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Editorial

ICAIS provides a unique forum for synthesizing knowledge of aquatic invasive species

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The 21st International Conference on Aquatic Invasive Species (ICAIS; http://www.ICAIS.org) was held in Montreal, Quebec, Canada in October, 2019. ICAIS continues to be an invaluable forum for scientists and natural resource managers to advance the science of invasion ecology and improve the management of invasive species in freshwater, estuarine, and marine ecosystems. The success of ICAIS relies on the participation of top-level scientists, decision-makers, and early career researchers and ICAIS functions as a forum for disseminating scientific advances and sowing the seeds of new collaborations. This special issue of the open-access, peer-reviewed, international journal *Management of Biological Invasions* also serves to share and disseminate the work conducted by different researchers. This issue will therefore continue the history of ICAIS as a reliable source of up-to-date research on aquatic invasive species, and will continue ICAIS's influence on policy makers and management agencies to help protect and conserve biodiversity, natural resources, and the communities that rely on aquatic resources that are impacted by invasive species worldwide.

With a theme of Aquatic Invasions in the Anthropocene, ICAIS 2019 maintained its global outlook. Keynote presentations discussed the importance of biogeographic origins of invasive species (Anthony Ricciardi, Canada), the need for stakeholder buy-in alongside practical biosecurity practices to prevent the spread of aquatic invasive species (Alison Dunn, UK), successes and failures in terrestrial, freshwater, and marine invasive species management (Daniel Simberloff, USA), the role of biotic and abiotic stressors on native communities' response to invasive species (Shelley Arnott, Canada), the synergy between global warming, organic enrichment, disturbance, and species additions that favors weedy communities and facilitates bioinvasion (Emma Johnston, Australia), and the way the dual stressors of climate change and species invasion interact

to increase the impact of both stressors on native communities (Cascade Sorte, USA).

This special issue contains papers that were presented at the conference and which focus on risk assessment, prevention, eradication, management, and control of aquatic invasive species. An additional eleven research articles are published in the ICAIS 2019 special issue of *Aquatic Invasions*, the sister journal of *Management of Biological Invasions* (see Bellini and Becker 2021; Cárdenas-Calle et al. 2021; Casas-Monroy et al. 2021; D'Hont et al. 2021; Fortunato and Lôbo-Hajdu 2021; Gettys and Leon 2021; Hallidayschult et al. 2021; Kingsbury et al. 2021; Marshall and Stepien 2021; Suescún et al. 2021; Woodruff et al. 2021).

Humans are the ultimate driver of species invasions, and are the weak link in invasion prevention and management. Two papers in this issue directly address the human side of the invasion equation. Verbrugge et al. (2021) examine best teaching practices for increasing public awareness of invasive alien species. They identify four challenges for invasive species education: inconsistent or ambiguous terminology, how to communicate risk, implementation, and evaluation. Verbrugge et al. (2021) also identify best practices, including the use of smartphone applications and gaming elements, place-based education and exhibitions, and open-access publishing of educational materials. Van Poorten and Beck (2021) describe how structured decision making can be used to identify shared goals and facilitate discussion among disparate stakeholders and arrive at collective decisions around natural resource problems, such as aquatic invasive species. Van Poorten and Beck (2021) walk through the steps of structured decision making and then illustrate their successful use in a case study involving non-native smallmouth bass found in Cultus Lake, British Columbia, Canada in 2018.

Efficacy and efficiency of eradication, management, or prevention methods are a particular focus of this special issue, with ten papers covering some aspect of these topics. Adolfsen et al. (2021) describe the process of attempting to eradicate the monogenean parasite, *Gyrodactylus salaris*, which affects salmonids and has nearly eliminated salmon populations in the Skibotn and Signaldalen Rivers in Norway. Although a number of failed eradication attempts led to criticism of the national eradication strategy for *G. salaris*, the authors point out that the failures resulted in valuable knowledge gained and modified treatment approaches. As a result, a two-year treatment strategy, with higher concentrations of rotenone was employed in 2015 and 2016. Although eradication confirmation has not yet been made, early results are suggestive of successful eradication from the Skibotn region.

Using a 27-day microcosm-based study, Sesin et al. (2021) measured the variation in effectiveness of glyphosate-based herbicides on two invasive macrophytes (*Phragmites australis* and *Typha* × *glauca*) and one co-occurring

native plant (*Typha latifolia*). They demonstrated that the three species varied considerably in their sensitivity to glyphosate (with *Phragmites australis* considerably more sensitive to the herbicide than the other two species), and that glyphosate accumulates within the tissues of macrophytes. Both variation in glyphosate response and accumulation are relevant to managers planning management of invasive macrophytes while trying to minimize environmental exposure.

Balancing effective removal of invasive species versus the risk of collateral damage to non-target species is also a consideration with invasive animals. Two papers contributed to this special issue approached this question from different directions. Oliver et al. (2021) tested the effectiveness of low-dose EarthTec® QZ to control New Zealand mud snails in a hatchery environment. Although initial treatment with concentrations of 60 µg/L did result in elevated mortality of brown (*Salmo trutta*) and rainbow trout (*Oncorhynchus mykiss*), lower doses (30 µg/L) administered over a long period (38.5 days) were effective at removing New Zealand mud snails without adversely affecting hatchery production. While additional testing across other conditions is warranted, EarthTec® QZ does appear to be an effective treatment for New Zealand mud snails in this hatchery environment.

Beyond the hatchery environment, molluscicides are also used in open-water conditions to treat for invasive species. Barbour et al. (2021) assessed avoidance behaviors in six species of fishes exposed to Zequanox, a molluscicide with demonstrated selectivity for dreissenid mussels (Molloy et al. 2013). Three fish species (brook trout [*Salvelinus fontinalis*], lake trout [*Salvelinus namaycush*] and bluegill [*Lepomis macrochirus*]) avoided Zequanox-treated water, one (yellow perch [*Perca flavescens*]) showed no apparent preference, and two (lake sturgeon [*Acipenser fulvescens*] and fathead minnows [*Pimephales promelas*]) preferred Zequanox-treated water. Combining these results with data on species sensitivity could help inform resource managers of the potential for damaging native fish species while controlling dreissenid populations.

Three papers in this special issue touch on the effectiveness of methods to prevent the spread of invasive species. Because ballast water carried by cargo vessels is an important vector transporting and introducing non-indigenous species (Carlton 1985; Bailey et al. 2020), regulatory and technical solutions have been developed to reduce the transport of non-indigenous species in ballast water. Wang and Corbett (2021) compare cost effectiveness of vessel-based vs. barge-based ballast water treatment under different regulatory standards. With a goal of achieving regulatory standards while minimizing compliance costs to industry, Wang and Corbett (2021) demonstrate that regulations matter a great deal. With a weaker standard, vessel-based technology may be lower cost than barge-based compliance.

However, with stricter standards, barge-based compliance may be lower cost than retrofitting the global cargo fleet.

Aquatic invasive species are also spread overland via contamination of recreational or personal protective equipment, watercraft, or trailers. Decontamination of this equipment is thus a critical practice to limit dispersal of aquatic invasive species. Bradbeer et al. (2021) and Mohit et al. (2021) both examined the efficacy of commonly used decontamination procedures. Collas et al. (2021) examined behavioral changes and survival times of quagga mussel (*Dreissena bugensis*) exposed to moving air, as might occur if mussels foul recreational boats and are subsequently transported by road.

Bradbeer et al. (2021) tested the effectiveness of hot-water spray machines at killing two species of invasive aquatic plants (floating pennywort, *Hydrocotyle ranunculoides*, and Australian swamp-stonecrop, *Crassula helmsi*) and two species of invasive invertebrates (killer shrimp, *Dikerogammarus villosus*, and zebra mussel, *Dreissena polymorpha*) under field conditions. By testing a range of treatment distances (10–30 cm) and durations (5–90 seconds) and comparing with cold water spray, Bradbeer et al. (2021) demonstrate that cold pressurized spray is effective at causing mortality in *H. ranunculoides*, while hot water spray applied at 10 cm for 15 seconds caused complete mortality of *D. villosus* and *D. polymorpha*. Unsurprisingly, shorter exposure durations and longer distances were less effective at inducing mortality in the two invertebrates. However, *C. helmsii* proved resistant to hot water spray even at durations of 90 seconds. This highlights the difficulty of developing one treatment standard for all aquatic invasive species, and also shows the importance of containing treatment water and removed biomass to prevent the introduction of potentially viable propagules.

Mohit et al. (2021) reviewed the current literature on decontamination methods including air-drying, pressure washing, rinsing with hot water, and using cleaning agents. While all the methods were effective at causing mortality in many (or most) of the tested aquatic invasive species, effectiveness varied widely among treatment approaches and taxonomic groups. Air drying, which is by far the most widely tested method (70.3% of the assessed studies), has clear limitations for certain taxonomic groups (e.g. aquatic snails) and is less effective for larger, older invertebrates and larger or clustered aquatic plants. Other treatments require specific conditions to be effective, including minimum exposure or immersion times, high temperatures (water immersion or hot water spray), or specific doses (household chemicals such as salt or bleach). Further research is clearly warranted to identify practical, combined, or alternative treatments that can be deployed easily and cost-effectively.

Because they are able to attach to in-water structures including recreational boats and other infrastructure using their byssal threads, Dreissenid mussels can readily be transported overland when boats are moved from one location to another. To assess survivorship of mussels exposed to moving air, Collas et al. (2021) tested two simulated wind speeds, 10 and 50 km/h, with individual mussels and clumps of mussels for up to 48 hours. They demonstrated that mussels changed behavior (decreasing the time spent gaping) in moving versus still air, that faster air decreased the lethal time, and that mussel clumps survived for longer than individual mussels. Of greater concern, Collas et al. (2021) found that mussels can survive over 18 hours of exposure to air speeds of 50 km/h, with 50% of mussels potentially surviving to be transported over 300 km, and 1% potentially surviving 900 km. As the authors observe, with such long-distance transport possible, decontamination will play a vital role in limiting spread of Dreissenids.

A pathway of concern for introduction of aquatic invasive species is the Buddhist practice of "life release," where animals that have been condemned to death are obtained and released to live out the rest of their natural lives (Zangpo 2005). This practice is known to be a significant pathway for invasions (Magellan 2019), but is little studied in the United States. Campbell et al. (2021) used semi-structured interviews to assess the risk of the practice of life release in the United States and to identify ways the ceremony can be performed while minimizing invasion risk. Combining this information with input from natural resource managers could help to mitigate this understudied invasion pathway.

Lemmers et al. (2021) assess the risk of spread and impact of nine species of alien crayfish that have been introduced to the Rhine-Meuse river delta. Potential impacts of these species stem from their ability to transmit the crayfish plague pathogen *Aphanomyces astaci* to native species, predation and herbivory on native animals and plants, and sedimentation and bank instability caused by their burrowing activities. The risk of spread of several species is high, and eradication is not feasible in the Rhine-Meuse delta. However, population control may be possible if it combines targeted crayfish trapping by fishermen, aquatic resource managers, and well-informed citizens with measures for supporting and rebuilding ecosystems.

This special issue of *Management of Biological Invasions* includes a variety of papers on advances in the prevention, management, or eradication of aquatic invasive species. These papers will be useful to scientists, managers, and other stakeholders addressing similar problems in their own corner of the world. Many open research questions on aquatic invasive species remain which would benefit from additional research, collaboration, outreach, and communication. Aquatic invasive species will continue to impact aquatic ecosystems and natural resource conservation,

and therefore the general well-being of society. We look forward to learning of additional new advances, discussing and debating management actions, and developing new collaborations at future ICAIS conferences.

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