibbosus*, red swamp crayfish *Procambarus clarkii*) and the Asian carp *Cyprinus carpio* has resulted in a unique community composed mainly of alien species. Previous efforts to eradicate these species have failed. Reintroduction of native predators could represent a complementary method, with an added biodiversity value. The reintroduction of the once native European eel *Anguilla anguilla* could lead to an increased predation on crayfish as shown by previous studies, but also affects the abundance of juvenile fish. To investigate the current situation of Lake Arreo, Stable Isotope Analyses were conducted using muscle tissue samples from each fish and crayfish species while simultaneously, stomach contents were analysed. Additionally, samples from the common reed *Phragmites australis*, the lowest available position in the trophic web, were collected and used as a baseline for the isotope analysis. To investigate the usefulness of Stable Isotopes to predict the effects of species reintroductions on present species communities, available Stable Isotope and diet data from *A. anguilla* in a German freshwater lake with a similar species composition were retrieved and included in the Arreo community analysis. While results from both, dietary and stable isotope analyses, indicate high interactions among alien species with *P. clarkii* having a central position, the modelled reintroduction of *A. anguilla* indicates possible effects on recruits of alien fish species as well as an increased feeding of *M. salmoides* on reintroduced eels.

Prayer Animal Release: An Overlooked Pathway for Introduction of Invasive Aquatic Species

Kit Magellan¹

¹University of Battambang

'Prayer animal release', in which animals are released into a natural environment, poses a paradox. Although it is assumed to benefit the animals being released as well as the practitioners, prayer release as it is currently practiced has negative impacts that are at odds with the intended compassion. Animals may die during capture and in captivity. The high demand has led to a large commercial trade in captive wild animals which may result in an unsustainable rate of harvest. Many animals carry zoonotic infections considered risky to public health. However, perhaps the greatest risk to biodiversity is the potential for biological invasions. Many of the species released during religious ceremonies are exotics which can have serious consequences for the recipient ecosystems, and multiple religious releases increases the propagule pressure of invasive species which enhances the likelihood of establishment and negative effects of invasions. It is more cost effective to prevent invasions than to eradicate or control invasive species once they have established. However, prayer release is rarely investigated as a potential pathway for introduction of invasive species and there is a marked lack of research on the subject, especially in aquatic ecosystems. Invasion researchers urgently need to 1) conduct research to establish the extent and impacts of prayer release, 2) engage with faith-based groups to encourage alteration of the practice so that it maintains its spiritual intent while promoting ecological responsibility, and 3) recognize prayer release as a major pathway for the introduction of invasive species.

A Novel Survey Technique Provides Unique Insights into Invasion Biology, Ecological Impacts and Potential Management of Signal Crayfish (*Pacifastacus leniusculus*)

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Freshwater crayfish are exceptionally successful invaders, with 90% of alien species introduced into Europe becoming established in the wild. As ecosystem engineers, they present a significant threat to aquatic ecosystems. Traditional, size class-biased survey techniques like trapping are unsuitable to generate quantitative data on crayfish population densities and structures, potentially explaining the conflicting results in previous studies regarding crayfish populations and their respective impact on native biota.

Here, we used a novel multiple drawdown technique at three sites (45 – 50 m²) along an invasion gradient to collect quantitative data on alien invasive signal crayfish (*Pacifastacus leniusculus*) populations in an upland headwater of North Yorkshire, England, where the species was illegally introduced in the 1990s. Our technique proved highly effective, with >90% estimated sampling efficiency at each site. Crayfish population density and size class distribution differed significantly along the invasion gradient, but all *P. leniusculus* populations were dominated by young-of-year individuals (~40%). Only 4.5% of all *P. leniusculus* sampled (n = 1156) were large enough to be caught in conventional traps. These findings emphasise the biases associated with trapping as a survey technique, and clearly demonstrate that trapping is unsuitable to manage or control invasive crayfish. Macro-invertebrate species richness and biomass were negatively impacted by *P. leniusculus*, with Bullhead (*Cottus gobio*) populations also severely depleted at the site where density of *P. leniusculus* peaked. The overall ecological effects appear strongly linked to the *P. leniusculus* population structure, highlighting the need for future quantitative crayfish population studies.

This case study challenges our current understanding of *P. leniusculus* invasion biology and provides an example of the severe ecological damage suffered at an upland headwater stream from this invasive alien species.

Balancing SAR Protection and Invasive Species Management: *Phragmites australis* Management in the Long Point Region

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The rapid expansion of non-native *Phragmites* is a threat to the habitats and species of the Long Point region. This region, including the dynamic sand spit on the north shore of Lake Erie, is part of a UNESCO World Biosphere Reserve due to its ecological significance and the engagement of the community in biodiversity conservation. Two National Wildlife Areas (NWAs) and more than 65 species at risk (SAR) are located in the region. *Phragmites* management has been limited in Ontario because of the lack of a licensed herbicide for over-water use. However, since 2016, the Province of Ontario has undertaken a pilot project in the Long Point region to manage over 1,100 ha of *Phragmites*. The Canadian Wildlife Service (CWS) has supported this project, but due to the regulatory system in place to protect SAR, the NWAs have not been treated. As part of the Pan-Canadian Framework, CWS identified the Long Point region as Ontario's Priority Place for Integrated Conservation Action (ICA). Subsequently, *Phragmites* was identified as a primary threat to the desired conservation outcomes. CWS is responsible for management of migratory birds, SAR and NWAs, all of which are negatively affected by *Phragmites*. However, achieving a balance between the regulatory requirements that protect SAR with the potential risks posed by invasive species management has been challenging. Following years of planning and coordination, CWS received approval to manage *Phragmites* in the region's two NWAs on a pilot-scale in 2019. Treatment efficacy, herbicide fate, and impacts to SAR and other fish and wildlife will be monitored to determine whether the long-term benefits of *Phragmites* management outweigh potential short-term impacts to SAR. Pending the outcome of the pilot, a larger-scale management project may be pursued toward a goal of reducing *Phragmites* to less than 10 percent of its current extent.

A Research Path to Achieving Control of Dreissenid Mussels throughout Entire Lakes

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Invasive dreissenid (zebra and quagga) mussels cause ecological disruption and pose a significant fouling challenge to infrastructures. Unfortunately there is no affordable and environmentally safe method for large-scale control of dreissenid populations once they have become established throughout an entire water body. This presentation reports on a research project that may offer a potential solution to this seemingly intractable problem. The key to the low, affordable cost of this proposed control approach is that it does not require treatment of the entire infested water body. In contrast to traditional control programs: 1) only a small portion of the infested water body would need to be treated ("seeded") with the control agent; and 2) the control agent would subsequently amplify itself and self-spread throughout the remainder of the water body. There is only one type of control agent with the latter two characteristics – a live one, a biological control agent. Based in Eurasia and funded by the Bureau of Reclamation (US Department of the Interior), the three-year research project to be discussed was launched in fall 2018 and is specifically designed to find a hypervirulent (i.e., extremely lethal), highly-specific dreissenid parasite that one day – following years of exhaustive environmental safety studies – would be considered for introduction into North American water bodies.

eDNA: Bridging the Gap Between Science and Management

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Detecting aquatic invasive species (AIS) in a timely manner can greatly improve the chances of preventing their spread, establishment and harm to species at risk or species of commercial importance. Environmental DNA (eDNA) sampling and analysis are developing quickly as sensitive tools that can efficiently and cost-effectively complement traditional early detection and monitoring methods for AIS. However, some natural resource managers lack confidence in eDNA technology due to ambiguous results and inadequate communication between researchers and managers. This leads to uncertainty regarding the application of eDNA results in real-time management actions, including rapid response to invasions. As a result, natural resource managers may choose to undervalue or discount eDNA results entirely for fear of sacrificing management integrity and public interest. To bridge this gap between science and management, we suggest the implementation of two critical tools: (1) reporting standards for communicating eDNA results, and (2) a policy statement providing guidance on responding to positive detections. In particular, the policy statement incorporates learning from provincial and territorial experience responding to eDNA positive detections and provides managers with support in decision-making, despite the still-improving practices of eDNA sampling and analysis. The National Aquatic Invasive Species Committee (NAISC) under the Canadian Council of Fisheries and Aquaculture Ministers (CCFAM) has lead the initiative for both tools, and their effectiveness now relies on widespread sharing and uptake by national collaborators. For example, standardized reporting protocols and defined terminology must be promoted across federal, provincial, territorial, cross-border and external partners, researchers, and stakeholders. This will allow managers at all levels of government to incorporate eDNA results into the weight of evidence for determining the presence or absence of AIS. ICAIS provides a unique forum to engage both managers and scientists to promote collaboration across disciplines towards action against the threats of aquatic invasive species.

Using eDNA Surveys to Detect Small Populations of Non-native Fishes

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Environmental DNA (eDNA) survey methods have shown considerable potential as a tool to inform management of non-native freshwater fishes, often out-performing more traditional survey methods in the early detection of new invaders and the mapping of their distributions. These applications may require the detection of small populations of the target species, present at low density within a water body, but limited information is available as to what level of sampling is necessary to give a high probability of detection. As the financial cost of increased sample replicates is an important consideration to environmental managers, the eDNA sampling effort necessary for detection needs to be compared with the effort required by more conventional survey methods. To this end, field trials were conducted to assess the level of field sampling needed to detect a small fish population in a pond, using three methods: eDNA, trapping, and electric fishing. Results of these trials, in which two fish species (*barbel* *Barbus barbus* to represent a benthic feeding species, and rainbow trout *Oncorhynchus mykiss* to represent a pelagic shoaling fish) were stocked into six fishing ponds (0.2 to 3.1 ha) at a density per species of 100 fish per ha, will be presented.

Sequencing and Assembly of the Quagga Mussel (*Dreissena rostriformis bugensis*) Genome: A Tool for Development of Biocontrols

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The quagga mussel (*Dreissena rostriformis bugensis*) has spread broadly in the Laurentian Great Lakes and surrounding waters since it was first identified in Lake Erie in 1989. In the Western United States quagga mussels were first detected in Lake Mead in 2007, and have subsequently become established throughout the Lower Colorado River, as well as in connected waters and other sites in the Lower Colorado River Basin. Quagga mussels pose a variety of risks to invaded waters, including impacts to ecosystems, infrastructure, and recreation. Ecological impacts due to high rates of selective filter feeding and competition for substrate occupancy may affect threatened and endangered species, and other native species. Fouling of infrastructure by quagga mussels also presents a significant risk to water delivery and hydroelectric power generation, particularly in the Western United States. The risk of transport and introduction to uninfested waters and impacts to sport fish can also limit opportunities for recreation by the public. Numerous physical and chemical controls have been developed to control quagga mussels in small waterbodies and to mitigate impacts to water delivery and hydropower infrastructure. However, no proven techniques are currently available for control or eradication of quagga mussels in large open water systems. Genetic control has recently received significant attention as an approach to control or modification of invasive species, based upon the development of widely applicable and versatile techniques for targeted genome modification. Any use of such techniques must be predicated on a detailed understanding of the structure and organization of the organism's genome. To this end we have conducted deep sequencing of the quagga mussel genome. The aim of this project is to develop a high-quality assembly of the quagga mussel genome and to identify potential targets for genetic control or other potential weaknesses that could be exploited for population control.

Biotic Resistance from Native Predators Predicts Mosquito Invasion Success and Informs Biocontrol Strategies

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Invasive species continue to proliferate and detrimentally impact ecosystems on a global scale. Whilst impacts are well-documented for many invaders, we currently lack tools to predict invasion success, in turn limiting effective management responses, such as biocontrol. Biotic resistance from resident community members may be a particularly important determinant of the success of invaders. The present study further develops traditional ecological concepts to better understand and quantify invasion success, utilising functional and numerical responses and prey switching. We apply these methods to the highly invasive Asian tiger mosquito *Aedes albopictus* and the trophically analogous native mosquito *Culex pipiens*, since the former is a superior resource competitor but fails to displace the latter in the field. We quantified predation towards the mosquitoes by three native and widespread cyclopoid copepods, *Macrocyclus albidus*, *Macrocyclus fuscus* and *Megacyclus viridis*. All copepods demonstrated higher magnitude type II functional responses towards the invasive prey over the analogous native prey, aligned with higher attack rates, lower handling times and hence higher maximum feeding rates. Further, all copepods exhibited significant prey preferences for the invasive *A. albopictus* over the native *C. pipiens*, and preferences did not switch depending on the proportional availabilities of the invasive prey. We subsequently develop a novel metric which integrates fecundity as a predator numerical response proxy, alongside the functional responses and prey preferences, to determine and compare the potential biotic resistance from the three predators. This metric revealed *M. viridis* as a particularly efficacious biocontrol agent towards *A. albopictus*. Our results corroborate with field patterns of invasion success and biotic resistance, illustrating the predictive capacity of our methods. We thus propose the further development of traditional ecological concepts, such as functional responses, numerical responses and prey switching, in the evaluation of invasion success and biotic resistance.

Predicting Impacts of Invasive Fishes Across Habitat Types

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Predicting impacts of introduced fishes is key to informing management decisions. Such predictions are challenging because impacts are often poorly documented and highly context dependent across the invaded range. An increasingly used method for quantifying and comparing per capita impacts of invaders under different ecological contexts involves measuring the invader's rate of predation in relation to available prey density – i.e. its functional response. We compared functional response curves for two invasive fishes, Tench (*Tinca tinca*) and Round Goby (*Neogobius melanostomus*), to determine how their feeding efficiency varies on different substrates. Published studies consistently report Tench in association with soft sediments, implying the species might be an inefficient predator on coarser substrates where prey have increased access to refugia (Hypothesis 1) and, therefore, a weak competitor to native fishes typically found in rocky littoral habitats. In contrast, Round Goby is reported to prefer rocky substrate over soft sediments in both field and experimental studies, possibly reflecting better adaptations to foraging on these substrates (Hypothesis 2). Both of these hypotheses are contradicted by the results of our functional response experiments. Further evidence is provided by a complementary mesocosm experiment which revealed that Tench growth is not dependent on substrate size. Finally, we examine the interacting effects of substrate and temperature on Tench to determine whether increasing water temperatures alter the influence of substrate on Tench functional response.

Influence of Climate Warming on the Ecological Impacts of Invasive Crayfishes

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Climate warming is expected to facilitate invasions of temperate regions by warm-adapted species by removing thermal barriers and increasing seasonal stress for cold-adapted competitors. It may also mediate the ecological impacts of invaders by promoting changes in abundances and per capita effects (e.g. feeding rates), thereby causing shifts in predator-prey dynamics and competitive dominance.

Invasive species are predicted to have higher resource consumption rates than natives (Resource Consumption Hypothesis, RCH), and their per capita effects are predicted to be inversely proportional to the difference between ambient abiotic conditions and their physiological optimum (Environmental Matching Hypothesis, EMH). Crayfishes are excellent model organisms to test these hypotheses, owing to the aggressive behaviour and invasion histories of numerous species. We assessed the effects of water temperature on prey consumption and competitive dominance of two close relatives: the rusty crayfish *Faxonius rusticus* and virile crayfish *F. virilis*. The invasive rusty crayfish has largely replaced the native virile crayfish within the Great Lakes basin.

Through a series of lab experiments, we compared the maximum feeding rates and food resource competitive abilities of these two species at current and elevated temperatures projected for nearshore habitats in the lower Great Lakes. Secondly, we examined whether differences in maximum feeding rates of rusty crayfish populations can be predicted by their latitudinal provenance. We tested the following predictions: 1) individuals from invasive populations will exhibit higher maximum feeding rates than those from native populations (RCH); and increasing temperatures will result in 2) higher maximum feeding rates and 3) increased competitive dominance of individuals from southern populations compared with northern ones (EMH).

Predicting Grass Carp Spawning Success using a 3-D Hydrodynamic Model

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Due to the potential for a Grass Carp invasion in the Great Lakes, there is a focus on identifying spawning tributaries to the Great Lakes to inform management efforts. Modelling Grass Carp egg movement in water is a potentially useful method, as spawning success is determined by egg suspension in the water column at the time of hatching. Current modelling approaches primarily use one-dimensional hydrodynamic models, which may simplify the velocity profiles laterally and vertically in a tributary. To investigate the impact of model dimension on hatching rates, a case study will be presented on the development of a three-dimensional hydrodynamic model on the Sandusky River, a tributary to Lake Erie, where Grass Carp is currently spawning. Methods of predicting egg movements in a velocity field, using a Lagrangian Particle Tracker and a temperature-dependent hatching model, were integrated into a commercial three-dimensional hydrodynamic model (EFDC Explorer). The model was calibrated and validated using water level and velocity measurements taken during a high flow event. Egg capture data, which includes egg developmental stage, location and time of capture, are used to validate model outputs. Model spawning runs successfully predict egg capture data and indicate that Grass Carp could successfully spawn in the Sandusky River at distances shorter than previously assumed. The model also showed a mechanism in which eggs were being re-suspended after being trapped in low-velocity zones, which made hatching rates considerably higher. Low-velocity zones and the re-suspension mechanism would not have been simulated by a one-dimensional model, indicating that the use of more complex models may be required in future modelling efforts. The model outputs provide useful insights on Grass Carp spawning and information about spawning success in different flow scenarios, which can be used to inform management decisions on preventative strategies.

Long-Term Invasion Impacts: Coexistence or Extirpation for Native Mussels in the *Dreissena* Era?

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Both dreissenid species, *Dreissena polymorpha*, the zebra mussel, and *Dreissena rostriformis bugensis*, the quagga mussel, are spreading in Europe during the last 200 years and in North America during the last three decades. Colonization of waterbodies by *Dreissena* has caused dramatic declines in native freshwater mussels, especially in Unionidae. Both European and North American experience suggest that the highest unionid mortalities are recorded during the rapid dreissenid population growth followed by local unionid extirpation or coexistence, however it is unclear what factors are important for survival of native mussels. Unionid "refuges" are created by a combination of factors that allow unionids to escape or remove attached dreissenids and/or inhibit high *Dreissena* densities. The first unionid refuges were found in Great Lakes a few years after *Dreissena* introduction, and ongoing studies revealed a suit of conditions that allow dreissenids and unionids to co-exist. We found that in contrast to the early stages of invasion, the effects on unionids may decrease as the population of *Dreissena* stabilizes or decreases. In addition, the competitive replacement of zebra by quagga mussels may also relax impact on native species since the rate of unionid infestation depends on the dominant *Dreissena* species in the lake. Using results of ecological niche modeling to predict potential refuges we identified large- and small-scale habitat parameters that can facilitate unionid survival. Critical evaluation of factors that aid or prevent unionid coexistence with dreissenids can provide an opportunity for native mussel conservation in regions on both continents that are still being invaded by dreissenids.

Quantifying the Ecological Impacts of Invasive Freshwater Fish through a Controlled Release Experiment

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Salmonids are amongst the most important invasive freshwater fish worldwide, with rainbow trout considered the most widely introduced salmonid in the world. Flooding across Northern Ireland in 2017 resulted in the escape of at least 300 000 farmed rainbow trout into the River Strule prompting investigation into the ecological impacts of escaped farmed rainbow trout. Upstream stretches of the River Bush in County Antrim, Northern Ireland, represent a unique opportunity for studying the ecological impact of rainbow trout in a freshwater stream, without resulting in the spread of the invasive organism. The upstream portion of the River Bush is isolated from other rivers by the Altnahinch Dam. Furthermore, a concrete platform and wall isolates upper stretches of the river from the lower stretches, allowing a controlled environment with which to compare results. In May 2019, rainbow trout will be released into the River Bush, upstream of the Altnahinch Dam but downstream of the separating wall across the river. Several key variables will be monitored along the river for one year following this release: invertebrate density and species richness, and the size, distribution and gut contents of the invasive and native fish species. In addition to this, riverside predator density will be recorded along the river using a system of camera traps. A subset of brown trout and rainbow trout will also be tagged with acoustic tags and their movement behaviour recorded, to observe behavioural effects on the brown trout of the release. This ambitious project will obtain a multifaceted picture of the ecological impacts of rainbow trout in a lotic system. In addition, the use of a single river with controlled and experimental sections will result in more confidence in the real impact of the invasive fish.

The Role of Native Marine Predators in Regulating Invasions: A South African Case-Study

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Strong predation pressure from native predators can invoke biotic resistance by limiting the abundance and distribution of invasive prey. Alternatively, native predators may fail to recognise novel species as an additional food source, which may in turn facilitate an invasion. The South African coastline has experienced a number of prominent invasions from alien species with the recent detection in 2009 of *Semimytilus algosus* on intertidal shores. In 2016 the species was found for the first time in subtidal zones, however it was unknown whether native predators would readily predate on this novel abundant prey. We therefore investigated whether this invasion was disrupting subtidal predator-prey interactions and whether there was potential for native predators to limit further subtidal spread of *S. algosus*. We first examined prey preference of native predator species in isolation to begin to evaluate potential predation pressure on the invasive mussel compared to native species. We examined predation by the rock lobster *Jasus lalandii* and spiny starfish *Marthasterias africana* towards various combinations of native and invasive mussels, finding that both predators displayed a preference towards native species. This occurred even when it was the least abundant prey on offer indicating a potential for invasion facilitation for *S. algosus*. We subsequently considered effects of multiple predator species by examining predation on mussels by native rock lobsters and whelks *Burnupena* spp. in isolation compared to when in combination. Both predators exhibited a preference towards native mussels when foraging alone, however prey selection in rock lobsters became more varied when co-occurring with whelks, resulting in overall increased predation risk for invasive *S. algosus*. The results from this work illustrates the dynamic nature of predator-prey relationships and demonstrates the need to account for multiple predators, and their identity, when assessing potential impacts of native predators on invasive prey.

Invasive Species Change Ecosystem Functions in Lake Constance

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¹Eawag

Lake Constance, one of the largest Alpine lakes on the border between Germany, Austria and Switzerland, has undergone extensive changes in the past century. In the 1950-1980s, Lake Constance experienced a phase of severe eutrophication caused by untreated sewage and intensive agriculture, resulting in significantly increased nutrient-levels. Although the natural trophic state of the lake has been almost completely restored, there have been irreversible changes to the communities of aquatic organisms.

In addition to eutrophication, climate change and especially the invasion of non-native plant and animal species are endangering natural biodiversity. This leads to changes in the food webs and affect ecosystem functioning in Lake Constance. Today, there are more than 37 non-native species in Lake Constance, including e.g. three-spined stickleback (*Gasterosteus aculeatus*), Zebra mussel (*Dreissena polymorpha*) and Quagga mussel (*Dreissena rostriformis bugensis*).

Especially the three-spined stickleback and Quagga mussel populations have exploded in the last years, with sticklebacks becoming the most abundant pelagic fish species of the lake. Sticklebacks compete for food (zooplankton) with other fish and even feed on their eggs and larvae, particularly of the commercial interesting whitefish. Compared to the Zebra mussel, the Quagga mussel is able to settle in greater water-depth, which causes problems with water intake pipes and other structures. Furthermore, the Quagga mussel is an important competitor for zooplankton-species feeding on phytoplankton. We hypothesize that the decline in catch yields and fisheries in Lake Constance is caused, at least partly, by these two invasive species.

We present a large EU funded project (www.seewandel.org) that i.a. investigates causes and consequences of such invasions for Lake Constance and its ecosystem functions, and that aims to develop methods to mitigate the consequences. We present first results with the goal to share and discuss our ideas and invite others that study similar systems to collaborate.

Wednesday, October 30, 2019

Session 11: Impacts on Biodiversity and Ecosystems

Invasive Species Sleeper Populations: How Important are They and What Do They Mean for Management?

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Invasive species are a key driver of global environmental change, yet our understanding of how populations of invasive species establish, persist, and grow in the early-stages of invasion is surprisingly limited. Here, we explore the concept of 'sleeper populations': persistent low-density invasive species populations that often occur below detection thresholds. While sleeper populations typically go undetected and are largely benign in the short-term, great risk lies in disturbance or environmental change triggering abrupt shifts in abundance and impact. Detection of the population at outbreak levels belies much more complex low-density dynamics. We review evidence for the prevalence of sleeper populations, explore mechanisms that trigger them to high density and impact, and suggest that the phenomena of invasive species sleeper populations is underestimated in invasion biology. We outline how this phenomenon may have important implications for our basic understanding and management of biological invasions.

Alien Species Management Policies in the Trilateral Wadden Sea

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The Wadden Sea area stretches from the northwest of The Netherlands, through the river estuaries of Germany to Skallingen in Denmark. It includes a multitude of habitats hosting numerous plant and animal species in tidal channels, sandy shoals, sea-grass meadows, mussel beds, sandbars, mudflats, salt marshes and estuaries. Because of the unique ecological value, Germany and The Netherlands inscribed their parts of the Wadden Sea on UNESCO's World Heritage List in 2009 and Denmark followed suit in June 2014.

Among the several species found in the Wadden Sea area, several invasive alien species are present including the Pacific oyster *Magallana gigas*, the American razor clam *Ensis leei* and the American comb jelly *Mnemiopsis leidyi*. These may have long-lasting effects on native fouling, infauna, and pelagic communities. In 1978, the three countries (Denmark, Germany and The Netherlands) formed a Trilateral Wadden Sea Cooperation (TWSC) to achieve as far as possible, a natural and sustainable ecosystem in which natural processes can proceed in an undisturbed way.

The formation of the TWSC resulted in a shift in policy making procedures for the Wadden Sea area. The traditional national policy making processes in the three countries were replaced by a trilateral approach with several challenges. Policy making for the management of alien species in the Wadden Sea presents several challenges due to differences in legislation, cultures, linguistic ties, and geographical locations.

This presentation describes the trilateral approach to policy making and specifically presents the procedure for the development of the Management and Action Plan for Alien Species (MAPAS) in the Wadden Sea area. The challenges and opportunities encountered in the process are enumerated and the steps taken to ensure the development of an acceptable trilateral policy for alien species management are discussed.

Lessons Learned from Broad-spectrum Early-detection Monitoring in the Laurentian Great Lakes

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Motivated by decades of ecologic and economic impacts from a growing list of nonindigenous species, the 2012 Great Lakes Water Quality Agreement between Canada and the United States calls for establishment of an aquatic non-indigenous species early detection and rapid response network. This presentation focuses on lessons learned from broad-spectrum (i.e., cross-species) early-detection monitoring conducted by the U.S. Environmental Protection Agency as part of this Great Lakes network. Such monitoring is inherently resource-intensive, with surveys capable of detecting 95% of the species pool taking on the order of 100, 200, and 500 samples for fish, benthic invertebrates, and zooplankton respectively. We have found a random probability design an effective starting point for monitoring; once information concerning species distributions is generated the design can be optimized by emphasizing habitats and collection devices that contribute most strongly to the species pool. Effective tools for generating such information include occupancy modeling and community rarefaction, neither of which hinge on the presence or identity of any particular non-indigenous species. In applying a combination of organism collections identified via morphology and DNA and water samples identified only via contained eDNA, we have learned to temper enthusiasm for DNA metabarcoding with constraints stemming from sequencing difficulties and still limited invertebrate barcode availability. An adaptive monitoring cycle involving repeated assessment, refinement, and outcome communication has proven a helpful framework for broad-spectrum early-detection monitoring in the Great Lakes.

Development of a Coordinated Regional Program to Monitor for Dreissenid Mussels in the Columbia River Basin

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Efforts to monitor for the presence of dreissenid mussels in the Columbia River Basin (CRB) have increased over the past decade in response to concerns that these invasive mussels may be introduced and become established. The motivation for the increased monitoring is to improve the probability of detecting infestations and, optimally, to provide early detection capabilities so that new arrivals are detected soon after their introduction and eradication and quarantine measures can be used to control their spread. Research that examined the attributes of dreissenid mussel monitoring programs in the CRB suggests that recent monitoring efforts are likely insufficient to provide a high probability of detecting invasive mussel infestations or to provide early detection capabilities. Consequently, even though more effort is being expended to monitor for dreissenids, the probability of detecting an infestation remains low. To increase the probability of detecting invasive mussel infestations in the CRB, scientists from the U.S. and Canada have come together to explore options to increase the efficiency of existing monitoring programs. For example, reallocating existing monitoring efforts to areas of higher infestation risk, such as areas where propagule pressure from areas already infested is highest and where dreissenids are most likely to become established, could increase the probability of detecting infestations. We will provide an overview of regional efforts to 1) convene an international forum to coordinate dreissenid mussel monitoring in the Columbia River Basin, 2) assess the extent and magnitude of current monitoring efforts within the CRB, 3) better define infestation risk for water bodies in the CRB, and 4) develop a strategy to coordinate and focus dreissenid mussel monitoring activities in the U.S. and Canadian portions of the CRB.

Avoidance Behavior of Cold-, Cool-, and Warm-water Fish Species to Zequanox®, a Biopesticide for Dreissenid Mussel Control

Matthew T. Barbour¹, James A. Luoma¹, Todd J. Severson¹, Jeremy K. Wise¹

¹U.S. Geological Survey, Upper Midwest Environmental Sciences Center

Zequanox® is an EPA-registered biopesticide for controlling populations of dreissenid mussels (zebra and quagga mussels). Zequanox has demonstrated selective toxicity toward dreissenid mussels; however, a recent laboratory study indicated the potential for Zequanox to impact a non-target salmonid species. We assessed the potential exposure risk by observing the avoidance behavior of two representative species of cold-, cool-, and warm-water fish (lake trout, brook trout, lake sturgeon, yellow perch, and fathead minnow). Fish were subjected to the maximum allowable concentration of Zequanox per the product label (100 mg A.I./L). Naïve juvenile fish (n = 30 per species) were individually observed in a two-current choice tank with simultaneous and unobstructed flow of treated and untreated water. Each individual fish was observed during a control period (20 min) with no treatment and two treatment periods (20 min each), where the treated side was alternated between treatment periods. Positional data was collected and tabulated in real time with EthoVision® XT software. Zequanox concentrations and water quality (pH, dissolved oxygen, temperature, and specific conductance) were monitored during each trial. Results from this research will help inform resource managers of the likelihood of non-target fish to avoid Zequanox treated areas, thereby assisting in the establishment of treatment-related risk assessments.

MPN Validation across North America using Genomic Tools

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The most probable number dilution-culture assay (MPN) is used in regulatory tests of ballast water treatment systems to enumerate viable phytoplankton. However the United States Coast Guard has not yet accepted MPN, in part due to concerns of biased results due to cells being viable but not growing. MPN does not assess the fate of every cell, and the bias can only be evaluated by a companion method that assesses the ability of the various taxa to grow. This "growability" is the complement of the bias, and has been evaluated by microscopic taxonomy of before-culture and after-culture samples. However, this is extremely laborious and few data have been produced for phytoplankton growability in MPN assays. To address the need for more and more reliable growability data, a method was developed using next-generation sequencing (NGS) and quantitative real time PCR (qRT-PCR) techniques that target the V9 region of the 18S rRNA gene for the taxonomic identification and growth assessment of eukaryotic phytoplankton, respectively. This companion method was used in an MPN method development experiment where 95 of 97 eukaryotic phytoplankton in the before-culture sample demonstrated growth, and an additional 13 taxa demonstrated growth from non-detect in before-culture samples. In order to assess a large numbers of MPN samples, a high-throughput MPN method was developed and validated with live and dead phytoplankton cultures, and then applied to 64 North American sites from the Pacific and Atlantic coasts, and from throughout the Great Lakes and other fresh water sites. The high-throughput capacity was also used to assess different size fractions of phytoplankton and compare different incubation conditions for all samples, all in triplicate. MPN values were correlated with total cell counts assessed by flow cytometry, and different incubation conditions had little impact on MPN results. The companion method showed high growability: across all sites 1,012 of 1,017 taxa demonstrated growth in MPNs. The average growability from all sites was 87% of taxa, with 12% undetermined and <1% non-growers. The average abundance-weighted or community growability value was 85%. These data address concerns of growth bias in the MPN method.

Global Aquatic Species Invasions in Urban Environments

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Invasions occur across a spectrum of landscapes from natural to human dominated. Human-dominated landscapes may be more susceptible to invasion as a result of increased propagule pressure and resource supply, reduced negative interactions, and altered environmental conditions. The ecological impacts in human-dominated landscapes may be disproportionately large, leading to altered ecosystem services and impacts on human health, and resulting in high associated economic costs. A *Global Urban Biological Invasion Consortium* (GUBIC) has been created to facilitate a network of projects and collaborations to determine the magnitude of ecological and economic impacts in urban areas globally. To examine these issues in aquatic systems, we are developing a global database of native and invasive species and environmental and demographic variables by watershed, and we welcome contributions to this database. In this presentation, we will outline the key research questions of GUBIC from an aquatic perspective and present a preliminary analysis of the data in our global freshwater fish dataset to date.

Predicting Non-Native Plant Species Richness with Confidence in Undersampled Watersheds

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Freshwater habitats provide a myriad of ecosystem services vital to the continued survival of human beings. Ecosystem services that are directly threatened by non-native species invasions include the provisioning of clean water, streambank stabilization, habitat for fish and invertebrates, and recreational boating and swimming. Despite the threat to freshwater ecosystem services that non-native species represent, we are currently lacking a complete reliable map of their distribution across the U.S. Our current understanding of the distribution of non-native and potentially invasive species is limited by the fact that the majority of U.S. watersheds are data deficient in terms of the number of records of alien species reported. We use ensemble modeling to predict the distribution of non-native plant richness across the contiguous U.S. based on the characteristics (e.g. climate, land use composition, hydrologic alteration and degradation) of watersheds that have 10 or more records (n=869). The ensemble model combines the predictions of three individual machine learning algorithms in a single model, resulting in higher predictive accuracy. We applied this model to the remaining watersheds of the U.S. that are considered to be undersampled (having less than 10 records). We also assessed and mapped the confidence of our predictions on a watershed-level using conformal regression, which has a guaranteed error rate and few assumptions. Our framework enables scientists to robustly predict non-native species richness, as well as, visualize the uncertainty associated with individual level predictions, which can be readily shared with decision-makers. This approach is applicable to predicting the macroscale distribution of other taxa with potentially undersampled habitats, and the data and R code will be freely available on GitHub.

Flood and Storm Tracker (FaST) Tool: Updates after the Initial Storm Season

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The Nonindigenous Aquatic Species (NAS) database (nas.er.usgs.gov) contains occurrences of over 1,280 aquatic species that are either exotic to the U.S. or have moved outside of their native range within the U.S. The NAS Flood and Storm Tracker (FaST) is a tool developed in 2017 to assess and map the potential spread of current aquatic nonnative species to new drainages after a flood or major storm such as a hurricane. The FaST maps highlight the areas that had inland and coastal flooding based off USGS flood gauges and high-water marks to infer inundation levels. We then match those flood level heights to landscape contour heights to determine locations of sufficient height to potentially connect adjacent drainages. Users can assess the proximity of established population occurrences to those breach points and determine if actions are needed to address potential spread.

We have improved the initial stage in the FaST map development by reducing the scale of the potential spread, adding risk categories to spread, and creating rules to account for downstream movement. The scale of spread across drainages decreased from HUC8 to HUC12, estimating a more conservative potential spread distribution. Risk categories were assigned to drainages based on distributions of historic high-water marks and breached flood stages near drainage divides. Rules were added to account for movement downstream and discount upstream movement when elevation gradients are too high for passive transport by water currents. The final stage in the FaST map is to validate potential spread due to flooding by checking for new species occurrences up to one year after a flood event. We were able to validate 2017 FaST maps with several new species reports in 2018 indicating possible movement coinciding with recent flood events.

Predicting Trends in Climate Similarity of Global Aquatic Watersheds Under Multiple Climate-Change Scenarios

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Climate change and invasive species are two major sources of potential impacts to global ecosystems. These two impact sources may interact in unknown ways to have greater negative impacts than currently understood. Existing software, CLIMATCH, uses the CLIMATE algorithm to measure how similar the native range of a potential invasive species is to areas of potential invasion using current climate data. In this study, we predict future climate similarities and their trends between global aquatic watersheds under different climate-change scenarios. We use data from the WorldClim database, downscaled general circulation model data generated from the International Panel on Climate Change Coupled Model Intercomparison Project 5 models. These models produce forecasts of many climate variables under multiple future greenhouse- gas emissions scenarios. These data were used in the CLIMATE algorithm based on 16 bioclimatic variables to identify future trends in climate similarity between global watersheds by completing pairwise analyses of climate similarity of these regions. This method can be used help predict the survival and establishment of aquatic invasive species in under future climate scenarios, information required for management actions such as risk assessments.

Life-history Traits for Predicting Invasiveness in Non-native Freshwater Fishes

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At the ICAIS 2007 in Nijmegen, Copp & Fox first proposed a model, based on the relationship between mean age at maturity and the mean fish length at age 2 years (i.e. juvenile growth), for predicting the invasiveness of introduced populations of pumpkinseed (*Lepomis gibbosus*) in Europe and in Turkey. That model was validated in subsequent studies of European pumpkinseed populations. This relationship between age at maturity and juvenile growth provided a template with which similar predictive models were developed for another North American freshwater fish introduced to Europe (black bullhead *Ameiurus melas*) as well as for crucian carp (*Carassius carassius*), which is native northerly parts of continental Europe but an introduced species in Great Britain. In this presentation, we will explore the background development of this predictive model in its application to pumpkinseed, including examples within a climate-warming context and the applications to black bullhead and crucian carp. In the case of the black bullhead, we examine the model's application to predict the biological trait response to a population boom and bust phenomenon. We examine the research needs for implementing this life-history modeling approach to small-bodied fishes.

Lake Morphometry Determines *Dreissena* Invasion Dynamics

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Population dynamics and distribution of dreissenids (zebra and quagga mussels) in the Laurentian Great Lakes are largely governed by lake morphometry. Specifically, population temporal and spatial patterns as well as the overall population size are different between shallow and deep lake regions, along with the decline in both food and turbulence in the benthic boundary layer. In just four years after the first discovery in 1986, zebra mussels spread across the Great Lakes region, colonizing shallow areas and initiating drastic changes in water quality and food webs. By the early 2000s, quagga mussels displaced zebra mussels in shallow regions and colonized offshore areas previously unoccupied by *Dreissena* in deep lakes, leading to additional ecosystem changes. We quantify these changes in dreissenid food web impacts by incorporating observed invasion dynamics into biophysical models that account for disparate mixing patterns and spatial gradients in temperature and primary production in shallow vs. deep lakes. In shallow regions, the replacement of zebra by quagga mussels does not greatly change the overall dreissenid density and their ecological impacts, but the ability of quagga mussels to expand and thrive in deep regions increases overall lake-wide population density by an order of magnitude and, therefore, increases overall dreissenid impacts. Typically, quagga mussels in shallow regions overshoot their carrying capacity and begin to decline 12-15 years after first detection. This decline is accompanied by the shift of population maximums toward deeper regions, which likely results in overall slower population growth and production on a lake-wide basis.

Seasonally Migrating Round Goby in Lake Ontario: A Case of Missing Adults?

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Population size structure is an important feature of migrating organisms with implications for future reproductive success, nutrient translocations, and conservation efforts. The round goby (*Neogobius melanostomus*) invaded Lake Ontario, USA over 25 years ago and it moves offshore to deeper waters in winter and returns to nearshore waters in the spring. We assessed round goby density and size structure using underwater video to document population conditions when the fall migration commenced and again when it returned in the spring. The departing goby population was dominated (65%) by adult fish >5 cm TL, whereas the returning population was predominately (62%) juvenile fish ≤5 cm. We speculate that the loss of larger fish during the winter in offshore waters represents a potentially significant nutrient translocation by round gobies. Possibly, offshore or migratory habitats contain fewer refugia, making larger fish vulnerable to offshore predators in winter or during migration. In support of this possibility, stable isotope and gut content data suggest Lake Sturgeon consume large numbers of round goby and predominately fish in the 4-6 cm size range.

Investigating the Effects of Eelgrass and Predation on Fouling Community Composition in a Temperate Estuary

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Connectivity via multiple pathways has increased the spread of non-native marine species. Many of these non-native organisms are fouling species, which include many sessile filter-feeding invertebrates. Despite the abundance and broad distribution of fouling species, few studies have investigated their potential to spread from the initial introduction site into surrounding habitats including seagrass beds. Seagrasses are important foundation species that influence the abiotic environment and can potentially act as a filter against invasion. For example, eelgrass structure can physically reduce flow, lower light availability, and alter water chemistry, affecting the species that are able to recruit in this habitat. Alternatively, the spread of invasive fouling species can be limited by native predators. Native predators can preferentially consume non-native prey, acting as a source of biotic resistance against invaders. This study examined the influence of seagrass structure and predation on fouling community composition and the abundance of non-native species in Tomales Bay, CA. We found that predation altered community composition through species-specific effects. Predation was highest on solitary ascidians, of which, predation was stronger on the non-native species *Ciona robusta*. The effects of predation slightly differed inside and outside of seagrass; nonetheless, the effects of seagrass on community composition were strong. Settlement plates established inside eelgrass beds showed more bare space and lower species diversity than plates located outside of eelgrass beds. Differences in the cover of non-native species between predation treatments and across habitats are complex and due to species-specific tolerances. Understanding the relative importance of factors that limit the spread of non-native fouling species is crucial in the face of climate change and additional biological invasions, informing future efforts to manage invasions.

Evaluating Upstream Passages and Challenges by Bigheaded Carp at a Mississippi River High-Head Dam

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Bigheaded carp (*Hypophthalmichthys* spp) populations continue to expand their range in North America, necessitating efforts to limit the spread and establishment of reproducing populations. Potential control measures include the installation of deterrents (e.g. electric, sound) and targeted harvest to diminish pressure on these deterrents. Mississippi River Lock and Dam 19 is a high-head dam that represents a 'pinch-point' because the gates are never open and passage through the lock chamber is the only means by which fish can complete upstream migrations. As such, L&D 19 represents a location that could be a pivotal control point for minimizing the spread of invasive species in the Upper Mississippi River. Our objectives were to 1) use an acoustic telemetry array around the lock to study the timing (i.e. seasonal and diel) and behavior of bigheaded carp movements within this system, 2) evaluate the relationship between fish presence in the array (challenges) and environmental factors (e.g. flow, temperature, barge passages), and 3) relate fish passage events through the lock to lock operations for river traffic. Acoustic transmitters were surgically implanted into 66 silver carp and 53 bighead carp and an acoustic receiver array was deployed in the downstream lock approach. Additional receivers were deployed in and above the lock chamber to detect successful upstream passages. From March through November of 2017, 21 silver carp and 14 bighead carp were detected in the array, of which 2 silver and 6 bighead completed successful upstream passages through the lock. Successful upstream passages occurred with the upstream lockage of a 12-15 unit barge, followed by the downstream lockage of another barge. These data will be used to design and evaluate the potential effectiveness of a deterrent in this location.

Alien Species Dynamics Within the UNESCO World Heritage Site the Wadden Sea

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The Wadden Sea forms one of the largest unbroken wetlands in the world. It includes a multitude of habitats with tidal channels, sandy shoals, sea-grass meadows, mussel beds, sandbars, mudflats, salt marshes and estuaries. Therefore the area is home to numerous plant and animal species, including mammals like seals and porpoises. Several invasive alien species like the Pacific oyster *Magallana gigas*, the American razor clam *Ensis leei* and the American comb jelly *Mnemiopsis leidyi* are expected to have long-lasting effects on the native fouling, infauna, and pelagic species communities. Acknowledging this biodiversity risk, alien species focused surveys including most of the marine habitats present, were conducted in 2009, 2011, 2014, and 2018. In addition to the rapid detection of various alien species new to the Wadden Sea, The Netherlands and Europe, these surveys resulted in a better understanding of the main import vectors, pathways, and sites of introduction. Furthermore colonization patterns were revealed in a 10 year time period throughout the Dutch Wadden Sea. Especially hull-fouling appeared to have been of importance for the introduction and spread of these species, as was also supported by the results of the SETL-project. Within this project settlement plates have been deployed and checked for fouling species in the region every three months since 2007. At least partly based on the results of these alien species focused monitoring initiatives, a trilateral alien species management plan for the whole Wadden Sea region is developed by The Netherlands, Germany and Denmark. As hull fouling appeared to be the main vector of the recent introduction and further distribution of marine alien species, several initiatives for potentially assessing, evaluating and managing this risk have been started nationally within the Netherlands and internationally within Europe.

Poeciliid Invasion Models

Kit Magellan¹

¹University of Battambang

One goal of invasion ecology is to find common factors that promote invasion success in disparate species. This aim is hampered by the huge range of contributing species-specific variables that need to be considered. One solution is to examine single species or related taxa in a range of invaded habitats over wide spatial and temporal scales. One suitable family in aquatic ecosystems is the Poeciliidae. This group of over 200 fish species includes several very successful invaders. The mosquitofish, *Gambusia affinis*, is considered one of the world's 100 worst invaders. Anthropogenic influence is perhaps the main factor in their success; mosquitofish and guppies, *Poecilia reticulata*, have been introduced to over 70 countries across 6 continents, primarily for mosquito control. Contributing family-specific factors include their wide environmental tolerances and high adaptability, which enables them to colonise aquatic ecosystems with a broad range of conditions, and their viviparous reproductive system and rapid population growth, which promotes competitive success and rapid spread. I will highlight some of the ways in which the Poeciliidae are already contributing as model species in invasion science and suggest future research directions that capitalize on the existence of this globally invasive family.

Effects of Ballast Water Exchange and Treatment on Microbial Community Structure

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The current regulatory framework for mitigating invasion risk via ballast water is based on the attainment of numerical discharge limits, primarily through ballast water treatment (BWT) relying on shipboard ballast water management systems (BWMS). These systems adopt technologies commonly used in drinking and wastewater treatment industries to kill, remove, or inactivate organisms in ballast tanks. In the US, the Environmental Protection Agency imposes additional requirements for certain vessels entering the Great Lakes to also undergo ballast water exchange (BWE). Here, we use a high throughput sequencing approach to assess effects of BWT alone and BWT in combination with BWE on microbial communities present in ballast water tanks. Samples were collected from shipboard trials on a bulk carrier trading on the US Pacific coast and using a filtration plus electrochlorination BWMS. Multiple trials were conducted comparing ballast tanks that had undergone BWT alone vs. BWT + BWE. We found that BWT dramatically decreased microbial abundance and diversity, and that inclusion of BWE resulted in additional reductions, with some BWT + BWE samples yielding too few sequences to be analyzed. Functional analysis further indicated that BWT + BWE communities were the most divergent from port uptake communities, suggesting that this management option has the strongest effects on aspects of community structure most relevant to risk. Tests for *Escherichia coli* and *Vibrio cholerae* using standard molecular approaches deviated from results of most probable number (*E. coli*) and fluorescent antibody (*V. cholerae*) analysis. These discrepancies may reflect the ad hoc nature of these molecular analyses as well as inability of our molecular approaches to distinguish viable or intact targets. Interestingly, post-BWT microbial communities from different voyages appear very similar functionally, although not taxonomically, suggesting that (1) there are strong selective effects of BWT and (2) particular functional groups may be capable of surviving treatment.

Ballast Water Invasion Probability Tool: Simplifying the Application of Scientific Knowledge to Real-time Monitoring Decisions

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Aquatic invasive species (AIS) have a greater chance of establishing when introduced to regions that are environmentally similar to their native range, and by extension, regions that are more similar are more likely to exchange species. This can be quantified using environmental distance (i.e., habitat matching) which measures environmental similarity between locations, and has been used to inform risk for AIS establishments. Environmental distance has application in real-time management decisions, but its implementation is not necessarily straight-forward to managers. Likewise, increased propagule pressure increases establishment success, but when only proxy indicators of propagule pressure are available, it can be difficult for managers to ascertain how best to use this information to inform management.

To bridge this gap, we developed a user-friendly application that allows shipping inspectors to enter ballast water information (i.e., ballast water source and discharge locations, ballast volume and age) to automatically quantify and rank incoming ships based on potential risk for invasions. This tool directs compliance monitoring efforts by informing inspectors or regulators of the relative likelihood of a vessel containing high-risk biota, so that ships that pose a high biological risk can be targeted for compliance monitoring. Environmental distance is calculated using the best environmental predictors (e.g. temperature) identified in an empirical validation. Propagule pressure is accounted for by considering ballast water volume and ballast water age, and this information is used to adjust risk ratings. This tool allows inspectors to use information readily available to them (via ballast water reporting forms) to obtain estimates of invasion probability based on best available science.

Evaluating Ballast Water Management Systems to Prevent Biological Invasions

Oscar Casas-Monroy¹, Sarah A. Bailey¹

¹*Fisheries and Oceans Canada, Great Lakes Laboratory for Fisheries and Aquatic Sciences*

Canada began research in 2017 in support of the Experience Building Phase associated with the Ballast Water Management Convention. The objectives of the research are to determine if ships using ballast water management systems (BWMS) are consistently meeting the limit for maximum number of viable organisms, and to test a number of indicative analysis methods to determine their accuracy under a compliance-type scenario. Fieldwork was conducted on Canada's Pacific and Atlantic coasts and in the Laurentian Great Lakes. Samples were collected from 30 ships using 11 different BWMS. Treated ballast water was collected from the ships' main ballast discharge line using isokinetic continuous sampling methods, consistent with International Maritime Organization sampling guidelines. We assessed the viability of organisms in treated ballast water samples using indicative analysis methods measuring cellular energy (Adenosine Triphosphate) and fluorescence of active chlorophyll, and compared results with counts from epifluorescence microscopy (using fluorescein diacetate) as a standard reference method. This presentation will present results for the size class 10-50 μm (i.e. abundances/diversity of phytoplankton in discharge ballast water) and a comparison of potential compliance assessment tools.

Scenario-based Cost-effectiveness Analysis of Ballast Water Treatment Strategies

Zhaojun Wang¹, James J. Corbett¹

¹*University of Delaware*

This work evaluates technological strategies that include conventional expectations and alternative strategies to achieve global and regional ballast water discharge regulations. The technology-policy goal is to achieve the regulated standards with appropriate technology, and at the same time, minimize the compliance cost to reduce the burden on the shipping industry. Three potential regulations are examined to explore the variation of performance standards, given the complexity and uncertainty of current regulations. The results show that the required numeric standards matter a lot. If a single global standard is a weak standard, then adopting vessel-based compliant technology is less costly than centralized barge-based compliance. If some region or all regions adopt stricter standards, barge-based systems can be a way to implement stricter compliance. The findings reveal the potential role of barge-based treatment measure. The increased \$0.7 billion compliance cost for the U.S. to achieve stricter ballast water regulation per year may inform the policy decision-making process.

Effectiveness of Ballast Water Exchange Plus Treatment as a Mechanism to Reduce the Introduction and Establishment of Aquatic Invasive Species in Canadian Ports

D. Andrew R. Drake¹, Johanna N. Bradie¹, Dawson Ogilvie¹, Oscar Casas-Monroy¹, Sarah A. Bailey¹

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The movement of ballast water is a prominent pathway for the dispersal of harmful aquatic species. As a continuous effort to better prevent invasions via this high-risk pathway, the current management strategy of ballast water exchange will be gradually replaced by the International Maritime Organization's D-2 ballast water performance standard with the use of onboard ballast water management systems (BWMS). This study conducted model-based analysis to estimate the invasion rate of non-indigenous zooplankton and harmful phytoplankton species via ballast water discharge in Canada under various ballast management strategies, with the objective to assess the relative performance of exchange plus treatment against exchange or treatment alone. The management scenarios were also assessed on a port salinity basis, as environmental conditions such as salinity are known to influence the effectiveness of BWE.

The effectiveness of exchange plus treatment compared to treatment alone varied among shipping pathways and habitat types. Overall, exchange plus treatment was the most effective management strategy for international ships arriving to the Great Lakes, while exchange plus treatment generally did not provide additional invasion risk reduction over treatment alone for other shipping pathways in Canada. Exchange plus treatment provided the greatest reduction in species establishment risk when the ballast source was either fresh or brackish water and the destination port had fresh water, while the efficacy of exchange plus treatment and treatment alone were similar for all other source and recipient port salinity combinations. When only 50% of voyages are managed to the D-2 standard, exchange plus treatment substantially decreased establishment risk when the ballast source was fresh water, regardless of the salinity of the recipient environment, indicating that exchange plus treatment could serve as an important back-up strategy during the transition to BWMS.

The Best Available Science Supports Most Probable Number (MPN) Testing Methods for Type Approval of Ballast Water Management Systems

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The Vessel Incidental Discharge Act of 2018 (VIDA) became law on December 4, 2018, instructing the United States Coast Guard (USCG), in coordination with the U.S. Environmental Protection Agency, to publish a draft policy letter, based on the best available science, describing ballast water management system (BWMS) type-approval testing methods that may be used to measure the concentration of organisms in ballast water that are capable of reproduction. The USCG was required to take into consideration a testing method that uses organism grow-out and most probable number (MPN) statistical analysis. The MPN Dilution Culture + Motility (MPN+M) type-approval testing methodology fits this description: with the U.S. delegation in agreement, MPN+M was approved by the International Maritime Organization for use in type approval of BWMS. Yet, the USCG draft policy letter stated that "the Coast Guard does not know of any type-approval testing protocols for BWMS that render nonviable organisms in ballast water that are based on best available science", and the letter does not even mention MPN. Highly qualified commenters, each providing supporting documentation, challenged the Coast Guard's dismissal of MPN, recommending instead that the USCG include an MPN+M protocol in its final policy letter, due on December 4, 2019. A review of the best available science – documented experience, relevant data and peer-reviewed publications, all on the public record – strongly supports the case for MPN+M as a type-approval testing method. The science shows that MPN+M is suitable for testing all BWMS treatment technologies and that it assesses permanent loss of viability. The method has been validated to a higher standard than the USCG-accepted FDA/CFMFA + Motility method and performance metrics show that it provides equivalent or better enforcement of type-approval discharge standards. The best available science supports USCG acceptance of the MPN+M methodology as described in a protocol submitted to them by one of their accepted Independent Laboratories.



Optimal Planning of Invasive Species Surveillance Campaigns

Denys Yemshanov¹, ¹Natural Resources Canada – Canadian Forest Service

Surveillance is critical for timely detection of biological invasions. We discuss the optimization-based approaches for planning complex surveillance campaigns aimed to detect the spread of biological invasions.

We adopt a network based approach to plan inspections during the survey campaign and use an acceptance sampling technique to develop an optimal surveillance strategy. We compare two application methodologies for terrestrial invasive pests (such as planning surveillance of emerald ash borer (EAB), a harmful pest of ash trees) and invasive aquatic species (such as planning watercraft inspections for detecting the spread of invasive aquatic organisms through a network of lakes and waterways).

We also explore the impact of uncertainty about local infestation rates and detection probabilities on the surveillance strategy. Accounting for the uncertainty addresses possible temporal and spatial variation in

infestation rates and helps develop a more robust survey strategy. The approach is generalizable and can support surveillance programs for detecting biological invasions.



A Management Perspective on Risk Assessment for the Live Trade Industry

Becky Cudmore¹, ¹Fisheries and Oceans Canada

Effective aquatic invasive species (AIS) programs are based on risk analyses, where risk assessments provide valuable information that can be applied to many areas of an AIS program. Based on biological and socio-economic risk assessments, appropriate risk management actions related to prevention, early detection and rapid response, and control can be undertaken. This presentation identifies some of these activities, with emphasis on using risk assessment to mitigate introduction of AIS from live trade.



Experiences in Ballast Water Management across Freshwater and Marine Ecosystems

Sarah Bailey¹, ¹Fisheries and Oceans Canada

The movement of ballast water is a prominent pathway for the dispersal of harmful aquatic species. The risk of this pathway, and the efficacy of different management strategies, varies according to habitat type (freshwater vs. marine). Research undertaken to examine different management strategies has been complicated by the myriad of regulators on the Great Lakes, as well as activities at the international scale.

This presentation will present some of the experiences in ballast water across freshwater and marine ecosystems, in the context of different regulatory regimes, with a view to sharing common challenges and lessons learned.



New Technologies for Invasion Management: Will they Work in Water?

Daniel Simberloff¹, ¹University of Tennessee - Knoxville, USA

Several new technologies to prevent, detect, or manage invasions are in various stages of development, mostly for terrestrial invaders. Only eDNA has been widely used for aquatic invaders. However, drones and robots can be used to detect some aquatic and marine invaders, and perhaps to kill them. Vibrometers used to detect invasive insects suggest the possibility of similar sound-based detection for aquatic and marine animals. Among genetic approaches, gene-silencing is already used to manage invasive insects, and the idea has been suggested for invasive aquatic species. Oxitec's genetically engineered Friendly® *Aedes aegypti* mosquito, though controversial, has been massively released in nature in the wake of the Zika epidemic, and two major gene-editing projects employing CRISPR Cas 9 gene drives to eradicate invasive terrestrial animals are under development despite substantial controversy regarding potential

unintended consequences. There seems no reason why gene-editing technology could not be applied to aquatic or marine invasions, though the same concerns would obtain.



Asian Long-Horned Beetle versus Emerald Ash Borer Eradication: Even with Good Ingredients You Still Need a Recipe for Success

Taylor Scarr¹, ¹Natural Resources Canada – Canadian Forest Service

Even though there was only one year between the discovery of emerald ash borer (EAB) and Asian long-horned beetle (ALB) in Ontario, the success of the management programs are vastly different. While we expect soon to be able declare ALB eradicated, EAB continues to kill trees and spread across the country. ALB success is due to several key ingredients: the biology of the insect, the geographic location of its establishment, experience from other jurisdictions, an effective survey method, and effective control measures. On the other hand, EAB biology encourages long distance spread, it was not contained in an urban area, we had no experience from other jurisdictions, surveys were highly inaccurate, and control measures were ineffective.

Both case studies provide lessons that we can apply to other terrestrial, aquatic, and marine invasions. The recipe for success included working with political allies and champions, managing communications and expectations, incorporating research to reduce uncertainties, collaborating with local interests and all levels of government, and recognizing the long-term commitment of 10 or more years. These two case studies also provide insight into the differences between terrestrial and aquatic and marine invasions, such as survey methods, control methods, public and political support, available legislation, and intergovernmental collaboration.



Biological Control of Invasive Alien Species in the Anthropocene

Peter G. Mason¹, ¹Agriculture and Agri-Food Canada

Invasive alien species are a major threat to global food security. The Food and Agriculture Organization (FAO) promotes integrated pest management (IPM) as the preferred approach to crop protection. Biological control is a key component of IPM and the FAO Commission on Genetic Resources for Food and Agriculture identified biological control as a top priority for future work on the sustainable use and conservation of micro-organism and invertebrate genetic resources for food and agriculture. The Convention on Biological Diversity considers that "the application of classical biological control for the management of established invasive alien species causing environmental impacts is relevant to the work of the Convention on Biological Diversity." Despite significant successes, biological control has been subjected to greater scrutiny in recent years due to unintended effects. The lessons learned

have enabled biological control to evolve into a stronger scientific discipline.



Overcompensation, Eradication Failure and the Case for Functional Eradication of Aquatic Invasive Species

Edwin Grosholz¹, ¹University of California, Davis

Population dynamics models show that harvesting can paradoxically increase the equilibrium level of a population. Formally known as overcompensation, this phenomenon known as the 'hydra effect', has been documented in several systems, but has rarely been documented with the reduction of an invasive species and never in marine systems. We documented a dramatic population explosion of the invasive European green crab (*Carcinus maenas*) in a California estuary following five years of intensive removal efforts. After a >90% removal of the adult population from 2009-2013, we recorded a 30-fold increase in population size in 2014 relative to the previous year. We found this is the result of overcompensation as the result of loss of adult control of recruitment due to intensive removal efforts. Concurrent survey data from nearby

estuaries and subsequent genomic studies confirmed that recruitment dynamics were internal. Mesocosm experiments also showed size dependent cannibalism that was consistent with model predictions and the unusual population dynamics. We view these results as an important, cautionary lesson for resource managers.

Consequently, we propose practical guidelines for identifying management targets for invasions for which eradication is not likely, based on achieving 'functional' eradication—defined as suppression of the invader below population levels which cause unacceptable ecological effects—within high-priority management locations. We outline the key ecological information needed to develop strategies for functional eradication and illustrate the potential for improving the management of broadly distributed aquatic invasive species. Identifying targets for suppression allows managers to estimate the removal required to mitigate ecological impacts, and the management resources needed to achieve these levels of control.



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Each day, pressure mounts on the unique ecosystems that produce the fresh water vital to all life.

Invasive aquatic vegetation degrades water quality, causing health problems for people, loss of habitat for fish and wildlife, and a decrease in property values. It also impacts recreational activities. Although traditional management techniques and tools are available, there is a pressing need to develop new strategies and refine existing ones that can selectively control these aggressive weeds in an environmentally compatible fashion.

Technological improvements can only be achieved through competent and sustainable research and development (R&D) programs. In the past, the federal government has played the prominent role in maintaining a coalition of research scientists, natural resource agencies, academic institutions, and private sector interests for studying and managing nuisance aquatic and wetland vegetation. However, significant reductions in agency funded R&D programs have created a technological void while invasive aquatic and riparian weeds continue to spread and cause grave environmental damage.

The AERF was formed to fill this void.



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The introduction of the zebra mussel, and later the quagga mussel, to North America caused major issues for water users throughout the continent. These tiny molluscs can deeply impact the integrity of water supply systems forcing each individual user to seek out methods of remediation.

ASI Group is widely recognized as the industry leader in mussel control, research and design. Since 1988, ASI Group has pioneered specific safe and cost-effective methodologies which continue to be used on a vast scale to mitigate problems associated with mussel fouling.

ASI Group's turnkey biofouling services include monitoring, maintenance and prevention programs. We utilize both chemical and non-chemical methods to provide proven results which minimize the overall risk and cost of unscheduled downtime due to fouling.



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Atlantium's Hydro-Optic™ (HOD) UV system is a highly efficient non-chemical biofouling control solution for invasive mussels in hydroelectric facilities. The technology uses less energy, has a smaller footprint and has achieved validations not seen by other UV systems. The system consistently monitors water quality, UV intensity and adjusts the UV dose rate accordingly to meet application-specific needs. HOD UV has the ability to achieve 100% inactivation even under conditions with < 50% UVT.



Bruce Power
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Situated on the shore of Lake Huron, Bruce Power provides nuclear power to one in three homes, hospitals, schools and businesses in Ontario at 30 per cent less than the average cost to generate residential power. Our people are the foundation of our accomplishments and are proud of the role they play in delivering clean, reliable, low-cost electricity across the province and life-saving medical isotopes across the globe. Bruce Power has worked hard to build strong roots in Ontario and is committed to protecting the environment and supporting the communities in which we live. Learn more at www.brucepower.com



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The Canadian Wildlife Federation is a national not-for-profit charitable organization. Our mission is to conserve and inspire the conservation of Canada's wildlife and habitats for the use and enjoyment of all. Through our work, we strive to have government, industry, NGOs, Indigenous Peoples, and the public to work together for wildlife. CWF has experts in marine, freshwater and terrestrial wildlife on staff.

We implement species recovery and habitat restoration projects across Canada. We conduct scientific research to better understand how we may help wildlife. We also challenge government and industry to improve legislation and practices to benefit wildlife and habitat. Our youth focused environmental programs reach thousands of kids and young adults annually and our awareness raising activities reach hundreds of thousands with messages about the importance of wildlife conservation. We believe Canadians should be able to enjoy the outdoors for all it has to offer through gardening, hiking, fishing, canoeing, camping, bird watching, swimming, wildlife photography, and so much more. Since our inception in 1962, we have worked diligently to foster this Canadian way of life.



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Earth Science Labs (ESL) is a U.S. company that manufactures EarthTec® algacide and other water treatment products, including Earthtec QZ for control of invasive mussels, and the PristineBlue® line of pool and spa chemicals. Earth Science Labs treats the water we use, drink and play in.

EarthTec QZ (QZ) is an EPA-labeled molluscicide for control of quagga and zebra mussels. Labeled for use in both open waters and pipelines, QZ's unique liquid formulation is proven effective at achieving 100% mortality of adult zebra and quagga mussels.

EarthTec and EarthTec QZ are both NSF-certified to ANSI Standard 60 for drinking water, making it an excellent choice for controlling the spread and infestation of this devastating species. EarthTec QZ can be applied in lakes and reservoirs or in pipelines leading to water treatment plants. It is a rapidly dispersing product and is completely bioavailable. Zebra mussels do not detect it as a threat and readily ingest the QZ. Studies confirm 100% mortality within 4-6 days. It is effective at concentrations that are non-toxic for most non-target organisms.

Canadian registration of EarthTec and EarthTec QZ with PMRA is in process and expected to be complete in 2020.

Advantages of EarthTec QZ:

- Liquid formulation and rapidly dispersing, thus greatly reducing time and labor for application.
- Effective at extremely low levels of copper: 30-180 parts per billion
- The copper is formulated in the biologically-active form (as cupric ion, Cu⁺⁺), and stays in solution until it encounters a cell wall to bind to and penetrate, so virtually all of the copper applied is effective, with no copper or other waste precipitating into bottom sediments.
- History of effective use with no negative impacts on fish and other non-targets.



Great Lakes Fishery Commission

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The Great Lakes Fishery Commission is an international organization established by the United States and Canada through the 1954 Convention on Great Lakes Fisheries. The commission was established partially as a response to one of the most noxious invaders to enter the Great Lakes system: the sea lamprey. Sea lampreys, primitive fish parasites native to the Atlantic Ocean, invaded the Great Lakes through shipping canals in the early 1900s. Lacking predators, sea lamprey were able to wreak catastrophic damage on the ecosystem and cause significant economic harm to the fishers of the region. The commission's control program has been successful, reducing sea lamprey populations by 90% in most areas of the Great Lakes.

The convention also directs the commission to formulate a coordinated bi-national research program. The program goals are to identify ways to nurture the maximum sustained productivity of Great Lakes fish stocks and, based on that research, to recommend specific management initiatives to the governments. The commission's research program is based upon two broad priorities: research in support of healthy Great Lakes ecosystems and research in support of sea lamprey control. Additionally, the commission directs and supports projects designed to transfer science to managers.

Finally, the commission is charged with facilitating the implementation of A Joint Strategic Plan for Management of Great Lakes Fisheries, a provincial, state, and tribal fisheries management agreement. While there exists no binding, centralized authority to compel cooperative fishery management on the Great Lakes, the jurisdictions realize that the Great Lakes fishery is interconnected and the actions of one jurisdiction affect the others. To manage the resource in this unique setting, the sub-national governments developed and adhere to The Joint Strategic Plan, an agreement that calls for cooperation among the jurisdictions, development of shared fish community objectives, data sharing, and adherence to ecosystem management.



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Under the 1909 Boundary Waters Treaty between the United States and Canada, the International Joint Commission assists the governments to help prevent and resolve disputes between the two countries and pursues the common good of both countries as an independent and objective advisor to the two governments.

In particular, the Commission rules upon applications for approval of projects affecting boundary or transboundary waters and may regulate the operation of these projects; it assists the two countries in the protection of the transboundary environment, including evaluating the governments progress toward restoring and maintaining the chemical, physical and biological integrity of the waters under the Great Lakes Water Quality Agreement and the improvement of transboundary air quality; and it alerts the governments to emerging issues along the boundary that may give rise to bilateral disputes.

In 1988, both the International Joint Commission (IJC) and the Great Lakes Fishery Commission (GLFC) alerted the governments of the United States and Canada that aquatic alien invasive species (AIS) in ballast water posed a significant threat to the Great Lakes. The two commissions urged the nations' Coast Guards to take immediate steps to end the ongoing introduction of exotic organisms via ballast water discharge, and have been reporting on AIS issues ever since including under Annexes 5 and 6 of the GLWQA which are dedicated to Discharges from Vessels and AIS respectively. In July 2019, IJC, the Great Lakes Fisheries Commission (GLFC) and Great Lakes Commission (GLC) formally endorsed coordinated binational action through the Invasive Mussel Collaborative (IMC) to spark further progress in controlling the spread of invasive zebra and quagga mussels. AIS has also become an IJC focus in transboundary basins beyond the Great Lakes, in watersheds such as Rainy-Lake of the Woods, Red and Souris, as well as western intermountain watersheds where Dreissenid species have recently arrived along with other invasives such as the spiny waterflea. The IJC has been a sponsor of ICAIS conferences since 1999.



Invasive Species Centre

Catalyst for research and response

Invasive Species Centre

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The Invasive Species Centre is a not-for-profit organization that prevents and reduces the spread of invasive species by connecting with a broad array of stakeholders to catalyze invasive species management and communicate policy and science knowledge in Canada and beyond.

The Invasive Species Centre is the secretariat for ICAIS, and some additional recent projects include:

- supporting policy and regulations by assessing ecological and socioeconomic risk for various invasive species and pathway, developing pre-risk assessment prioritization tools, and expanding an open web database of risk assessments;
- improving detections and enhancing jurisdictional prevention efforts by training professionals and enforcement officers in advanced invasive species identification and current best practices in invasive species management; and
- equipping Canadians with resources through public information sessions and webinars, community action networks, and digital tools.



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Marrone Bio Innovations, Inc. (MBI) is a leading provider of biopesticides for use in water and agricultural applications to control pests, weeds, and plant diseases. MBI developed ZEQUANOX® to address the increasing economic and ecological impact of invasive dreissenid mussels. The company is also investigating potential biological solutions for the control of invasive algae and aquatic weeds.

Recognized as a ground-breaking innovation in water technology, Zequanox is the industry's only EPA approved biological molluscicide for controlling zebra and quagga mussels (*Dreissena* species). Composed of killed cells from a ubiquitous soil microbe (*Pseudomonas fluorescens*), Zequanox is highly selective; and while lethal to zebra and quagga mussels, it is safe for humans, infrastructure, or the environment. Zequanox is non-persistent and toxicology studies demonstrate that at concentration levels that produce mussel mortality, no product-induced effects occur in non-target organisms, including algae, fish, mollusks, or crustaceans. Zequanox can be used in a broad range of water conditions and temperatures, and has been proven effective for controlling adult mussels as well as reducing juvenile mussel settlement and controlling planktonic veligers.

Zequanox is registered by the U.S. EPA for use in enclosed or semi-enclosed systems, such as service water and irrigation systems, and in open water settings like lakes and rivers. In Canada, Zequanox is registered for hydroelectric facilities with planned expansion into other enclosed systems, as well as open water. Registration is also underway for use in enclosed and open water systems in the EU. No special precautions are required for employees working near Zequanox treatment areas. Zequanox is non-corrosive, and causes no accelerated deterioration of pipes, valves, and other infrastructure as can happen with other chemicals. There are minimal regulatory restrictions on the use of Zequanox, and MBI staff is comfortable and experienced working with regulatory authorities to support obtaining any necessary permits for those wishing to use Zequanox.

**Forêts, Faune
et Parcs**

Québec 

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The mission of the Ministère des Forêts, de la Faune et des Parcs (MFFP), in its capacity as manager of public forests, wildlife, habitats and the natural collective heritage, is to ensure sustainable management of these sectors and support their economic development for the benefit of the citizens of Québec.

In wildlife management, the MFFP is responsible for a number of aspects, including:

- Overseeing the conservation, development and protection of wildlife and habitats with a view to achieving sustainable development.
- Acquiring and circulating scientific knowledge on wildlife and habitats.
- Governing hunting, trapping and fishing by adopting regulations and management plans, issuing licences and preparing policies, programs and partnerships.

Specifically with regard to the fight against aquatic invasive species, the MFFP is tasked with establishing strategic guidelines and taking action to prevent, monitor and control invasive species. Among other things, the MFFP deploys:

- Québec Program to Fight Asian carp, which has helped to develop expertise adapted to the reality of Québec and collaborations with regional partners.
- An aquatic invasive species detection network in various bodies of water including the St. Lawrence River.
- Its water body access program (component B) to finance the construction of boat cleaning stations alongside Québec's bodies of water, to encourage cleaning of watercraft and equipment.



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The Ontario Federation of Anglers and Hunters was founded in 1928 due to concern over the future of Ontario's natural resources. It is Ontario's largest, non-profit, conservation-based organization, representing 100,000 members, subscribers and supporters, and 740 member clubs. OFAH members enjoy various outdoor pursuits, but share a common interest in sustaining our natural resources and the quality of life that healthy resources make possible. As a result, the OFAH supports programs to conserve and restore fish and wildlife habitat, as well as to help protect our fishing and hunting heritage.

Recognizing the impacts of invasive species and the role of outdoor enthusiasts in their introduction and spread, in 1992 the OFAH initiated the Invading Species Awareness Program in partnership with the Ministry of Natural Resources and Forestry, with the objective to raise public awareness of invasive species and to engage support and participation in prevention, monitoring and control measures. The program is focused on the primary pathways of invasion and encourages citizen reporting of invasive species via the toll-free Invading Species Hotline and online reporting system (www.eddmaps.org/ontario). Through our partnership with the Government of Ontario to deliver this province-wide program, the ISAP has become a leader in invasive species education and awareness in Ontario, and has achieved enormous success in raising the profile of invasive species by working with industry leaders, government agencies, other ENGOs, universities, and a variety of community groups to reach our target audiences.

For more information on the Invading Species Awareness Program, please visit www.invadingspecies.com or call the Invading Species Hotline at 1-800-563-7711.



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As the province's leading clean power generator, Ontario Power Generation (OPG) produces reliable, low-cost power using our diverse mix of generating sources. OPG generates 50% of the electricity used in Ontario and is Ontario's lowest cost generators; 40% below the average price paid to other generators. With the help of our employees, site communities and partners, we're also working to ensure a more sustainable future, a cleaner environment, a stronger economy and more livable communities.



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Established in 1947 by consent of Congress, the Pacific States Marine Fisheries Commission (PSMFC) is an interstate compact agency that helps resource agencies and the fishing industry sustainably manage our valuable Pacific Ocean resources in a five-state region. Member states include California, Oregon, Washington, Idaho, and Alaska. Each represented by three Commissioners.

**RESEARCH INSTITUTE
NATURE AND FOREST**

**Research Institute for Nature
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The Research Institute for Nature and Forest (INBO) is the Flemish research and knowledge centre for nature and its sustainable management and use. INBO conducts research and supplies knowledge to those who prepare or make the policies or are interested in them.

As a leading scientific institute, INBO primarily works for the Flemish government, but also supplies information for international reporting and deals with questions from local authorities. In addition, INBO supports organisations for nature management, forestry, agriculture, hunting and fisheries. INBO is a member of national and European research networks. It makes its findings available to the general public.

INBO employs some 200 staff, mainly researchers and technicians.

With regard to aquatic invasive species (AIS), INBO plays a lead role in research, monitoring and management of invasives in the northern part of Belgium. Current AIS research topics include: monitoring of spread and impact of Ponto-Caspian gobies, management of American bullfrog, drafting and reviewing risk assessments for invasive alien species, horizon scanning of new AIS, monitoring and surveillance of AIS, the publication of open data on invasives as well as the development of registries and data warehouses. The institute is a key player in implementing the European Union Regulation on the prevention and management of invasive alien species. INBO scientists liaise with European and other international experts on AIS to tackle the issue on a pan-European or worldwide scale. Results of these collaborations can be found in reports to managers and stakeholders and in numerous peer reviewed papers.



**Environmental Laboratory
US Army Engineer Research
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The Environmental Laboratory at the U.S. Army Engineer Research and Development Center, Vicksburg, MS, is the problem solver for the U.S. Army Corps of Engineers and the Nation in environmental science and engineering. The laboratory supports the environmental missions of the U.S. Army, the Department of Defense, and the Nation through research, development, special studies, and technology transfer. The Environmental Laboratory conducts multi-disciplinary research in environmental quality and ecosystem restoration. Research activities include: evaluating and projecting the consequences of water resources development, navigation, and dredging on the environment; developing improved tools and metrics for environmental benefits analysis; assessing and restoring wetlands; evaluating and modeling inland and coastal water quality; guiding stewardship of natural resources; developing tools for cleanup of contaminated groundwater and soils; developing techniques to improve stream and riparian restoration; accelerating growth of desirable vegetation/habitat; implementing risk and decision frameworks in planning; forecasting potential impacts from climate change and sea level rise on coastal ecosystem restoration, identifying and applying biological, chemical, and physical control strategies for the management of nuisance and invasive aquatic plants and animals; applying risk-based contaminated sediment and soil toxicological assessment protocols; and performing upland disposal testing and assessment for dredged material.

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The University of Florida is one of the nation's leading public land-grant universities, and the Institute of Food and Agricultural Sciences (UF/IFAS) is the UF agriculture and natural resources program. UF/IFAS is operated via federal, state and county partnerships and has three main units, dedicated to teaching, research and Extension outreach. Besides educating undergraduate and graduate students, UF/IFAS provides research and development, Extension education and technical assistance to Florida's agricultural, natural resources and related food industries, which had total value-added contributions of \$165.5 billion for Florida's economy in calendar year 2016, the most recent year analyzed. UF/IFAS has presence statewide, including the College of Agricultural and Life Sciences on the main UF campus in Gainesville, more than two dozen off-campus research facilities and UF/IFAS Extension offices in all 67 Florida counties. UF/IFAS also administers the Florida Sea Grant program, an international program, the Florida 4-H Youth Development Program and aspects of the UF College of Veterinary Medicine.

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