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Short Communication

Improving the management of aquatic invasive alien rodents in France: appraisal and recommended actions

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Abstract

Invasive alien species (IAS), including aquatic invasive alien rodents (AIAR), cause extensive damage to ecosystems with significant economic, human health, and environmental concerns. In France, AIAR populations are well established, and a permanent control programme has been set up in several areas to reduce their impact. While some studies have reported the results of AIAR control activities, detailed information on current management strategies and how control activities are implemented in the field is lacking. This study evaluates the implementation of the management plan and control activities of AIAR in France regarding (i) problem definition, feasibility and objectives, (ii) planning from action plan, organization, funding and methods, (iii) field implementation from spatial prioritisation and personnel and (iv) monitoring and evaluation. Our study reveals that in France, (i) local and regional institutions mainly manage control activities primarily through volunteers and (ii) national and regional management plans on AIAR controls are missing. We elaborate on several actions that can help local and regional entities in improving their control programme, including zonation for priority actions, development of performance indicators of control activities, engagement of volunteers, and scientific monitoring of AIAR populations.

Key words: alien species, species control, capture, control program, volunteers, *Myocastor coypus*, *Ondatra zibethicus*

Introduction

Wetlands are threatened by many stressors, such as water extraction, flow modification, pollution, and climate change (Vörösmarty et al. 2000). They are also affected by invasive alien species (IAS) (Gherardi et al. 2008; Vilà and Hulme 2017). Among the numerous wetland invasive species, aquatic invasive alien rodents (AIAR), including coypu (*Myocastor coypus*) and muskrat (*Ondatra zibethicus*), trigger widespread damage with important economic (Cuthbert et al. 2021), human health (Chinchio et al. 2020), and environmental impacts (Bertolino et al. 2005). The coypu is responsible for

one of the highest estimated costs of IAS worldwide, with US$19 billion of damage (e.g. the value of crop losses and damage repair) (Diagne et al. 2020), and its economic costs have exponentially increased during the last decades (Cuthbert et al. 2021). Although both species are abundant and widespread in France (coypu: MNHN and OFB 2023a; muskrat: MNHN and OFB 2023b), their economic impacts have been poorly quantified (Renault et al. 2021).

Coypu and muskrat dig burrows and contribute to siltation and riverbank instability drastically reducing the water flow in some areas (Sofia et al. 2017). Although damages for agriculture have been reported, the most direct and indirect critical damages caused by coypu are related to drainage structures and the associated risk of flooding (Panzacchi et al. 2007). AIAR act as a reservoir of several infectious diseases in humans and other parasites transmissible to livestock, pets and wildlife (Ayral et al. 2020). In France, nearly 600 leptospirosis cases were confirmed in 2014 with 75% of these cases (i.e. 450 cases) detected in people who had used wetlands through water recreation activities (e.g. water sports, fishing) (Tourneur and Julliat 2019) suggesting a potential correlation between leptospirosis in humans and wetlands colonized by AIAR. Dense coypu populations reduce the diversity of native plants in wetlands by reducing seedlings, disrupting vegetation succession and preventing natural re-vegetation (e.g. Boorman and Fuller 1981; Bertolino et al. 2005). Other studies have reported adverse effects of the presence of coypu on populations of native waterbirds (Bertolino et al. 2011) and bivalve molluscs (Diggins and Stewart 2000; Nagayama et al. 2020). Although it is commonly assumed that AIAR alter ecosystem functioning, assessments of the direct and indirect effects of the presence of AIAR on native biodiversity are still limited (e.g. Boorman and Fuller 1981; Bertolino et al. 2011), particularly on the potential cascading effects of vegetation changes due to AIAR presence on other native species. The negative effects of AIAR on ecosystems might be exacerbated if natural top-down controls on invasive populations do not operate. In Italy studies have suggested that the red fox *Vulpes vulpes*, and the grey wolf *Canis lupus*, could prey upon coypus (Mori et al. 2020), but possible regulation effects are still to be investigated. Although few studies have investigated the main predators of AIAR in France, the red fox and the common buzzard, *Butteo butteo*, might prey upon young individuals. Finally, as coypus and muskrats can co-occur and would have close ecological requirements (Ruys et al. 2011), we can predict that populations might compete for food and space particularly in areas where densities are high and food is limiting. Direct evidence of competition between the two species have not been reported yet. However, studies in the United States have suggested that between-species competition may occur (Ahlers and Heske 2017). Indeed, the rapid expansion of muskrat populations observed after coypu populations being removed from areas of coexistence suggested that that coypu populations affected the population dynamic of muskrats (Evans 1970).

The assessment of the direct or indirect costs produced to human activities or related to the presence of AIAR in ecosystems, and the evaluation of control effectiveness is fundamental to encourage decision-makers and financers to fund further actions against IAS (Bradshaw et al. 2016). However, no study evaluating the results of the current management of AIAR in France at a country level has been published during the last three decades. A recent article reported that in a western region of France (Pays de la Loire) covering 32 000 km^2, a control programme removed 287 763 AIAR in 2016 (8.99 individuals/km^2/year) (Bonnet et al. 2021). In other European countries, some studies evaluating the management of AIAR exist as for the muskrats in Netherlands (van Loon et al. 2017) and Britain (Gosling and Baker 1989) and for coypu in Britain (Gosling and Baker 1989) and in Italy (Panzacchi et al. 2007). In South Korea, a control programme covering an area of 23 384 km^2 managed to trap 27 487 coypus in five years (0.24 individuals/km^2/year) (Kim et al. 2019), and more than 64 338 coypus were removed in a year from 41 515 km^2 area in Italy (1.55 individuals/km^2/year) (Panzacchi et al. 2007). Control activities managed to remove up to 2.19 muskrats per km waterway per year in Netherlands (Bos et al. 2019). Coypu was successfully eradicated in Britain (Gosling and Baker 1989) and recently from 1.7M ha in the Delmarva Peninsula, USA (Anderson et al. 2022).

The management of pest species is a complex issue that require a strategic approach. The present article aims to examine the way AIAR control activities are implemented in France with reference to the stages of a vertebrate pest management framework (see Braysher 1993) including: (i) problem definition, feasibility and objectives, (ii) planning from producing an action plan, to organization, funding and methods, (iii) implementation including spatial prioritisation and personnel, and (iv) monitoring and evaluation. This evaluation detailed hereafter is used to highlight potential weaknesses and suggestions (summarised in Table 1) for improving the effectiveness of the control measures and the management of AIAR in France and other countries.

Problem definition, feasibility and objectives

In Europe, the coypu and muskrat have been included in the list of IAS of Union Concern (European Union 2014). This regulation provides for the rapid eradication of IAS at an early stage of invasion and management measures for species already widespread in a member state. Management measures are applied according to the environmental impact and the specific local situation. Decisions are based on costs-benefits analysis. Thus, if eradication is no longer feasible, the aim is to limit the impacts, particularly on biodiversity. The regulation aims to minimise and mitigate the adverse effect of IAS on biodiversity and their introduction and spread within the European Union. Therefore, the impacts of IAS on the economy and human health are considered in the risk assessment necessary to list a species as IAS of Union Concern but are not the main focus of the regulation.

Table 1. Recommended actions for improving the current management plan for AIAR control activities in France following the four stages of a vertebrate pest management framework (Braysher 1993).

Stages of a vertebrate pest management framework	Recommended actions
1) Problem definition	
Feasibility	Define objectives with stakeholders, i.e. the possibilities of local eradication, population control or spatial containment
Objectives	Establish with stakeholders specific management targets at national and local levels (e.g. animal removed per year and/or reduction of damages)
2) Planning	
Action plan	Communicate to all stakeholders on the national action plan required by EU Regulation 1143/2014 Elaborate a regional (or watershed-scale) action plan including clear strategies for field operators when not available
Organization	Improve coordination when many bodies are involved Need to strengthen the decision-making process
Methods	Improve traps Develop new control methods when trapping and shooting are not sufficient
Funding	Perform a cost-benefit analysis of control activities Reward volunteers (i.e. bounty-system) as they reduce costs of control activities
3) Implementation	
Spatial prioritization	Perform risk maps to define priority actions
Personnel	Improve coordination of volunteers Improve coordination between the regional government watershed agency and field operators Understand motivation and involvement of volunteers
4) Monitoring and evaluation	
Data collection	Assess capture effort as animals removed per year is not enough to evaluate effectiveness Develop a systematic system of data collection and provide key analyses Develop performance indicators to evaluate control effectiveness Develop performance indicators to evaluate reduction of damages (e.g. on natural vegetation, riverbanks, crops) Develop a monitoring system of AIAR populations (e.g. census) and dynamics (e.g. reproduction) Develop indicators of ecological changes
Feedbacks	Establish a feedback system to improve previous management stages Provide feedback to all stakeholders to improve their engagement

This European Union regulation has been translated into French laws with a specific decree (Decree n°2017-595 21/04/2017), and IAS have been listed as species that pose human health concerns and impact biodiversity. According to the decree L. 2513 16/04/2020 of the Rural and Maritime Fishery Code, AIAR control activities are no longer compulsory for crop damages in France. However, wetland owners must regulate AIAR to reduce their impacts, both for themselves and the community. Indeed, in many departments in France experiencing high AIAR populations, decrees have frequently been set by the Prefect to lead control activities compulsory for owners and land users. Decrees also mention that owners can delegate management to certified trappers with a land access agreement. To our knowledge, owners who ignore these decrees are not prosecuted.

The available data on the distribution of coypu and muskrat in France (Figure 1) show that AIAR populations have spread all over France (Schertler et al. 2020, Figure 1). Bonnet et al. (2021) have reported that the number of rodents removed per year increased by 50% in the last ten years in Pays de la Loire region. Since AIAR populations are significantly abundant and widespread in many areas of France (Figure 2), we think that eradication of

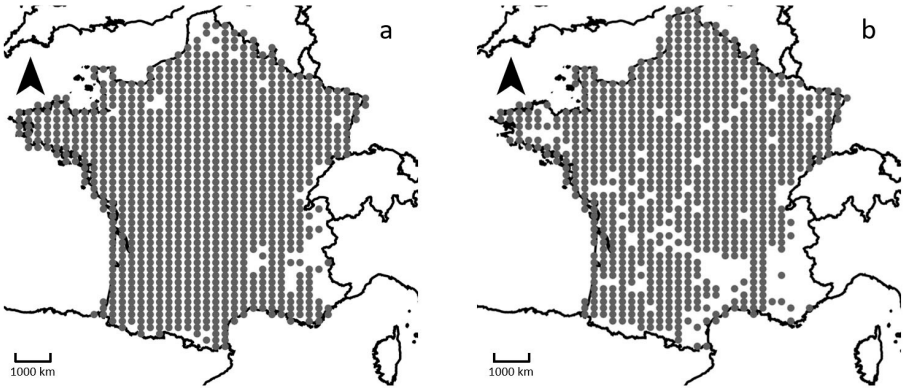

Figure 1. Distribution of the coypu (a) and muskrat (b) in France. Open access data come from the *Inventaire national du patrimoine naturel* performed by the *Muséum National d'Histoire Naturelle* and the *Office Français de la Biodiversité* and available on the following websites (for coypu: https://inpn.mnhn.fr/espece/cd_nom/61667 and for muskrat: https://inpn.mnhn.fr/espece/cd_nom/61448).

Figure 2. The Briere marsh (regional nature park) located in Pays de la Loire, France,(a) containing a high density of AIAR including coypus, which can be easily observed during the day (b).

these species at a regional or national level is unlikely. AIAR control activities have been set to reduce the impacts of AIAR on ecosystems and human activities. However, there is no clear defined objective for achieving a specific number of captures, reducing population densities or decreasing the impacts of AIAR in an area. In this context, objectives of control activities should be discussed and defined with stakeholders, considering local priorities for biodiversity protection (e.g. protected areas), human health (e.g. recreational aquatic activities), or local economy, including agriculture (e.g. crops and animal production) and human-made structures (e.g. drainage and dams) (Simberloff et al. 2018; Kim et al. 2019).

Planning and activity organization

A national strategy against IAS has been drafted by the French Ministry of the Ecological Transition in 2017 (Ministère de l'environnement, de l'énergie et de la mer 2017). This report provides an overall strategy against IAS while specific guidelines for the management of AIAR are lacking. An action plan against the introduction and spreading of IAS has recently been launched by the French Ministry of Ecological Transition and the French Office for Biodiversity with the collaboration of stakeholders such as FREDON-France, the "One Health" entity against pest species (Ministère de la transition écologique et de la cohésion des territoires 2022). A regional action plan (PAR) for AIAR has existed for Pays de la Loire region since 2017 (Bornier et al. 2019) and it has mainly been elaborated when AIAR were classified as pests for crop damages (which is no longer applicable). Thus, currently there is no national or regional strategy for AIAR management in France.

The AIAR control programme involves many local and regional entities which provide: (i) training, (ii) equipment, (iii) network management or (vi) financial support (Figure 3). FREDON-France is a national network of the regional entity against pest species, which are historical actors collectively coordinating the control of several IAS, including coypus and muskrats. Regional FREDON monitors the network of FDGDON, which are local entities in each department that coordinate groups of trappers in each municipality (GDON). Depending on the implemented control activities, field actions may be taken from decrees of the regional administration. Field actions may also be organised in each department by local hunting federations (FDC) and associations of certified trappers (ADPA). Trappers are typically involved in most field activities initiated by FREDON and FDGDON.

Although regional variations may exist, FREDON and FDGDON usually coordinate the control activities of AIAR by (i) training and recruiting new volunteer trappers, (ii) rewarding captures, (iii) providing technical and legal support, and (iv) managing AIAR carcasses. Other entities may be locally involved in control programmes. For instance, the public entities for inter-municipality cooperation (EPCI) may provide guidelines for employees

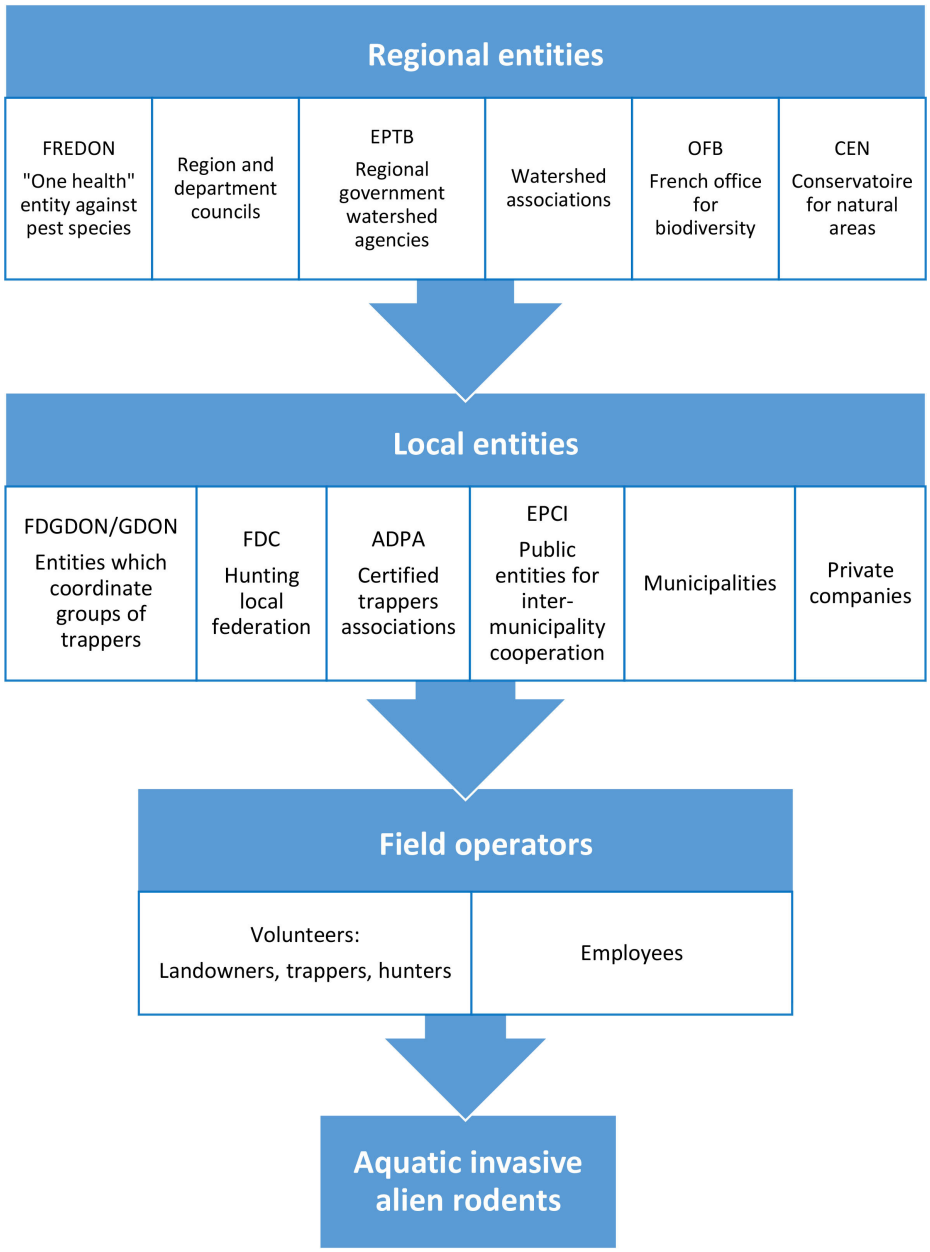

Figure 3. Framework of the network of local and regional entities and field operators involved in the permanent control programme against aquatic invasive alien rodents in France.

to coordinate field activities and priority actions in their territory. Other entities, including regional and departmental councils, municipalities, and watershed associations (see Figure 3 for details), may occasionally contribute to control programmes. However, their involvement varies across the French territory. Such a complex system involving many stakeholders has also been established in South Korea, where the Nutria Eradication Project is operated by a cooperative system comprising 18 organisations (such as, Ministry of Environment, local environment agencies, and the local Government, Kim et al. 2019). Although the number of stakeholders involved might benefit from the dynamics of the control programme, the complex network of multiple stakeholders and entities may also negatively affect the efficiency of control activities if there is a lack of coordination of actions.

Table 2. Summary of the activities funded by the main contributing entities of the permanent control programme. Details of each entity are presented in Fig. 3.

Entity	Actor	Equipment	Transport	Time	Carcass management	Capture reward	Trapper training
Field operator	Volunteer						
	Landowner	S	S	S		RP	S
	Trapper	S or RP	S or RP	S		RP	S
	Hunter	S or RP	S or RP	S		RP	S
	Employee						
	Private	RSD	RP	RP			
	Public	RP	RP	RP			
Local entities	FDGDON-GDON	PP	RP	PP or SD	RP	PP	
	EPCI	PP	PP	PP	PP	PP	PP
	FDC						RP and PSD
	ADPA			PP	RP		RP and PP
	Private company	PSD	PSD	PSD			
Regional entities	FREDON	PP		PP	PP	PP	PP
	EPTB			PP		PP	
	Regions	PP		PP			

S indicates self-financing; PP, provide public funds; RP, receive public funds; PSD, provide service delivery; and RSD, receive service delivery.

The main funders of the control programme are departmental councils, local governments for inter-municipal cooperation, municipalities, and watershed associations. The programme is occasionally funded by regional councils and drinking water supply associations and seldom by water agencies. On 1st January 2018, the management of the aquatic environment and flood prevention (GEMAPI) management was transferred and upscaled from municipalities to EPCI. EPCI dedicate part of their budget to fund actions against AIAR. Several EPCI have set a tax, namely aquatax (US$43.2 maximum per year per inhabitant), part of which can be dedicated to the control activities managed by local entities (e.g. FDGDON). Table 2 summarises the main funders of the control programme according to the main expense items: equipment (e.g. traps, baits, and shotgun cartridges), transport (e.g. travel fees), personnel (e.g. mainly salary for control and steering activities), carcass management (e.g. carcass storage and destruction), capture rewards (from 0 to US$5.4 per animal), and trapper training (e.g. training of certified and non-certified trappers).

Although managing the network of trappers is complex and expensive, the advantage of a control programme that use volunteers is the reduction of field activity costs. In Pays de la Loire region, field operators can be volunteers (e.g. by landowners, trappers, and hunters) or employees (private or public); but employees are approximately 2–3 times more expensive (Guédon 2019). A network of 2 500 volunteer trappers in this region, working 2 h/day and 20 days/year, is equivalent to 62 full-time employees (working 1607 h/year), with an estimated cost of US$3.2 million wages/year. However, it is necessary to evaluate the effectiveness of the removal activities of professional trappers and volunteers with respect to costs and involvement and how to integrate their activity effectively.

In France, bromadiolone poisoning has been used extensively for several decades (Jouventin et al. 1996). However, it has been prohibited since 2006, as the poison may affect other wild native or domestic species (Mill et al. 2020). Presently, AIAR populations are mainly controlled by trapping and shooting, even though these methods require long-term efforts, and are expensive (Panzacchi et al. 2007; Mill et al. 2020). Lethal and non-lethal, one- or double-door traps are used, although live trapping cages seem to be the most efficient method to trap coypus (Verbeylen 2002). The cost of a live-cage trap varies from US$50–83 in France. Comparing the efficiency of single- and multi-capture live-cage traps, Sheffels et al. (2019) reported that multi-capture traps are more expensive, difficult to transport and set up, but less likely to capture non-target species. Shooting is also frequently used to control AIAR when wetlands are difficult to access (e.g. marshes). However, in terms of the number of AIAR removed in France, trapping is predominant. Considering the increase of number of captures per trapper and year over the last ten years in western France, Bonnet et al. (2021) questioned whether trapping or shooting affect the demographic parameters of AIAR populations (e.g. survival and reproduction) on a broader scale.

Further studies are required to improve the coordination of all stakeholders particularly between local and regional entities and field operators. This would require an analysis of the information flow and the chain of command to strengthen them to be more integrated and efficient. A cost-benefit analysis is needed to evaluate the effectiveness and cost of AIAR control at a regional level. Efficiency of trapping methods should also be improved including the use of (i) new trap models (e.g. smart traps with electronic sensor and image-recognition systems), (ii) more palatable attractants, and (iii) a combination of trapping and archery in areas where the use of guns is prohibited.

Implementation from spatial prioritisation and personnel

Prioritising control areas to optimize control effectiveness is fundamental, particularly when funds are limited. In this context, field operators should decide whether to prioritise AIAR reservoirs (i.e. population sources) even if these areas are not easily accessible. When the objective is to reduce the impacts of AIAR and their activities on ecosystems and human well-being, control activities should target areas of conservation priority to protect biodiversity and sites where the risk of zoonotic transmission or damages to dams, riverbanks, or crops are expected to be high. In many areas, locations of control activities of volunteers (i.e. the majority of trappers) are opportunistic and are not decided and shared by regional or local entities coordinating management actions. Therefore, there could be a mismatch between the localisation of control priority areas and the distribution of volunteers. Accordingly, it is necessary to produce risk maps and coordinate

the trappers by concentrating their activity in priority areas. Prioritization should consider (i) biodiversity hotspots and area with high conservation value (RAMSAR sites, Natura 2000 areas, and natural areas of ecological interest), (ii) areas with a high risk of zoonosis transmission (e.g. bathing areas, water sports, water tourism, and fishing), and (iii) hydraulic and engineering structures.

From a legal standpoint, control activities can be conducted throughout the year in France except for periods of intense tourism, recreational activities and protected bird nesting. They are also unproductive during drought. As the water level in wetlands fluctuate with seasons, animals can move from temporary to permanent wetlands during drought, leading to high local densities of AIAR populations. During this period, AIAR are less inclined to be attracted to and enter baited traps as food (e.g. vegetation biomass) is highly available in the environment (Grimault-Frémy, FDGDON, 2022, *pers. comm.*). In marshland areas, hunters take advantage of rising water levels in winters to conduct intensive shooting operations. Thus, it appears crucial to identify the specific seasons or periods during which the efficiency of controlling AIAR populations can be maximised (Bertolino et al. 2020).

The question whether the administrative scale is adequate for coordinating field actions remains unclear. As the scale at which ecological processes drive the population dynamics of AIAR is the drainage basin and not administrative boundaries, such as municipalities, departments, or regions, the management of control activities should be transferred to the regional government watershed agency. This entity operates at a watershed scale, which is a better match for investigating the ecology of these aquatic species.

Selecting sites for priority actions is crucial for implementing effective field actions against IAS (McGeoch et al. 2016). Defining local priority areas may allow to (i) confine existing populations, (ii) reduce their impacts in risky areas, (iii) eradicate or at least limit the dynamics of local populations, and (iv) prevent the establishment of new populations. The latter is particularly important to apply in Corsica, an island in the south of France where AIAR are not recorded yet. In France, although local/regional entities can set zoning for priorities actions (e.g. from EPTB, see Figure 3), control activities of volunteers are not explicitly coordinated in a spatial strategy. Volunteers are likely to set up traps based on their choices and approaches, irrespective of priority sites or efforts. Many volunteers use traps for recreational activity not for preserving ecosystems or preventing human health concern and economic costs (Grimault-Frémy, FDGDON, 2022, *pers. comm.*).

Recruitment (i.e. engagement) of volunteers as field operators to conduct control activities is pivotal for the control programme of AIAR in France. Although volunteers are sometimes involved in control activities against alien species (Melero et al. 2018), the number of volunteers and their trapping success per year are unique at this spatial scale for AIAR control

in France. For instance, the management programme in Pays de la Loire increased from 2 000 to about 3 000 trappers in 10 years in an area of approximately 32 000 km^2 and currently reaching about 1 trapper/10 km^2 (Bonnet et al. 2021).

Maintaining or increasing the motivation of volunteers is challenging. Currently, the primary motivation strategy adopted in France is a reward for each captured or shot animal. Volunteers receive rewards when they bring back the tails of AIAR to local (governmental) entities. Reward values are defined locally and are not consistent across municipalities. For instance, in Pays de la Loire region, the reward is US$1.6 per removed animal on average; it can reach US$5.4 in several municipalities. In South Korea, the local government also manages a monetary reward system to encourage citizens to capture coypus (Kim et al. 2019). In response to degradation triggered by coypu, Louisiana established the Coastwide Nutria Control Program (CNCP) rewarding each captured coypu with $4.00 (Louisiana Department of Wildlife and Fisheries 2005). Although price incentive was successful at encouraging trappers to increase harvesting, Dedah et al. (2010) reported that a reward value of $5.00 per capture would likely achieve the state's goal of harvesting 400 000 animals per year.

Rewarding volunteers is questionable because they may find an economic interest in maintaining AIAR populations. Studies have questioned whether rewards that are perceived as an extra salary might alter the performance of trappers (Sheail 1999). Rewards are a convincing (but not unique) motivation for recruiting volunteers, and trappers may maintain populations of AIAR if rewards act as a significant yearly income. To the best of our knowledge, removing this reward may lead to a substantial disengagement of trappers in France. Although rewards are not the primary motivation of trappers, they are perceived as a fundamental contribution to their involvement in control activities. Future studies examining the efficiency and sustainability of rewards in control programmes and the motivations of trappers, would provide helpful contributions to improve AIAR management.

Understanding the incentive of people for participating in such programmes is critical for successfully recruiting and retaining volunteers (Anđelković et al. 2022). Volunteers are also engaged by steadily communicating about their key actions in preserving ecosystems. The skills of volunteers can also be upgraded to enhance their knowledge of IAS and engage them more deeply as sentinels of ecosystem health, combining control activities with engagement in other conservation activities, such as sightings and data collection. In this context, we recommend in areas where a permanent control programme exists, to (i) perform a survey to understand how to improve volunteers' engagement, (ii) co-design control activities, including objectives, (iii) provide adequate support to volunteers, (iv) promote collaborations between stakeholders including the scientific community to

stimulate engagement of people, to share collective concerns and objectives and to improve local and scientific knowledge, and (v) ensure that information on control output is accessible (Anđelković et al. 2022). For instance, regional and local entities should increase their activities on (i) training operators and communicating good practices, (ii) informing and educating the local population on AIAR impacts and related risks, (iii) leading and programming control activities, and (iv) promoting the analysis of capture data with the scientific community.

Monitoring and evaluation

One major challenge for the management of AIAR in France is ensuring that data and information from control activities are appropriately collected, stored and analysed to evaluate field action efficiency and to improve policy and management strategies. Collecting data from the control programme (e.g. trapping effort and animals removed) and critically assessing outputs are necessary to verify whether control activities are effective. In France, trappers transmit the number of coypus and muskrats removed per year to local entities when rewarded, but this information does not allow a precise evaluation of the effectiveness of the control activities. Indeed, most data regarding captures were not standardised and are often incomplete (e.g. the capture effort is lacking) and do not allow for comparing captures results and efforts among year and site. Thus, the number of individuals removed per municipality per year is a poor indicator to evaluate the effectiveness of the control programme in France when the trapping effort is not evaluated. A helpful indicator should include the number of trap-nights (e.g. effort), but the evaluation would need to determine the exact location of each trap or group of traps, which is currently determined at a communal scale. The control effort/area/period (i.e. individual removed/ km^2/year) analysed with regression models would be a robust indicator (Bertolino and Viterbi 2010).

Setting benchmark indices of control activities is critical, and some of them have been proposed on a global scale for biological invasions (McGeoch et al. 2010). For AIAR, performance indicators have begun to be locally developed from trapping books (although they are not used everywhere). Each trapper is encouraged to fill and report the number of trapping days, cage-traps, and captures and identify the species that have been trapped. Subsequently, data from trapping books must be digitised and analysed by managers and used as feedback to improve the control programme. While employees can easily be asked to fill out this book, strategies should be elaborated to encourage volunteers to do it. In some areas, filling out this book is a condition for volunteers to be rewarded for their captures. Developing an app for smartphones where volunteers and trappers could quickly fill the data, which then automatically goes to a centralized database, could be a way to increase the share and return of data.

The final goal of AIAR the control programme is to reduce damage to biodiversity and human activities at the local or regional level. Therefore, performance indicators should be developed to evaluate the effect of population control in reducing the impact on these rodents on natural vegetation (e.g. Bertolino et al. 2005), riverbanks or crops (e.g. Bertolino and Viterbi 2010) according to local targets.

In France, scientific monitoring of AIAR population dynamics through assessing demographic parameters (e.g. reproduction and survival), along with dispersion and migratory rates, from marked individuals or population genetics studies is lacking. Scientific data on the ecology of AIAR that stakeholders use as a reference in France are outdated and come from studies conducted more than 25 years ago (e.g. Jouventin et al. 1996). These biological and ecological data need to be updated, particularly in the context of climate change, which potentially affects habitat suitability (Adhikari et al. 2022). Assessment of the local population size would also be useful using pedestrian transects (Balestrieri et al. 2016), capture recapture protocol (Reggiani et al. 2006), and camera traps although detection of individuals may be challenging in aquatic ecosystems (Mori et al. 2020). Detailed knowledge of the spatiotemporal behaviour of IAS is also pivotal for increasing the success of AIAR control activities. Thus, we recommend local and regional government institutions fund scientific programmes to improve control effectiveness.

Finally, the use of AIAR as a resource should be evaluated (Tessema 2012). The possibility of reusing captured AIAR (e.g. to feed captive raptors) should encourage people to exploit populations. In Pays de la Loire, 288 000 AIAR captures a year may represent about 1 500 tonnes of carcasses. A small part of this is given to zoos to feed scavengers, such as vultures, as they are not affected by zoonotic diseases that AIAR might transmit. Efforts should be made to examine the inherent potentials of AIAR as a food resource, which should be harnessed into useful bioresources with economic gains for stakeholders (Borokini and Babalola 2012).

Conclusion

AIAR, including coypu and muskrats, are a major threat to wetland ecosystems and an economic cost for society (Diagne et al. 2020). Control activities are challenging and require adequate legislation, straightforward and well-established processes, and the availability of personnel and funds. The objective of the control programmes should thus to locally reduce as much as possible impacts of AIAR on ecosystems, agriculture, human-made structures or zoonoses transmission. However, indicators to evaluate the effectiveness of the control programme in France are lacking. Coordinating field actions between regulation entities and field operators remains difficult. We urge stakeholders to (i) elaborate on the objectives for coordinating actions in

priority areas to mitigate AIAR impacts, (ii) develop indicators of control effectiveness, (iii) improve strategies, in addition to rewards, to recruit and maintain new volunteers by raising their motivation, and (iv) fund scientific programmes to improve management activities. Although funds for the control programme come from multiple entities and volunteers' actions allow for drastically reducing costs, funds allocated to the programme appear insufficient in the face of the current AIAR population control challenge in France. Here we have analysed the management process of AIAR in France and proposed suggestions that we think help to improve the strategic approach to alien species control. This analysis could be used to improve management actions with other species or in other countries as well.

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Authors' contribution

MB contributed to the study design, writing of the original draft and editing, GG contributed to the study design, writing of the original draft and editing, SB contributed to the study design, writing of the original draft and editing, CH contributed to writing and editing, AP contributed to writing and editing, DP contributed to writing and editing, OP led the research conceptualization and study design, contributed to the writing of the original draft and editing.

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