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Marine and freshwater invasive species research with emphasis on South America: An overview and synthesis of MFIS, Argentina

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Introduction

Aquatic invasive species (AIS) are a global environmental issue in both marine and freshwater ecosystems and have had significant impacts on global ecosystems and economies. A wide range of aquatic organisms are being transported daily through vectors such as international shipping, aquaculture and stocking programs, as well as live trade. For a long time, South American coastal and freshwater ecosystems were considered safe from biological invasions due to their relatively remote geographic locations, but recent studies have revealed that this view was misinformed. As many as 31 confirmed AIS, such as the Golden Mussel, Wakame Kelp and Veined Rapana Whelk, and 46 cryptogenic species were identified in the first comprehensive study of the Patagonian coast by Orensanz et al. (2002); and intensification of human activities including trade has likely raised this figure substantially over the last decade. As elsewhere in the world, these introductions have brought about ecological impacts including competition with, and predation on, native species, changes to nutrient cycling and foodweb alterations. Other impacts include biofouling of

man-made structures, depletion of economically valuable populations and deterioration of coastal habitats. Adequate management involves understanding the risks posed, how those potential effects are modulated across regions and the implementation of preventative actions to mitigate those risks.

The study of biological invasions has historically been biased to certain regions, often leaving entire continents understudied (Pyšek et al., 2008; Schwindt and Bortolus, 2017). More than once, there have been calls for invasion scientists to cooperate on a world-wide scale to get a more balanced picture of global invasion patterns (Speziale et al., 2012; Fonseca et al., 2013).

In South America, over the last ten years, the scientific focus has been to report on what invasive species researchers are doing and what should be done in order to better synchronise the relationship between management efforts and resources (Quiroz et al., 2009; Anderson and Valenzuela, 2014). Unfortunately, few advancements have been made looking at the big picture for the entire sub-continent, and even less so for aquatic ecosystems (Pyšek et al., 2008; Frehse et al., 2016). Currently, the scientific community of South America

is strongly recommending a coordinated collaboration between countries to slow the rate of introduction of AIS worldwide (Bortolus and Schwindt, 2010, p. 32; Schwindt and Bortolus, 2017).

In an attempt to encourage global discussion and future collaborations between global organizations, the Aquatic Ecosystem Health and Management Society (AEHMS) hosted an international conference in Argentina. This is the second conference on AIS convened by the AEHMS, following the meeting in Oman during February 2014 (AEHM, 2015). Like the previous one, MFIS-Argentina's goals were (1) to promote the science and management of invasion biology in South America and (2) to bring together leading researchers from across the world to share the current state of knowledge on the biology, ecology, impacts, risks and management of AIS and their vectors. To account for important invasion processes outside marine habitats, freshwater studies were incorporated into the conference since some of the largest and most unique freshwater ecosystems on Earth are located in South America.

The event was convened in Buenos Aires, capital city of Argentina, an eye-catching metropolis standing on the shores of Río de la Plata. This important shipping hub contains unique aquatic ecosystems such as the delta of the Parana River and also constitutes a major gateway for AIS in South America (e.g. the Golden Mussel and Asian Clam between 1965 and the early 1990s; Pastorino et al., 1993; Ituarte, 1994). The MFIS-Argentina conference ran from 2–4 May 2016 and consisted of three keynote speakers, five sessions, 31 oral presentations and 31 poster presentations from all over the world. The conference was focused on the following themes:

1. Vectors and Pathways
2. Ecology and Biology of Invasive Species
3. Impacts of invasive species
4. Management Strategies
5. State of Aquatic Invasion Ecology: Argentina and South America

Session synthesis

Given below are summaries of the conference theme sessions. Some articles based on presentations from the conferences were selected for this special issue, including the keynote submissions.

Day 1

Conference introduction: Pablo Penchaszadeh Invaders in Coastal Waters in Argentina?

Coastal Argentina, extending for about 6,000 km, has long been believed to be a pristine area. However, during the last 60 years, when marine and estuarine research started to be systematically carried out, an increasing number of alien species have been recorded. Among the most astonishing is the establishment in the early sixties of invasive barnacles on open rocky shores.

With the exception of the above example, the majority of the exotic species have become established in our coasts during the past 30 years. Some of them were deliberately introduced by humans, but most were transported accidentally. To the first group belongs the well-documented introduction of the Japanese oyster *Crassostrea gigas*. The most conspicuous and widespread invader is perhaps the Golden Mussel *Limnoperna fortunei*; although a long list of plants and animals introduced in the Argentine coast exists. Our coastal habitats have received a large number of ships and billions of litres of ballast water during the last decades, which served as vectors for those introductions. Despite recent efforts, we cannot offer a single example of a successful eradication of an alien species. Are scientists mere witnesses to invasion? Is this our future?

Keynote: Hugh MacIsaac

Changes in invasion vectors, changes in risks

The world has experienced an enormous increase in biological invasions. In the aquatic realm, global shipping is responsible for a disproportionate number of invasions in global ports. Changes in global regulations may have opposite effects on invasions due to hull fouling versus ballast water discharge, with the former potentially increasing while the latter abates. These changes will alter the relative importance of other vectors, notably aquarium and live garden, sport or pet fishes, and seafood and mariculture. Some systems, like the Great Lakes, will likely switch entirely or nearly so to non-shipping vectors. Similarly, coastal marine environments utilized for mariculture inadvertently provide ideal settling substrates for a host of marine pest invaders. It is important that invasion scientists and especially managers be aware of changes in existing vectors as well as development of new ones.

Summary of session 1: Vectors and pathways

John Polglaze reported on biofouling assemblages, which play an important role in the transfer of marine invasive species, and how these assemblages are different for each vessel/vessel type and can subsequently have significantly different risks towards the biota of naïve regions.

Jeremy Thomason described a biofouling prediction model which was developed using satellite tracking and indicators of the oceanographic conditions in which a vessel has been operating. A portion of this model is currently being used on commercial vessels on a global scale, which continuously contribute to the growing database from which future transport risks are determined.

Mattias Johansson examined the microbial communities in ballast water, with particular attention to the potential changes to the microbial community during transport into the Canadian Arctic.

Darren Yeo provided a brief overview of the status of AIS in Singapore, highlighting potential pathways (ornamental trade, food trade and shipping), and discussed a number of case studies of introduced organisms, the majority of which are in inland freshwater environments.

Jia Huan Liew discussed how anthropogenic disturbances of natural habitats can be the main driver of species loss which leads to invasion opportunities. The study consisted of a global meta-analysis of dammed and undammed rivers which resulted in an increase of alien species due to vacant niches left behind by species unable to withstand a change in the environment.

Finally, *Yiwen Zeng* used species distribution modeling, MaxEnt, to predict the potential distribution of AIS. This study investigated two new methods to identify the best biological predictor variables of the potential distribution of eight invasive crayfish.

Summary of session 2: Ecology and biology of invasive species

Sara Stahlman examined the relationship between changing climate and range expansion of non-native aquatic species in Pennsylvania by modeling predicted movements of more than 50 species. It was determined that current climatic conditions were not suitable for nearly half of the species studied, but that by 2099, the climate will have warmed sufficiently to create a suitable climate for a large proportion of AIS.

Jésica Goldsmit assessed the risk of introduction for non-indigenous benthic species in the Canadian Arctic, finding that the larvae of three benthic species can be transported via ballast water, and that the area has likely already been exposed to propagules of these non-indigenous species.

Stephen Bollens discussed the status of the Columbia River Estuary with regard to the arrival of several invasive species of Asian copepods, *Pseudodiaptomus forbesi* and *Corbicula fluminea* in particular, highlighting their impacts in the context of the local foodweb and potential climate change effects.

Finally, *Jeffrey Kwik* described how novel, artificial reservoirs in Southwest Asia are developing communities dominated by non-native cichlids in contrast to natural forest lotic environments which act as refugia for native species of fish. The dominance of cichlids in these reservoirs was attributed to certain reproductive strategies, diet, and habitat preference.

*Day 2**Keynote: Demetrio Boltovskoy*

Dispersion and impacts of *Limnoperna fortunei*: Myths and evidences

Only a fraction of the many publications on the Golden Mussel contain valuable field or experimental results, and there are a significant number of anecdotal observations and unsubstantiated conclusions. Particularly disturbing is the fact that a large proportion of the literature centers on claiming that the Golden Mussel has tremendous deleterious effects on native biota with little or no direct evidence. A review of the major environmental impacts claimed and comparison with actual evidences available underline the complexity of the problem, reveal the scarcity of our knowledge, and suggest that basing conclusions on the effects of other invasive mussels, in particular *Dreissena polymorpha* and *D. rostriformis bugensis* in Europe and North America, can be misleading.

Summary of session 3: Impacts of invasive species

Jaimie Dick discussed a metric to determine the impact of invasive species based on their maximum feeding rates (i.e., the ecological impact of invaders), by interpreting the effect of the potential abundance of invasive and native species, which

indicates the degree of potential impact they could have on a given environment.

Sarah Hasnain examined the Prey Naiveté Hypothesis in light of the interactions between the invasive crustacean predator *Bythotrephes longimanus* and native crustacean zooplankton, notably *Daphnia* species. The anti-predator response of the *Daphnia* species, which included deeper vertical positioning, was influenced by prey size and density, suggesting an appropriate prey response despite a lack of shared evolutionary history.

Kęstutis Arbačiauskas examined the results and consequences of historical stocking of lakes and reservoirs in the Ponto-Caspian region in the middle of the 20th Century, and the subsequent impacts of a number of highly aggressive invasive species originating from the area, which have resulted in negative economic and ecological outcomes in the invaded areas.

The final contribution to the third session was *Mbamwai Mbewe* who discussed the invasion pathway of the arrival of *Oreochromis niloticus*, Nile Tilapia, and *Cherax quadricarinatus*, Crayfish, and subsequent impacts on other aquatic species as well as on the fishery industry in the Kafue Floodplain.

Summary of session 4: Management strategies

Sarah Bailey started the largest of all the sessions at MFIS-Argentina by discussing the lessons learned from ballast water testing, examining the efficacy of treatment systems such as filtration and electro-chlorination, as well as highlighting some of the challenges and uncertainty which arise when sampling ballast under operational conditions.

Esteban Paolucci gave a talk on the effect of ballast water treatment on microplankton survival and the implications it could have on propagule pressure. By assessing changes in colonization and propagule pressure, Paolucci examined if variations were dependant on source water or treatment method, or both.

Elizabetha Briski discussed the prevention of species introduction through ballast water exchange and treatment techniques, particularly when used in combination with each other, by showing that when ballast water exchange is used with ballast water treatment, tanks contained mostly low risk organisms which were unlike to survive and establish in recipient freshwater habitats.

Marcelo Mantelatto described the testing of a technique to manage invasive corals, namely *Tubastraea tagusensis*, by wrapping with plastic and raffia sheets in order to kill the invasive corals. The conclusions of the test suggested that although the plastic was more effective, the raffia was easier to manipulate and lasted longer.

Tracey Burton examined management strategies for the protection and restoration of New Zealand lakes following the arrival of AIS. Given the unique flora and fauna, and highly diverse ecosystems of these lakes, AIS have had devastating consequences on the natural ecosystems, and this talk highlighted examples of successful invasion preventions, detection and containment.

Aibin Zhan discussed the advantages and challenges associated with early detection systems, particularly high-throughput DNA screening. The talk noted that DNA-based approaches are effective for the census of nonindigenous aquatic species, particularly for species in low abundance, but there continue to be many factors which can lead to errors.

Ryan Scott described how processing methods for molecular data (environmental DNA) can have a large impact on the sensitivity for detecting AIS at low abundances.

Thomas Landry shared how the control of four invasive tunicates, originally reported on Prince Edward Island in Canada two decades ago, has provided examples of key management strategies for use on other solitary tunicates which impact (or potentially impact) shellfish farms, either economically or environmentally.

Gretchen Rollwagen-Bollens wrapped up the session with a discussion on the invasive copepod *Pseudodiaptomus forbesi* and feeding and behaviour experiments which led to the discovery that the diet of *P. forbesi* overlaps with native copepods, potentially leading to competition for resources and substantial impacts on native foodwebs.

Day 3

Keynote: Evangelina Schwindt

Status of Aquatic Invasion Ecology: Argentina and South America

Dr. Schwindt reviewed the current state of AIS in South America, between 2004 and 2014. Her literature search found nearly 500 publications for South America, 60% of which were framed by biological/ecological topics, followed by 22% of

new-record or range-expansion publications. The number of marine studies equalled freshwater ecosystem studies. Crustaceans, algae, mollusks and fishes are the focus of most studies in marine habitats, while fishes and mollusks are the focus in freshwater habitats, and polychaetes and mollusks in estuarine habitats. The study of ecological strategies threatening the integrity of invaded ecosystems are scattered in time and space. Publications were mostly regional studies focused on relatively few species, suggesting an urgent need for inter-regional collaborative studies that might lead to a more integrative and precise sense of the ecological impacts of AIS within this vast region.

Summary of session 5: State of aquatic invasion ecology: Argentina and South America

Guillermo Cabrera Walsh examined how managers deal with freshwater aquatic plants becoming invasive in novel environments, where they have been separated from natural predators or their habitat becomes altered by human impacts. The study focused on how the introduction of specific herbivores (weevils) might control the expansion of invasive plants.

Julieta Manrique described the status and current research trends of invasive *Didymosphenia geminata*, which have been causing nuisance blooms in Chile and Argentina since 2000. Manrique described an improved DNA extraction technique for *D. geminata* to help determine the regional differences as well as explore the molecular diversity of the organism.

Marcos Tatián explained that ascidians of the Southwestern Atlantic are poorly studied, yet have potential to be a good indicator of anthropogenic transport. Species richness in the region was determined based on surveys of archived museum samples and field sampling, thereby elucidating the status of ascidians from the area.

Andrea Junqueira described results of a long-term monitoring program which discovered the introduction of *Saccostrea cucullata* in Guanabara Bay, Brazil, and a comparison of population density of native and alien oysters over four years.

María García examined how the diets of invasive *Oncorhynchus mykiss* and the native *Hatcheria macraei* overlap in Andean streams. It was determined that the diets of these fishes shift with the seasons, likely to reduce predation risk, inter-species competition, or both.

Joel Creed reviewed the invasion and management of invasive corals in Brazil, describing their arrival on oil rigs and subsequent spread into native communities across more than 3000 km of shoreline. Management and monitoring of this invasion is ongoing, highlighting the importance of pre- and post-border management.

Finally, *Gabriel Laufer* examined the invasion of bullfrog populations in Uruguay and discussed the negative impacts of this non-native species on the native community. On top of being important algae consumers, the bullfrogs are also preying on native tadpoles, and may carry a pathogenic fungus lethal to the native species. The arrival of these bullfrogs could have a devastating on native ecosystems, but there has not yet been any control action taken to eradicate this invasive species.

Posters

María Victoria Álvarez examined the reproductive characteristics of *Undaria pinnatifida* at Caleta Córdova, Chubut, Argentina. By studying the life cycle and reproductive capacity of this seaweed, this group will better understand its success in the area.

Nicolás Battini described how native anemones use defense mechanisms (behavioural response) to reduce predation of invasive sea slugs. While this will not prevent the arrival of the invasive sea slug, it may play an important role in the reorganisation of the foodweb in these benthic communities.

Tomás Chalde presented the arrival and life history of Chinook salmon in the Grande River, in the south of Patagonia. These salmon were compared to an established population in Lapataia River and key differences between stream- and ocean-type salmon were identified.

Patrice Charlebois discussed the creation of a national (USA) comprehensive website on AIS in the marketplace – TakeAIM.org. This website provides interested parties with information on state and federal regulations related to aquatic organisms, and is a repository for outreach materials to allow managers to assess the risk of individual invasive species.

Daniela Duchini examined the changes in consumption of *Limnoperna fortunei* in the lower Río de la Plata basin, Argentina, by various fish species. Results indicate that predation on this invasive mussel has increased since its first arrival ~20 years ago and that a large predator population may be causing decline of larger-sized mussels.

Celeste Franceschini presented the native grasshopper *Cornops aquaticum* as a novel control agent of Water Hyacinth in the Del Plata wetlands. This study examined the grasshopper's life cycle, feeding preferences associated with Pontederiaceae, and its potential as a biological control agent.

Fabrizio Frehse described geographical patterns and ecological interactions of non-native species in aquatic ecosystems in Brazil through a comprehensive literature review, thereby identifying knowledge gaps and national biases in the hopes of guiding continued research on the topic.

Clara Giachetti examined the role played by local predators during the colonization of invasive *Asciidiella aspersa* in Puerto Madryn, Argentina. Mortality due to predation by native sea slugs, sea stars and sea urchins suggested that these predators will prey upon, but not kill *A. aspersa*.

Sofía Haller reviewed historical trips which introduced many new species to Argentina, both land-based and aquatic. Using historical databases to track the comings and goings of historical expeditions, she concluded that the majority of expeditions originated in the northern hemisphere and often made stops in Brazil or Uruguay prior to arrival in Argentina.

Leandro Hünicken discussed the phenotypic plasticity of the invasive freshwater clams of the genus *Corbicula*. He examined the morphology of six populations across Argentina for changes in shell morphology, gills and labial palps, and showed significant differences between these populations indicating that the phenotypic plasticity shown by *Corbicula* spp. may be instrumental to the adaptive success of these species.

Andrea Junqueira described how native vermetid reef-building species may be providing shelter for invasive bivalves, by comparing population densities of invasive bivalves in protected versus exposed rocky shores locations in Brazil. It was found that vermetid reefs act as a shelter and restrict the growing size of certain invasive species of bivalves.

Ciaran Laverty presented how changing climates and increased pollution might alter the impacts of invasive species. By investigating how oxygen levels altered the predatory impact of native versus invasive *Gammarus* species on prey, it was revealed that reduced oxygen levels are likely to be more detrimental to the native species.

Jungsuk Lee discussed the International Maritime Organization's (IMO) recommendations for ballast water management systems G9 approval procedures for use of active substances. Bioassays of *Vibrio fischeri* and *Skeletonema costatum* were used to test the residual toxicity of treated ballast water under various test conditions.

María Gabriela Liuzzi examined invasive bryozoans in Quequén Harbour, Argentina. By creating artificial attachment surfaces to survey the bryozoan community in the Harbour, 12 species were recorded including six alien species.

Ana Laura Machado described a survey of invasive species in Montevideo harbour, Río de la Plata, Uruguay by collecting scrapings from the Bay. A total of 14 taxa were identified, of which three were exotic or cryptogenic in origin, with no novel species being identified since a previous survey.

Fedra Solange Martínez explored the abundance and composition of invertebrate herbivores on *Eichhornia crassipes* and *Salvinia* sp., species indigenous to South America which have become important pest species around the world. Of the species of invertebrate herbivores detected, the majority showed seasonal variation in their composition with implications on the introduction of potential biocontrol agents in affected areas.

Lucas Molina discussed how the widespread colonisation of *Conopeum seurati* growing on *Spartina alterniflora* stems at Villa del Mar, Argentina, has begun to strangle *Spartina* colonies, and is the likely cause of a widespread *Spartina* die-off in the area.

Luciana Montalto evaluated the drift and daily distribution rhythms of *Limnoperna fortunei* in the Middle Paraná River floodplain, Argentina. Drift rates have increased at the river center and during the morning hours (3 a.m.–9 a.m.), suggesting that the Paraná River main channel and large secondary channels are important corridors for the dispersal of this invasive species.

María Laura Presta examined the influence of seasonal temperature and chlorophyll-*a* conditions on the abundance of the invasive copepod *Eurytemora americana* in Bahía Ushuaia. High abundances of copepods were associated with high levels of chlorophyll-*a* and increased temperatures, and ovigerous females were noted along the entire seasonal cycle suggesting that the population is present all year through subitaneous eggs.

Sofía Quiroga described the invasion status and management strategies of three exotic predatory fishes in the Valcheta stream, Río Negro, Argentina, highlighting new and updated range information. With these exotic species thriving in the area, native prey species are on the decline and management actions are needed to reduce the number and impact of these fishes.

Paola Reyna presented current work to model worldwide areas of climate suitability for two invasive freshwater clams. Using six environmental predictors, it was determined that there are areas where the two invasive clams overlap, despite *Corbicula fluminea* having a wider potential distribution than *C. largillierii*.

Kitae Rhie statistically summarised and evaluated test conditions for ballast water management systems with regard to International Maritime Organization's G9 approval for use of active substances.

Alicia Rico examined non-indigenous benthic species on the southern coast of Chubut, Argentina, expanding the current knowledge of the geographic distribution of several benthic species, including solitary and colonial species, since initial arrival over the last decades.

Florencia Rojas Molina discussed the spatial distribution of *Limnoperna fortunei* larvae in the Middle Paraná river, Argentina, during a period of low water. By sampling at various environmental conditions, they determined that larval concentrations were similar among the environments but showed different larval stages, thereby providing relevant information on a little studied topic.

Vanessa Salomone described the chemical content of invasive and native brown algae in the central Gulf San Jorge and determined their potential as food and as bioindicators. The results of the study suggest that the native algae, *Macrocystis pyrifera*, have consistent mineral content throughout the year whereas the invasive algae, *Undaria pinnatifida*, shows seasonal variation, thereby making either suitable for commercial development for human and animal consumption.

Kyoungsoon Shin examined potential survival of phytoplankton in ballast water by inoculating various treatments to test various scenarios of ballast water release and subsequent phytoplankton success. The number of phytoplankton taxa in a sample was found to decrease as voyage duration increased, while high nutrient concentration and water temperatures after ballast water release may

encourage exponential population growth, increasing invasion potential.

Anabela Taverna compared two ascidians: *Asterocarpa humilis*, native to New Zealand, and *Cnemidocarpa robinsoni*, native to the Juan Fernández archipelago, concluding that these two species are synonyms and that *A. humilis* was not present in the South Western Atlantic until 1977, confirming its status as an exotic species to the area.

Noelia Uyua described possible invasion routes of *Didymosphenia geminata* based on valve morphology of specimens collected from South Patagonia, Argentina, compared to various regions of the world. Based on the first identification of the species in Argentina, human mediated transport is considered the primary means of *D. geminata* introduction, but morphology is not sufficient to understand the origin of the species.

Noelia Uyua examined the distribution of an invasive diatom, *Didymosphenia geminata*, in Andean-Patagonian, Argentina, by analysis of invasion dynamics using Geographic Information Systems. Using a database of monitored sites, provincial and national level distribution maps were developed which show the range expansion of *D. geminata* from 2010–2015, providing an important resource for the future management of the species.

María Guadalupe Vázquez described work on the first sightings of *Palaemon macrodactylus* in Quequén harbor and subsequent colonization of Quequén River. In comparison to collections made in 2008, where no individuals were found upstream, a sampling program from February 2016 found a stable population up to 6-km inland, where waterfalls act as a natural barrier to their expansion.

Highlights and recommendations

MFIS succeeded in bringing together diverse high quality presentations to an audience with strong student and regional representation. In our view, a main achievement of MFIS was the unusual level of audience feedback and debate seen during sessions and breaks. While this was surely encouraged by the relatively small size of the conference, it also underscores a pressing need for specific, state-of-the-art, international meetings such as MFIS in regions that are geographically

distant from scientific hubs yet rapidly expanding in economy, commerce, and science.

In this synthesis, we cannot repeat the wealth of information and ideas put forward during three very intense days of presentations and debate. We definitely cannot (and do not try to) accommodate all views – the above mentioned level of debate having necessarily evinced a diversity of opinions on specific topics. But we here try to summarize points that by virtue of their potential consequences, innovativeness, or degree of consensus elicited may be relevant to South America and the field of aquatic invasions in general.

Theme 1: Vectors and pathways

In environmental policy regarding invasive species, prevention is key. Regardless of the identity of the species, severity of the potential impacts, local capabilities for early detection, mitigation, and other considerations, there was general agreement that the best we can do is try to keep AIS out.

Themes 2 and 3: Ecology, biology and impacts of AIS

Discussion over impacts led to the hottest debates during the conference and this topic is likely where the highest disparity of views exist within the field. This diversity of positions is, in our view, ultimately rooted in disagreement over very basic questions such as “what is an impact?,” “how are impacts to be measured?” and “is change *per se* negative when we are dealing with ecosystem conservation?” Since the impact of AIS is a topic with direct budgetary consequences (either in form of money invested in the fight against AIS or lost to their effects), working on consensus within this area is in our view urgent to effectively inform managers. Specific recommendations during MFIS included the incorporation of metrics such as functional responses to the assessment of AIS impacts to provide objective grounds for comparison; the use of plasticity of AIS feeding modes as a potential predictor for impacts; and the use of meta-analyses to broaden the reach of our conclusions. Two risks, however, were identified in relation to the latter recommendation: (1) The repetition of untested ideas may bias conclusions towards a perception of higher impacts than are realized in areas where extrapolation of impacts

from better studied regions is frequent (see below) and (2) More generally, conclusions based on these type of analyses are no better than the database they are based upon. There is a concern that invasion science has traditionally paid more attention to negative than positive interactions.

Theme 4: Management strategies

Management priorities were identified in the following order of importance: (1) prevention (see above); (2) early detection and eradication when feasible; (3) mitigation of impacts. Ballast water was identified as a particularly well-studied vector, providing learning opportunities for other vectors (e.g. hull fouling). For instance, the combination of methods (e.g. mid-ocean exchange of tanks and use of new technologies to treat the water before discharge) dramatically increased ballast water management performance, and similar measures should be considered for other vectors. Prevailing concerns are the efficacy of the transference of scientific information to legislators, lag-times until measures are effective (approval of guidelines, certification of methods), and the transference of cost to the industry by increased management requirements.

Theme 5: State of the field in the region

This topic was exhaustively summarized in E. Schwindt’s excellent keynote talk, and a diversity of poster and oral presentations further illustrated the points made. A primary concern is that South America is clearly an understudied region. The recent increase in the number of confirmed and cryptogenic marine AIS in Argentina (jump from 31 and 46, respectively, in 2002 to 1997 and 65 in the same categories in 2012; Orensanz et al., 2002; E. Schwindt personal communication) not only reflects an intensification of introduction pathways, but likely also the recent detection of old introductions in the country (i.e. a detection lag-time). In this context, the paucity of knowledge on pre-invasion conditions in coastal and freshwater ecosystems across South America is particularly problematic. Global change may add to further uncertainty in this region through promotion of processes such as the evolution of

invasive behaviour in natives or previously non-problematic cryptogenics (e.g. case of *Didymosphenia geminata* thought to have been introduced in South America in the 60s, but recently showing invasive behaviour in its native range). While more research is clearly needed, an increase in the number of publications may fail to improve our knowledge and management capabilities unless there is a clear focus on information gaps. Experimental work is particularly required in peripheral regions such as South America, where the extrapolation of conclusions from better-studied parts of the world is frequently a first approach to problems. Yet if perpetuated, extrapolations are counter productive because they misinform management and provide a false feeling of knowledge that potentially hinders research. A paradigmatic case, brilliantly illustrated by keynote D. Boltovskoy, is the direct importation of conclusions from Dreissenid mussels in Europe and North America to (mis-) predict effects of Golden Mussels in South America. These difficulties are somewhat countered by the rapid consolidation of research groups dealing with marine and freshwater introductions in Argentina more recently.

Future activities

We hope MFIS has stimulated interest for further scientific research; has brought South American researchers closer together with each other and researchers from other regions; and has promoted collaborative work among participants. There is a need for additional national and international meetings in the fields of marine and freshwater invasions in Argentina to continue this forward progress. Coincidentally, the International Conference on Marine Bioinvasions (ICMB) will be held in the Patagonian town of Puerto Madryn in October 2018, which is bound to carry forward the post of some of the debate points relevant for Argentina and South America promoted during MFIS. Our next MFIS meeting will be held in Beijing, China in 2018. We look forward to continuing to build connections between scientists and managers across global geographic boundaries. In our view, benefits are double sided when international speakers are brought to decentralized

regions, bringing a wealth of knowledge and experiences to guide developing programs but also benefiting from the possibility of establishing collaborative work with groups from regions otherwise inaccessible to them – this is particularly so in the field of biological invasions where more and more the world is becoming one interconnected story yet exotics' sources remain by definition remote.

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