Knowl. Manag. Aquat. Ecosyst. 2024, 425, 7
© G. Laufer and N. Mazzeo, Published by EDP Sciences 2024
https://doi.org/10.1051/kmae/2024006

www.kmae-journal.org

Knowledge & Management of Aquatic Ecosystems

Journal fully supported by Office français de la biodiversité

OPINION PAPER OPEN ACCESS

Preserving Uruguay's freshwater systems: the need to restrict invasive species introductions for sustainable production

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Received: 21 January 2024 / Accepted: 15 March 2024

Abstract – This manuscript critically examines the history of non-native aquatic species introductions in Uruguay, emphasizing the role of public institutions. Despite global concerns about biodiversity threats from these introductions, Uruguay's reliance on animal production and aquaculture involving non-native species has grown since the 1980s. State institutions, despite past failures, have promoted these introductions without comprehensive risk assessments. Notable cases, including failed attempts with species like the herbivorous carp, American bullfrog, Nile tilapia, Australian redclaw crayfish, and American mink, raise concerns about invasive populations due to a lack of proper risk assessments and prevention measures. Previous examples were deficient in escape monitoring, oversight of specimens after farm closures, and considerations for the presence of new pathogens. This highlights the need for more informed and responsible approaches to prevent invasive species' establishment, advocating for rigorous analysis and risk assessments before any introduction. We propose overcoming historically fragmented decision-making processes by establishing a bridging structure that coordinates inter- and intra-institutional efforts, engages with the academic sector and social organizations, and evaluates the introductions. This platform can prioritize protecting aquatic ecosystems, fostering sustainable growth, and maintaining ecological balance, contributing to the solution of the problem by facilitating coordinated efforts and engaging diverse stakeholders.

Keywords: Biological invasion / aquaculture / introduction path / environmental policy

The global concern regarding the introduction of non-native species, which poses a severe and escalating threat to biodiversity, is particularly pronounced in aquatic ecosystems due to their heightened vulnerability and management complexities (Ricciardi and MacIsaac, 2011; Mormul *et al.*, 2022; Magalhães *et al.*, 2023). In the field of ecological conservation, prioritizing prevention emerges as the paramount strategy, necessitating a focused approach to identify and manage potential introduction pathways (Magalhães *et al.*, 2021; Simberloff, 2021). Prevention strategies have the potential to mitigate the adverse impact of invasive species on aquatic ecosystems but also to uphold the ecological integrity of these critical habitats.

This manuscript delves into the historical context of introducing non-native aquatic species for animal production in Uruguay, with a particular emphasis on the role of state institutions. The examination of the decision-making processes associated with promotions and oversight, allows us to explore and incorporate more informed and environmentally responsible strategies to prevent future invasions in aquatic ecosystems.

Uruguay, dating back to the 17th century, has been deeply reliant on primary industries, notably livestock farming (*i.e.* cattle and sheep), as a cornerstone of its cultural and economic identity. These pursuits have consistently centered on non-native animals, with particular emphasis on cattle ranching capitalizing on the natural grasslands' high productivity, a hallmark of the Pampa biome (Sena, 2012). Beyond the socio-economic repercussions, this development model has wrought profound changes in the composition of native large mammal communities. Traditionally perceived as potential menaces to this production paradigm, large predators have been supplanted, making way for substantial populations of herbivores, fundamentally altering the dynamics of terrestrial ecosystems (Pereira-Garbero *et al.*, 2013). In contrast, freshwater ecosystems did not share the early spotlight as sources of animal production. Nevertheless, during the 20th century, these systems bore the brunt of urbanization, pollution, and dam construction.

Since the early 1980s, there has been a growing trend towards the implementation of animal production and aquaculture projects. This trend has been systematically rooted in discrediting the value of native species and seeking to

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establish non-native species for such endeavors (*e.g.* Carnevia and Mazzoni, 1990) (Tab. 1). In these attempts to develop entrepreneurial ventures centered around freshwater species, public institutions have played a central role, serving as enablers, promoters, introducers, and facilitators in disseminating these species throughout the country. Despite this reliance on traditional agricultural practices, there have been repeated attempts to introduce "new species" (often aquatic animals considered invasive in other regions) for the purpose of developing breeding programs on farms. Unfortunately, these introductions were not properly risk-assessed and mostly resulted in non-economically viable ventures, with little control over the fate of the introduced animals. State institutions have often played a significant role in promoting or participating in these introductions (Carnevia, 2008). The following cases describe such introductions, serving as a basis for reflection and learning for future endeavors.

One of the most notable cases is that of the common carp (*Cyprinus carpio*), a large-bodied fish native to Western Asia and Eastern Europe, which has likely been present in the Río de la Plata for over a century, having been used as an aquaculture resource on numerous occasions (Mac Donagh, 1948). Between 1993 and 2008, as part of a public policy promoting fish farming on rural properties throughout the country, the National Directorate of Aquatic Resources of the Ministry of Agriculture, Livestock and Fisheries (DINARA-MGAP) promoted the stocking of juvenile *C. carpio* and the herbivorous carp *Ctenopharingodon idella*, in various types of water reservoirs in agricultural systems nationwide (Spinetti *et al.*, 2010). Despite the significant investment of time and resources, an industry was never developed, nor was the consumption of this non-native species established among rural residents. Zarucki *et al.* (2021) suggest that *C. carpio* is clearly invading Uruguay, spreading through different river basins. This species is having negative effects on native communities, positively interacting with invasive mollusks, consuming priority native conservation species, and overlapping trophic niches with native fish (Amestoy *et al.*, 1998; Zarucki *et al.*, 2021; Diaz-Angeriz *et al.*, 2022). Zarucki *et al.* (2021) also raise concerns about the high invasion risk associated with *C. idella*, given its history as an invader and its introduction in multiple sites.

Subsequently, in the 1980s, DINARA-MGAP and the Faculty of Veterinary Medicine at the University of the Republic (UdelaR) promoted the introduction of the American bullfrog (*Aquarana catesbeiana*), a large aquatic anuran native to the eastern coast of North America. These institutions implemented several research and outreach projects aimed at establishing a bullfrog industry in Uruguay (Carnevia and Speranza, 2002). However, the idea did not prosper, and by the early 2000s none of the more than 20 farms that had been established in the country remained. Most of the farm facilities were not robust, making escapes common, and there was no control when they closed. As a result, five populations of *A. catesbeiana* were reported in Uruguay, three of which persist and appear to be expanding in Canelones, Maldonado, and Cerro Largo (south, southeast and northeast respectively). This invasive species is altering aquatic communities' structure and their food webs, and negatively impacting native amphibian's diversity (Laufer *et al.*, 2008, 2018, 2021; Laufer and Gobel, 2017; Gobel *et al.*, 2019, 2023). Furthermore, during the operation of the bullfrog farms, the presence of at least two significant diseases (chytridiomycosis and ranavirosis) that can impact native amphibians was detected (Mazzoni *et al.*, 2003; Galli *et al.*, 2006).

The only apparent commercial success story in Uruguay involves various sturgeon species, including *Acipenser baerii*, *A. gueldenstaedtii*, *A. ruthenus*, and *Huso huso* (Serra *et al.*, 2014). These species have been bred for caviar production on a private farm in the Rio Negro (central region of the country) since the early 1990s. Most of the Uruguay's caviar production is exported, resulting in significant economic revenue (Valladão *et al.* 2016; FAO Fisheries, 2023). There have been multiple instances of escapes, with specimens of *A. baerii* and *A. gueldenstaedtii* being recorded in the wild, often by fishermen, even at considerable distances from the farm's location (Azpelicueta and Almirón, 1999; Demonte *et al.*, 2017; Chuctaya *et al.*, 2019). However, at present, there is no concrete evidence to classify these species as invasive (Zarucki *et al.*, 2021).

In 1998, DINARA-MGAP introduced the red-claw crayfish (*Cherax quadricarinatus*), native to Australia, to study its cultivation feasibility in the country. Accompanying this promotion, a private aquaculture farm for the production of this species was established in the Maldonado Department (southeastern Uruguay) in 2000 (FAO Fisheries, 2023). Although it is considered a significant invader in various regions (*e.g.* Nunes *et al.*, 2017; Vecchioni *et al.*, 2022), it has not yet been recorded in the wild in Uruguay. An important concern is the presence of new pathogens within the farm in the Neotropical region, which have been classified as a significant risk for native biodiversity (Volonterio, 2009).

Despite past unfavorable experiences, DINARA-MGAP embarked once more on the introduction of the Nile tilapia (*Oreochromis niloticus*), disregarding ample evidence from other regions that highlighted its status as a highly invasive species. This initiative was accompanied by a rapid risk assessment, ostensibly aimed at safeguarding local biodiversity while "preserving the potential case for aquaculture development". Consequently, in 2013, Nile tilapia was introduced into Uruguay based on this risk analysis that, in hindsight, presented questionable arguments, such as the species' presence in neighboring countries or the assertion of a 'local climatic barrier' (Spinetti *et al.*, 2010; Foti and Spinetti, 2012). Collaborating with a private enterprise, a farm was established in the Salto Department (northwestern Uruguay) (Vilches, 2010). However, as history repeated itself, the venture proved unviable, leaving lingering questions about the fate of the specimens maintained in open ponds until 2017 (DINARA, 2019).

While invasions have not occurred, it's worth noting that local authorities and technicians contracted by FAO are advocating for the introduction of other potentially risky fish species (*e.g.* Carnevia, 2008). Notably, there is an aquaculture facility managed by DINARA-MGAP in Salto Department, which has actively propagated and encouraged the farming of goldfish (*Carassius auratus*) and the herbivorous grass carp, *C. idella* (Carnevia, 2008; DINARA, 2019).

Introductions of potentially invasive species extended beyond crustaceans, fish, and amphibians; the American mink (*Neovison vison*), known for its invasive history, was introduced to boost Uruguay's fur industry, previously reliant

on native coypu (*Myocastor coypus*) breeding (Otero *et al.*, 2005, 2006; Pereira-Garbero *et al.*, 2013). The National Institute of Agricultural Research (INIA) initiated this introduction program in the early 2000s. An executive decree in 2008 provided tax exemptions on equipment imports, promoting mink farming (Resolution N° 1673-2014 of the General Tax Directorate). A single fur farm near Montevideo (southern Uruguay) was established bordering a national protected area and remains operational. Wild mink sightings around the farm have escalated since 2018, raising concerns about their local establishment, necessitating a thorough assessment of their presence and ecological impact (Laufer *et al.*, 2022). The mink is invading ecosystems globally and regionally, with potential significant environmental repercussions if established in Uruguay (Zabala *et al.*, 2010).

The evidence demonstrated that none of these species should have undergone a rigorous risk assessment. At the time of their introduction, all of them had well-documented and extensive records as dangerous invaders (see Invasive Species Specialist Group ISSG, 2015). The capacity of these species to invade Uruguay was consistently underestimated without scientific basis (*e.g.* Carnevia and Speranza, 2002; Foti and Spinetti, 2012). However, it is well known that the attributes sought for a productive species (*e.g.* plasticity, tolerance to local climate and diverse environmental conditions, especially anthropogenic environments, high fecundity, disease resistance) are the same qualities that make them successful invaders (Ju *et al.*, 2020).

A common feature of all these introductions is the significant effort by national authorities to introduce these species that can threaten natural freshwater ecosystems, but a complete disconnect regarding the monitoring and control of the environmental impacts generated. The management manuals provided to farm owners and workers lack explanations of the associated risks and fail to provide guidance on preventing escapes or releases into the wild (Mazzoni, 2001; Otero *et al.*, 2006; Spinetti *et al.*, 2010). Even more, nothing was done to prevent the entry of associated organisms, such as hitchhikers, especially pathogens (Carnevia *et al.*, 2010; Laufer *et al.*, 2018; Garcia *et al.*, 2019).

It's crucial to highlight that the introductions led by state authorities in Uruguay have, for the most part, failed to establish thriving industries for the nation. This raises a fundamental question: are these environmental costs, which manifest as economic expenditures and the loss of valuable ecosystem services, justifiable in the context of such initiatives? Most of these endeavors, linked to economic ventures, have resulted in repeated failures, except in the cases of sturgeon and mink. This pattern raises the question of why these initiatives have continuously faltered. Besides the evident environmental concerns, these efforts also expose a lack of economic foresight and market research.

Private actors involved in species introduction lack comprehensive information about the potential risks and negative environmental impacts involved, as the information provided by the state emphasizes solely the economic benefits. Some of the technical staff associated with private initiatives often overlap with the public domain, involving both research institutions (universities and institutes) and governmental agencies (ministries, directorates). However, this integration can lead to biased analysis and a subtle risk underestimation. To address this issue, coordination and communication among key entities such as MGAP, INIA, and Ministry of the Environment are essential, ensuring that authorizations for initiatives from the private or public sector undergo a decision-making process that considers multiple dimensions. Such communication must be grounded in solid scientific evidence.

Lessons learned from past experiences highlight the need for careful planning, risk assessment, and robust evaluation of potential ecological and economic impacts before introducing any new species into the country. For all these reasons, we argue that this ongoing practice of introducing, legalizing, and promoting the cultivation or breeding of non-native freshwater organisms in Uruguay should be collectively halted if the country intends to fulfill its biodiversity commitments. While recognizing the global significance of the invasive species problem, Uruguay has taken steps to address it through its National Biodiversity Strategy (ENB) for the conservation and sustainable use of biological diversity. By adhering to the ENB and international agreements (Aichi Biodiversity Target 9 of the Convention on Biological Diversity; The Sustainable Development Goal 15.8 of the 2030 Agenda for Sustainable Development of the United Nations; and The Principle 5D of the Earth Charter), Uruguay seeks to control, eradicate, and manage high-priority invasive species, ensuring the protection of its biodiversity and fostering a more sustainable future for its aquatic ecosystems (MVOTMA, 2016; Meyerson *et al.*, 2022).

Since large-scale productions such as aquaculture farms often require state instruments, permits, and controls, this introduction pathway can be easily regulated. A prohibition on the import, possession, consumption, and/or export of these species or their derived products could make a significant contribution to biodiversity conservation and appears to be an achievable goal for different countries.

This work underscores the responsibility associated with environmental issues, which falls under the purview of the Ministry of the Environment. We advocate for a significant shift in decision-making concerning the introduction of non-native species in the country. One of the central issues to address is the fragmentation of the state during the decision-making process. We propose that ministries and institutions cease the introduction of non-native organisms without prior environmental authorization from the Ministry of the Environment. To resolve this matter efficiently, we recommend the establishment of coordination mechanisms (bridge structure, a multifactorial and multilevel platform similar to basin commission) that compel the entire network of relevant public institutions to come together at a common table for deliberation. Furthermore, we recommend that the Ministry of the Environment consult with specialized academic experts when assessing future requests for the introduction of non-native species, in addition to relevant government agencies and civil society, making these consultations binding instances. Environmental governance should be constructed upon participatory, flexible, and highly adaptive frameworks (Boyd and Folke, 2011). None of these pillars are currently present in the decision-making process regarding the introduction of non-native species to Uruguay. This approach should also extend to the allocation of management resources, tax benefits, and research funds. Prior to granting such support, especially in cases involving the introduction or dispersal of non-native

Table 1. Current status of aquatic non-native species introduced in Uruguay for commercial purposes. For each species we provide information on the status: populations in captivity (CA), individuals registered in the wild (IW), population established in the wild (PW), invasive populations in the wild (IN), and their occurrence in the large hydrographic basins: Rio de la Plata (RP), Rio Negro (RN), Río Santa Lucía (RL), Río Uruguay (RU), Laguna Merín (LM), Océano Atrántico (OA). Additionally, we include details about the purpose of its introduction and the invasive capacity, classified as Potential (PO) based on invasive history, Confirmed (CO) with documented invasions in Uruguay, and Unknown (UN) lacking evidence suggesting invasive potential. Finally we provide the aquaculture score (ranging from 0 to 10) assigned in a national evaluation for aquaculture development (Carnevia 2008; species not evaluated identified with NE), along with literature references.

species	Status	Hydrographic basin	Purpose	INVASIVE CAPACITY	Aquaculture score	References
Cherax quadricarinatus	CA	RP	Food	PO	9	Nunes *et al.*, 2017; Haubrock *et al.*, 2021
Aquarana catesbeiana	IN	RO, LM, RN, OA	Food	CO	9	Barbosa *et al.*, 2017; Laufer *et al.*, 2018
Xenopus laevis	CA	RP,LM	Aquarium	PO	NE	Laufer 2011; Measey *et al.*, 2012; Barbosa *et al.*, 2017
Cyprinus carpio	CA, IN	RP, RU, RL, RN, LM, OA	Food, recreation	CO	8	Crichigno *et al.*, 2016; Zarucki *et al.*, 2021
Ctenopharingodon idella	CA, IW	RP, RU, RL, LM	Macrophyte control, Food	PO	8	Zarucki *et al.*, 2021; Moreira and Silva 2023
Carassius auratus	CA	RU,RP, OA	Aquarium	PO	10	Xi'ao *et al.*, 2014; Chan *et al.*, 2019
Acipenser baerii	CA, IW	RN, RU	Food	UN	10	Zarucki *et al.*, 2021; Loureiro *et al.*, 2023
Acipenser gueldenstaedtii	CA, IW	RN, RU	Food	UN	10	Zarucki *et al.*, 2021; Loureiro *et al.*, 2023
Acipenser ruthenus	CA	RN	Food	UN	10	Zarucki *et al.*, 2021
Huso huso	CA	RN	Food	UN	10	Zarucki *et al.*, 2021
Oreochromis niloticus	CA	RU	Food	PO	8	Cassemiro *et al.*, 2018; Zarucki *et al.*, 2021
Bubalus bubalis	IW	UN	Food	UN	NE	Pereira-Garbero *et al.*, 2013
Neovison vison	CA, IW	RL	Fur	PO	NE	Pereira-Garbero *et al.*, 2013; Laufer *et al.,* 2022

species, a comprehensive environmental risk assessment by expert academics should be mandatory. By adopting these proactive measures, Uruguay can avoid the mistakes of the past, protect its delicate aquatic ecosystems, and foster sustainable growth while maintaining the ecological balance of its waters.

Biological invasions have emerged as a significant and escalating global issue, posing severe threats to biodiversity conservation and the provision of essential ecosystem services. The challenges associated with controlling established invasive species have led to a paradigm shift in focusing on prevention, primarily through the restriction of entry pathways (Pyšek *et al.*, 2020). This approach recognizes the importance of intercepting and mitigating the introduction of new invasive species, thereby safeguarding ecosystems and minimizing the subsequent ecological and economic impacts (Robertson *et al.*, 2020). In the future, it is crucial to prioritize the potential of native species (Valladão el al. 2016) over introducing non-native species.

Acknowledgments

The authors are members of the Sistema Nacional de Investigadores (SNI), Uruguay. This research was supported by the Agencia Nacional de Investigacióne Innovación, Uruguay, Grant ANII_FMV_3_2020_1_162548. Additionally, NM thanks the fundind of ANII (ANII_FSDA_1_2018_1_154610) and Global Water Partnership (GWP 2020).

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Cite this article as:,Laufer G and Mazzeo N. 2024. Preserving Uruguay's freshwater systems: the need to restrict invasive species introductions for sustainable production. Knowl. Manag. Aquat. Ecosyst., 425, 7.