IUCN French Committee

GT IBMA
FRENCH NATIONAL WORK GROUP
for biological invasions in aquatic environments

MAKING USE OF INVASIVE ALIEN SPECIES settled in natural environments: an effective approach to management?

An initial analysis and discussion of points requiring attention

With the support of:

AGENCE FRANÇAISE POUR LA BIODIVERSITÉ
ÉTABLISSEMENT PUBLIC DE L'ÉTAT

Document published by the French Committee of the International union for the conservation of nature, in conjunction with the French biodiversity agency

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Citation : IUCN French Committee. 2018. Making use of invasive alien species settled in natural environments. An effective approach to management? An initial analysis and discussion of points requiring attention. France. 84 pages.

Cover photo credits: Patrick Barrière (New Caledonia Nature Conservatory), Marc Collas (French Biodiversity Agency), Jean-Philippe Reygrobellet (Smage des Gardons), Jean-Philippe Maréchal (NBE).

ISBN : 978-2-918105-79-4

Legal registration: June 2019

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INTRODUCTION

Biological invasions with multiple consequences

Invasive alien species (hereinafter IAS) constitute one of the main pressures weighing on biodiversity worldwide, similar to the destruction of natural habitats, overuse of resources, pollution and climate change.

Introduced species, if and when they become invasive, induce multiple consequences, direct and/or indirect, affecting the native species, the functioning of natural habitats and the services provided by ecosystems, as well as economic activities and human health.

Around the world, spanning different geographic scales and levels of intensity, IASs cause damage to ecosystems and the regression of native species. According to the latest estimates by the IUCN Red list of threatened species, these species represent a threat for almost one-third of the terrestrial species facing extinction and have been involved in half of all known extinctions (UICN France, 2015).

Economically speaking, major negative consequences may result from biological invasions (Kettunen *et al.*, 2009). The impacts causing economic losses for various economic players or for society as a whole may take on many different forms, e.g. lower agricultural yields, health costs, the costs incurred for the management in the field of invasive species, for the restoration of invaded natural environments, and damage to ecosystem services, though it is more difficult to quantify the latter.

In terms of the health considerations, the many introduced species may threaten local fauna and flora, or even constitute a threat to human health. They may be allergenic, pathogenic or toxic, or they may carry pathogenic micro-organisms and viruses.

INVASIVE ALIEN SPECIES (IAS)

A species introduced by humans to an area outside its natural range, voluntarily or accidentally, and whose establishment and propagation threaten local ecosystems, resulting in negative ecological, economic and health consequences.

EMERGENT EUROPEAN AND NATIONAL POLICIES

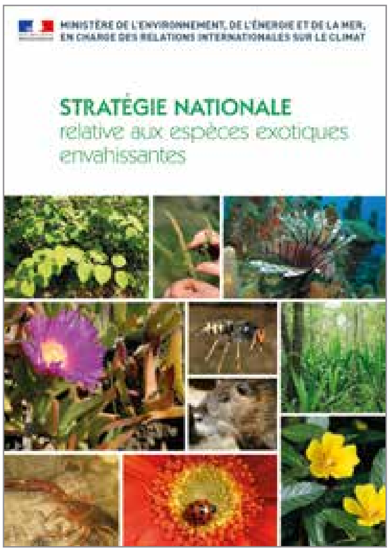

Figure 1. The French national strategy for invasive alien species.

Given the importance of this issue, the Convention on Biological Diversity decided to include it among its major lines of work in 1992 and the 2011-2020 strategic plan, approved by the convention, set a specific objective that the ratifying States, including France, have committed to achieving by 2020. The European Union has made the management of IASs a major objective and a regulation on preventing and managing their introduction and propagation entered into force in January 2015.

In France, the national strategy for IASs was published in 2017 (Muller (coord.), 2017) (Figure 1). The strategy, structured in five major sections with twelve objectives, identified 37 lines of work concerning IAS prevention, the creation of a national monitoring system, control over species already established in the country, ecological restoration, regulations, and further information, training and awareness raising for all stakeholders involved in IAS management.

This new strategic framework should put France in a position to enforce the European regulation on IASs and to comply with its international obligations, notably Aichi objective number nine, approved by the Convention on Biological Diversity. The objective lists the obligations concerning IASs, namely "*By 2020, invasive alien species and pathways are identified and prioritized, priority species are controlled or eradicated, and measures are in place to manage pathways to prevent their introduction and establishment.*" (Secretariat of the Convention on Biological Diversity, 2010).

On the scale of local territories, in both continental France and the overseas territories, strategies have existed for several years to confront these issues and to meet the local needs in terms of organisation, coordination and in setting priorities for work. These strategies were made possible by the work of a wide array of local committees bringing together non-profits, managers of natural areas, researchers, public organisations, State services and local governments (IUCN France, 2015).

MANAGEMENT DIFFICULTIES

IASs are a source of significant difficulties for stakeholders in territories confronted with the problem. However, over the last few years, advances in scientific knowledge have contributed significantly to better understanding invasions, to better assessing their impacts and to designing corrective measures. That being said, numerous management difficulties remain.

An increasing rate of introductions difficult to block in a context of globalisation

In Europe, over 12 000 species introduced by humans, voluntarily or otherwise, have been inventoried (DAISIE, 2009). Among these species, approximately 1 500 are currently considered invasive.

The rate at which new species, of all biological groups, are being introduced is increasing. A recent study showed that worldwide, the introduction rate of species has risen significantly over the past two centuries (Seebens *et al.*, 2016) and that the increase is largely due to the growth in trade and the transport of people and goods since 1900. For most taxonomic groups, the trend in the number of alien species has shown no sign of slowing and has even accelerated for some groups.

These results highlight the fact that the rare measures implemented to date to reduce the risks of introduction have not been sufficiently effective given the worldwide increase in trade and the transport of people and goods. Major efforts have however been made around the world to gain some control over the pathways for introductions.

In Europe, where aquaculture has been responsible for the introduction, intentional or accidental, of several IASs, a European regulation (Council regulation 708/2007 of 11 June 2007) concerning use of alien and locally absent species in aquaculture is now in force. On the larger international level, in 2004, the International Convention for the Control and Management of Ship's Ballast Water and Sediment (BWM Convention) was launched. However, it entered into force only fairly recently, in September 2017. The objective of the convention is to control the transfer of potentially invasive species and to establish international biosecurity rules given that ballast water is a major vector for marine species worldwide (over 10 000 species are involved according to Bax *et al.*, 2003).

In Europe, the impact study for the European regulation 1143/2014 on the prevention and management of the introduction and spread of invasive alien species of Union concern estimated that the average annual number of new introductions of IASs to Europe since 1700 was equal to eight (European commission, 2013). The study also estimated that the new regulation could cut that number in half, thus avoiding many of the costs incurred by IASs (costs for damages and a reduction in management costs).

On the national level, estimates are similar for continental France. A new indicator developed by the National Observatory for Biodiversity, based on a selection of 84 IASs, revealed that over the past 40 years, each French department has been confronted with a new IAS every two years on average.

Complexity in setting up regular management

Eradication of a species, i.e. an intervention resulting in its total (and permanent) disappearance from an area, is possible only during the first stage of colonisation, i.e. the emergence and early invasions phases, when the alien population is located on very few sites and in small numbers (Figure 2).

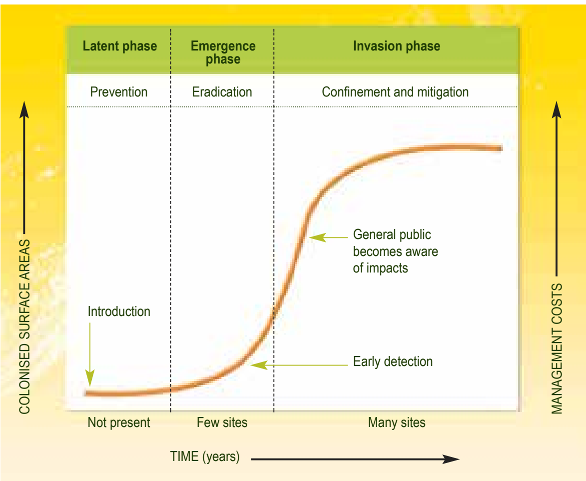

Figure 2. Different stages of invasion and management objectives. See Branquart, 2010.

For species that have spread widely, only regular interventions (see Figure 3) and biological control techniques can, in some situations, maintain the population at a level at which the disturbances and damage caused remain relatively limited with respect to the local ecological functions and human uses of the environment. Ideally, this management work should address all colonised sites, be sized to handle the observed colonisations and be undertaken regularly in order to maintain the "managed" situation.

Figure 3. Manual uprooting of parrot-feather watermilfoil (*Myriophyllum aquaticum*) in Normandy. © Normandy Nature Conservatory

However, the actual implementation of management work to eradicate or regulate a population comes up against numerous obstacles. The technical aspects of interventions and the practical implementation conditions must be systematically adapted to the site or area and to any specific needs or desires of the managers. Knowledge on the biology and ecology of species and on the technical possibilities is now more widely available thanks to the increased numbers of studies and better dissemination of information from various sources, however the contextual aspects are often not sufficiently taken into account. Neglecting them runs the risk of unexpected results or more or less serious failure of the intervention. This analysis approach, by avoiding the indiscriminate use of a "technical cure-all" implemented by another manager in a completely different context, reduces the risk of attempting to employ a solution not suited to the site in question (Sarat *et al.*, 2015a).

High public outlays

The expenditure required for constant management of IASs is high and growing continuously. The work by Kettunen *et al.* (2009) listed a total annual amount of 12.5 billion euros in the EU, including 9.6 billion for economic damage caused by IASs and 2.8 billion for management work. The above figures include only the available, documented costs. According to the authors, certain extrapolations indicate that the actual cost could exceed 20 billion euros, i.e. 1.6 times greater than the documented costs.

In France, a study run in 2014 by the General commission for sustainable development (Wittmann & Flores-Ferrer, 2015) calculated the costs of IAS management on the basis of a survey carried out in continental France and in the overseas territories. The average, annual expenditure, including the damages caused and management work, was estimated to amount to 38 million euros over the period 2009 to 2013. The study also noted that the collected data were not complete and warned that the costs may have been underestimated. Table 1 provides information on management costs using examples of aquatic and terrestrial IASs in France.

Given the technical difficulties encountered in the field and the overall results deemed unsatisfactory in some cases, the large amounts of money spent may discourage the managers of natural areas and result in decisions to halt funding by the State, local governments and the other stakeholders bearing the costs.

SPECIES	SITE	PERIOD	TYPE OF WORK	Cost (€)
Large-flowered waterweed (*Egeria densa*)	Marans-La Rochelle canal (Charente-Maritime department)	2012	Waterweed harvesting over 13 km of river	32 000
Japanese knotweed (*Reynoutria japonica*)	Confluence of the Luye and Durance Rivers (Hautes-Alpes and Alpes-Maritimes departments)	2015	Grinding and tarping of knotweed over 4 000 m²	114 000
Common bamboo (*Bambusa vulgaris*)	Guadeloupe national park	2015	Bamboo management (cutting and tarping) along 15 km of road	53 000
Signal crayfish (*Pacifastacus leniusculus*)	Vosges department	2011	Emptying and elimination of a 2 100 m² pond and eradication of the signal crayfish	26 000
American bullfrog (*Lithobates catesbeianus*)	Sologne (Loir-et-Cher department)	2009 - 2012	Project to eradicate the bullfrogs through monitoring, destruction of eggs, traps, hunting, nightly shooting and dewatering of sites	342 645
Red-eared slider turtle (*Trachemys scripta elegans*)	Mouth of the Rizzanese River (Corsica)	2009 - 2011	Trapping of the turtles	79 500
Giant cane (*Arundo donax*)	Confluence of the Thongue and Lène Rivers (Hérault department)	2015	Experiments with grinding and tarping the cane on two sites (500 m² and 250 m²)	31 200
Groundsel bush (*Baccharis halimifolia*)	Grande Brière Mottière marshes (Loire-Atlantique department)	2011 - 2016	Manual uprooting and cutting of shrubs over 7 000 hectares	27 000

Tableau 1. Examples of management costs for IASs in France, collected in the framework of the project to gather management reports, organised by the National Work Group on Biological Invasions in Aquatic Environments, an organisation created by the French Biodiversity Agency and IUCN France.

Commercial value...

On the other hand, certain IASs may be considered a resource that can be exploited commercially, for example species that can be fished and sold (Red lionfish, North American crayfish, common slipper shell, etc.), invasive alien plants used for basket weaving (water hyacinth, etc.), wood products (acacia, Cattley guava, black locust, etc.), potentially valuable compounds for pharmaceutical purposes (resveratrol contained in the rhizomes of Asian knotweeds), etc.

European regulation 1143/2014 explicitly mentioned the possibility of using IASs in its article 19: "*The commercial use of already established invasive alien species may be temporarily allowed as part of the management measures aimed at their eradication, population control or containment, under strict justification and provided that all appropriate controls are in place to avoid any further spread*" (European Parliament and Council, 2014). In continental France, recommendations have been made to study the possibility of making economic use of certain IASs that have spread widely (e.g. Wels catfish and red swamp crayfish) and relaxing the applicable regulations in order to facilitate their sale. The recommendations to "enhance the economic profitability of commercial fishing in fresh waters, while respecting the environment" were recently made by the Council for the environment and sustainable development (Boisseaux, 2015).

... but not without risks for natural environments

However, in addition to the potential economic value and the management objectives put forward, this approach is not without risks for natural environments and raises a wide array of questions on the possible consequences of attempts to exploit IASs. A number of these questions concern the increased risks of dispersal (intentional or accidental) of a "resource" species and efforts to maintain IAS populations in colonised areas once the species have become a commercial item.

STUDY OBJECTIVES AND SCOPE

Prior to making a decision, it is necessary to have sufficiently solid information on the relevance and effectiveness of using IASs as a potential means of management. It is also necessary to determine the practical aspects of IAS uses that avoid the risks of voluntary or accidental dispersal and produce real, quantifiable ecological benefits.

With the above in mind, the National Work Group on Biological Invasions in Aquatic Environments (IBMA), which is managed by the IUCN French committee and the French biodiversity agency (see the box), decided to launch a study to **identify the issues and risks involved in using IASs established in natural environments as a potential means of IAS management.**

The results of this work, presented here, are based on numerous examples and projects dealing primarily with IASs in aquatic environments in continental France, in Europe and in other industrialised countries, as well as with IASs in terrestrial environments and in the French overseas territories. The study did not address captive IASs and those already used for commercial purposes (e.g. mink farms in North America and new types of pets), nor any species introduced voluntarily to be farmed or for aquaculture. A further topic not discussed directly was the agronomic use of the waste produced by management work on invasive alien plants.

This document attempts to answer the questions listed below:

- Do documented examples of uses of IASs (both successes and failures) exist in France, Europe or other countries?
- What are the positive results, the negative consequences and the risks involved in using IASs for natural environments and for project managers?
- Could the use of certain IASs contribute to controlling those species in natural environments?
- What are the issues and points requiring attention involved in making sure the proposed projects do no harm to the environment and produce real ecological benefits?

The results of this study are intended for all entities that must produce an opinion on projects involving the use of IASs, notably State services (e.g. the regional environmental directorates and the departmental territorial directorates) and local governments, both in continental France and in the overseas territories.

NATIONAL WORK GROUP ON BIOLOGICAL INVASIONS IN AQUATIC ENVIRONMENTS

The national work group was created in 2009 and is jointly managed by the IUCN French committee and the French Biodiversity Agency (AFB). Its mission is to provide technical support and assistance to all the stakeholders involved in IAS management. The work group serves as an interface for communication and discussion on IAS management. Current members include approximately 60 representatives of various stakeholders, including managers of natural areas, researchers, non-profits, public agencies, State services, local governments, etc.

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IBMA "digests" and makes available the knowledge gained on how to manage invasive alien species by:

- developing operational tools to improve knowledge and management of IASs (collections of management reports, good-practices guides, etc.);
- identifying scientific issues and proposing programmes of applied research;
- assistance in developing strategies and public policies;
- serving as a platform for data exchange and contacts between stakeholders;
- supporting management operations for certain species.

All the tools and instruments produced by IBMA, as well as the various other resources are available on the internet site of the French IAS resource center (www.especes-exotiques-envahissantes.fr).

The IBMA team in the field. © A. Dutartre

Creeping water primrose. © E. Mazaubert

The different categories of IAS use

Over the past few years, an increasing number of proposals, both public and private, have suggested culling IASs from the natural environment and using them (either directly for consumption or for sale). These proposals have been increasingly taken into consideration by institutions and the general public (Franke, 2007 ; Rosenthal, 2011 in Nuñez *et al.*, 2012 ; Matsumoto, 2013 in Pasko & Goldberg, 2013).

The objective of these proposals is to encourage the use of IASs for various purposes, including as food, raw materials or as biofuels (Invasive species advisory committee, 2014)**.**

A review of the available literature on the topic and the analysis of projects from around the world presented here identified two major categories of IAS use:

1 • Commercial use of IASs

Commercial uses of IASs result in the creation of a market where the stakeholders, generally private, claim possession of a resource prior to transforming and selling it. In this case, financial benefits result for the stakeholders with the creation of producer/consumer relations. Such initiatives are grouped in the category of "**Commercial use of IASs**" in this document.

2 • Incentive measures

The second category is that of incentive measures where the public authorities encourage activities such as the hunting, fishing or gathering of IASs. The authorities may pay for or reimburse the costs of trapping a species, where the amount paid does not necessarily correspond to a market price. In this case, the remuneration (or "bounty") is set by the authorities following negotiations with the potential beneficiaries. The relation created is between the public authorities and the hunters/fishers/gatherers, where the beneficiaries do not receive a "revenue". These initiatives are grouped in the category of "**Incentive measures**" in this document.

COMMERCIAL USE

Direct commercial use

Commercial use of IASs corresponds to the set of activities, generally undertaken by private entities, to market **IASs present in the natural environment** (Pasko & Goldberg, 2013). These projects are launched when a market has been detected for the species in question and it can be effectively sold (Pasko & Goldberg, 2013). The primary objective is to derive a profit from the resource.

Projects to market IASs are in some cases presented with two complementary objectives, namely 1) use the resource to produce a profit and 2) contribute to managing IASs present in natural environments in order to reduce their adverse impacts on biodiversity, the local economy and/or human health.

Secondary use of products resulting from IAS management

The organic (or agronomic) use of waste produced by IAS management work cannot truly be considered to fall under the category of IAS commercial use. It does not consist of directly culling IASs from the natural environment in order to produce a commercial profit. It deals rather with the waste resulting from work to manage the species, i.e. interventions generally undertaken to preserve biodiversity, the functioning of ecosystems and the uses of the ecosystems. The objective is to dispose of the waste produced by the interventions, taking care to eliminate any risks for the environment that could result from the incorrectly managed disposal of the waste on natural sites (see Figures 4a and 4b). Subsequent agronomic use of the waste became a secondary objective that arose following the changes in the legal status of the waste from invasive alien plants. The shift from waste to product may however be considered a form of "indirect" commercial use of an IAS that should be included in the analysis (see the box).

ORGANIC USE OF GREEN WASTE PRODUCED BY IAS MANAGEMENT WORK (see Sarat *et al.*, 2015a)

One of the difficulties encountered by managers concerns the waste produced by the work to control IASs. What should be done with the plants that are removed from sites, occasionally in very large quantities? The disposal of green waste, a necessary part of the management system, was long solved, without putting any thought into a comprehensive solution in most cases, by simply depositing the waste in a nearby dump or by burying it on-site. However, the increase in the quantity of plant waste and changes in the regulations governing the management of green waste made it necessary to reassess the problem as a whole and to change work habits (Dutartre and Fare, 2002).

The initial studies dealt with using the waste of invasive alien plants for forestry or farming purposes, e.g. spreading, composting, etc. The primary objective was to dispose of the waste produced by interventions. The reuse of the waste was a secondary issue that nonetheless facilitated the overall approach given its positive aspects. The changes in the regulations governing organic waste encouraged managers to look more carefully into this secondary objective. Once withdrawn from the natural environment, invasive alien plants were long considered ultimate waste, but according to the new definitions contained in legislative documents, they are a form of green waste that should be processed in a manner limiting the emission of greenhouse gasses and that returns the organic matter to the earth (ministerial circular dated 18 November 2011).

The main, potential techniques are composting and methanisation, where the latter produces both compost and biogas. Standards apply to compost, which may be freely marketed as a fertiliser, and to biogas, which is produced by methanisation and sold for electrical generation. Thermal use consists of burning the waste of invasive alien plants to produce heat and supply heating networks or for electrical generation. Tests are currently under way on water primrose (Cerema Ouest *et al.*, 2018). In all the above cases, what was perceived as waste has now become a product, i.e. in addition to disposing of the plants, the management system turns it into a marketable product.

However, that may be difficult for several reasons. First of all, agronomic and thermal uses require a certain level of product quality that can determine where and how the plants are processed. For example, the presence of sediment or dirt mixed in with plants that have been harvested mechanically may result in the refusal of the batch by treatment centres and/or entail additional costs that are billed to the managers of the IAS intervention. Secondly, the waste of invasive alien plants produced by management work is available only during certain seasons, represents small volumes compared to other sources of biomass and is not a sustainable resource. Consequently, the processing centres cannot count on this source for a regular supply. Centres aiming to create a marketable product will not take the risk of reducing the performance level of their facilities by incorporating invasive alien plants unless a large and reliable supply can be ensured.

Concerning fauna, projects for agronomic use are less frequent, however the case of common slipper shells in the bays of Saint-Brieuc and Cancale should be mentioned. The idea was to process the shells to produce a calcareous soil conditioner and the project was put into effective operation from 2002 to 2006 (see the box on page 41).

This type of use, which results in the production of marketable IAS by-products and thus creates a need to ensure a reliable supply of IASs, risks creating a situation similar to that produced by the commercial use of IASs. Other concerns, dealing notably with the insufficiency or lack of precautions to avoid the dispersal of invasive alien plants by processing centres, are regularly raised by managers and local governments.

Figure 4. An example of waste produced by work to control the spread of invasive alien plants in rivers. a) Large-flowered waterweed in the Loiret River waiting for transport to a composting unit © Carine Biot and b) waterweed uprooted in the Poitevin Marshes and used for fertiliser trials in fields © Alain Dutartre

INCENTIVE MEASURES

Legal provisions in favour of IAS elimination

These measures target primarily recreational activities such as hunting, fishing, trapping and gathering. Their purpose is not commercial and they encourage the culling of IASs from the natural environment.

In France, these measures are in some cases included in the Environmental Code. For example, the taking of certain animal IASs is provided for in articles pertaining to hunting and fishing (Title II and III in the Environmental Code). The implementation decrees for these texts target the control of these species by authorising enhanced control methods, in some cases with no limits on the numbers culled, including intervention periods for shooting or trapping that are longer than the standard hunting season in continental France. For certain species, the administrative procedures have also been simplified.

In continental France, the legal provisions are contained in the decree dated 2 September 2016, organising the population management by hunting of certain non-native species, namely Nutria (*Myocastor coypus*), Muskrats (*Ondatra zibethicus*), Raccoon dogs (*Nycteuretes procyonides*), American minks (*Neovison vison*), Northern raccoons (*Procyon lotor*) and Canada geese (*Branda canadensis*). For example, culling of nutria and muskrats is authorised by trapping and shooting year-round without a special permit for trapping (decree dated 29 January 2017, modified), but requiring a valid hunting permit for shooting. These regulations may be implemented by each departmental hunting federation via its hunting management plan established for periods of six years.

Bounties for trapping and hunting

This incentive measure, used traditionally to regulate the populations of aquatic rodents in continental France and commonly called a “capture bounty”, consists of paying a set amount to partially cover the costs incurred by volunteer trappers acting in the framework of a mission legally assigned to a non-profit. The money is not considered a remuneration and the activity is not a business.

In addition to being listed as huntable pests by the Environmental Code, Nutria and Muskrats are listed in the Rural and Maritime Fishing Code, in the framework of the plant-protection policy, as pests and are subject to mandatory control measures (Figure 5). The regional and departmental federations of pest-control groups (FREDON and FDGDON) are certified control organisations in charge of monitoring, preventing and managing dangers to plants.

By ministerial decree dated 6 April 2007 on controlling nutria and muskrat populations, the above federations and their local groups are in charge of monitoring and the collective efforts to cull nutria and muskrats. Depending on the situation in each department and region, the federations may call on other organisations to assist in coordinating and implementing the collective control measures, for example the departmental associations of certified trappers or agencies run by the departmental councils.

Figure 5. Mandatory hunting of nutria is undertaken in the framework of the plant-protection policy. Capture bounties are paid to trappers by certain local governments. © Sylvain Richier, ONCFS

The federations provide the administrative, legal and technical management for the employed or volunteer trappers, as well as generally organising the local networks. The regulatory aspects governing the collective control measures are issued in decrees from the prefectures and in municipal ordinances. In the framework of the collective measures organised by the pest-control groups and their federations, as per articles L. 251-1 to L. 252 in the Rural and Maritime Fishing Code, persons capturing nutria and muskrats using cage traps are not subject to certain provisions in the Environmental Code and in particular the trapping authorisation (decree dated 29 January 2007 setting the conditions for trapping animals classified as pests in application of article L. 427-8 in the Environmental Code). Similarly, a municipal ordinance on mandatory collective measures dispenses the trapper of the need to obtain the rights to kill the animals from the land owner.

When the trappers work individually to capture and kill the animals, authorisation must first be granted by the prefect and the trapper must obtain the rights to kill the animals from the land owner.

Local governments (departments, towns, intermunicipal boards, river-basin boards, etc.) are the main entities financing the collective control measures. Capture bounties may be offered, in conjunction with the above funding entities, to volunteer trappers based on the number of animals trapped. For nutria and muskrats, the bounties amount to between one and three euros per animal, depending on the department and the town in question (FDGDON de la Manche, 2014; FDGDON de l'Orne, 2015 ; Blottière & Egal, 2017 ; Guédon, 2017). The ends of the tails of the trapped nutria and muskrats must be presented for collection by the FDGDONs, the departmental hunting federations or the departmental associations of trappers. The annual reports on captures are available in most departments.

In New Caledonia, bounties are offered by APICAN (Agency for the Prevention and Compensation of Agricultural and Natural Catastrophes) to encourage hunting and trapping of the **Javan rusa** (*Rusa timorensis russa*) (Figure 6a) and the **Wild boar** (*Sus scrofa*) (New Caledonia Nature Conservatory, 2016). A capture bounty per Javan rusa, ranging from 1 500 francs CFP (currency of the French Pacific territories)[1] i.e. 12.50 euros, in 2009 to 5 000 francs (42,00 euros) from 2014 onwards, has been paid to 23 land owners for almost 23 000 animals that were subsequently raised as livestock and butchered.

Figure 6a. Javan rusas. © New Caledonia Nature Conservatory

1 • 1 Pacific franc = 0.01 euro as of 1 January 2018.

In 2008, the New Caledonia Nature Conservatory instituted a bounty for rusa mandibles (in 2012 for wild boar) in order to raise awareness among hunters and encourage them to cull the reproductive females, and to enable the conservatory to estimate the numbers killed, the age structure and the physical condition of the populations. The bounty was initially set at 1 000 francs per rusa, but in 2017 it was decided to increase the amounts depending on the number of animals culled per year, i.e. 1 000 francs (8,40 €) up to 25 mandibles, 3 000 francs (25 €) for 26 to 100 mandibles, 4 000 francs (33 €) for 101 to 200 mandibles and 5 000 francs (42 €) for more than 200 mandibles (see Figure 6b). For the period 2008 to 2015, bounties were paid for 154 000 rusas (and 12 500 boar from 2012 to 2015) to over 2 000 hunters having a hunting permit (or papers for a firearm) and hunting rights. These numbers may appear large, however a majority of the animals are hunted in easily accessible lowlands (with the exception of priority zones in the wet forests that are particularly difficult to access at high altitudes) and, when private property is involved, the land owners must give their permission to reduce the populations.

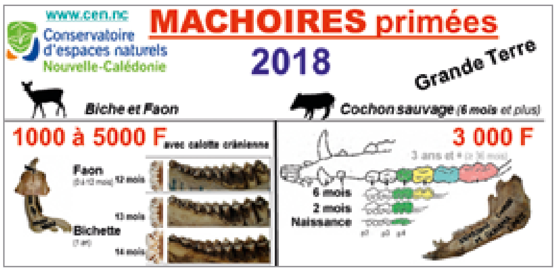
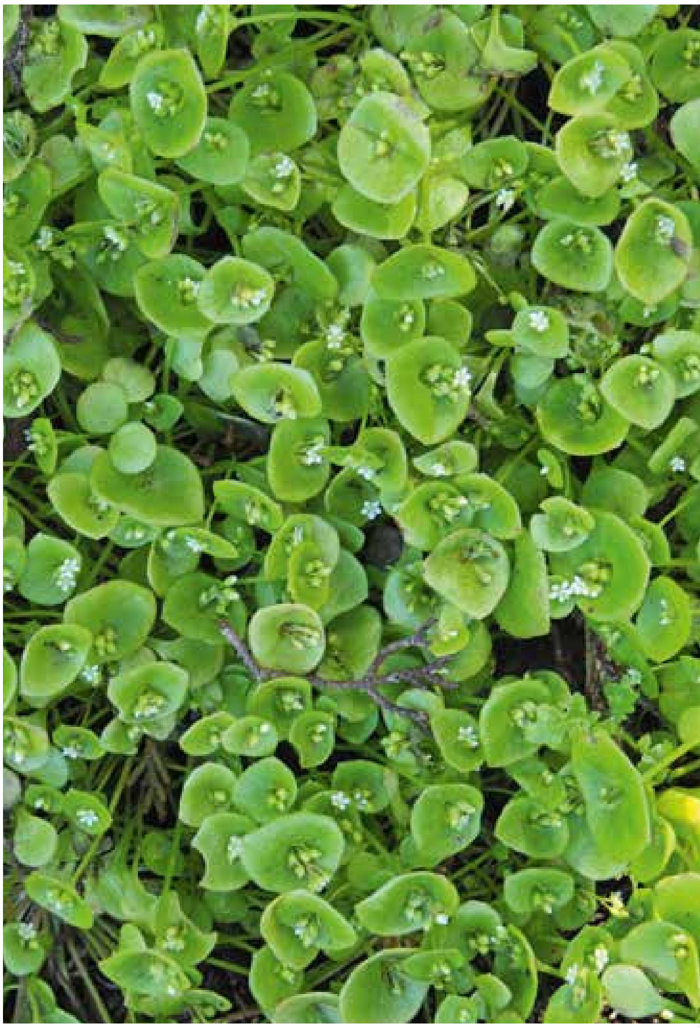


Figure 6b. A poster informing on the "mandible campaign" for wild boar and Javan rusas in New Caledonia. © New Caledonia Nature Conservatory

To be effective, the legal incentives and the bounties require not only a clear regulatory framework, but must be accompanied by efforts to mobilise the participants. Management of the local networks is indispensable to maintain motivation levels, recruit new hunters and trappers, reinforce the links between organisations operating in the field (federations of pest-control groups, hunting federations, structured groups of hunters and trappers) and to collect the data required for the annual reports.

Incentives to eat IASs

Campaigns to encourage people to eat invasive alien species (and consequently to cull them from the natural environment) have recently been launched in various countries. They may be set up by public authorities, academics, private entities or citizens. Though there was no commercial intent at the start, a number of these initiatives have nonetheless contributed to creating or reinforcing economic sectors and markets for IAS use (see the box below).



Claytonia perfoliata, originated in the western section of North America and has become naturalised in the understories of forests in Brittany. It may be consumed as a type of salad. © G. Grisard

SAVE THE PLANET, EAT IASS.
A SHORT HISTORY OF ERADICATION THROUGH MASTICATION!

The idea of eating IASs found in the natural environment is not new. Human consumption of certain invasive alien plants, e.g. *Claytonia perfoliata*, a type of lettuce, or kudzu (*Pueraria montana*), was encouraged starting at the end of the 1900s, due to the high nutritional value, availability and significant amount of biomass (Rapoport *et al.*, 1995). A number of cook books with recipes for alien species were also published around the same time (Baldwin, 1999; Reed, 2002). However, these initiatives were not presented specifically as means to manage IAS populations in view of reducing their impacts on biodiversity, natural environments, the economy or human health.

Recently, this movement entered a new development phase. Cook books (see Figure 7), internet sites such as “Invasivores.org”, “Eattheinvaders.org” and campaigns managed by large institutions, encouraging people to eat IASs, have grown significantly in number since the late 2000s. A recent article by Snyder (2017) reviewed the situation in detail.

The idea behind these initiatives, presented as an appeal to “common sense”, is apparently simple. If humans have been capable of pushing species to extinction through hunting, why not make use of our insatiable appetites to control certain IASs? This idea, presented for the first time in 2004 by Joe Roman, from the University of Vermont, in a publication (Eat the invaders, Roman, 2004), progressively gained the attention of various groups interested in food ethics, e.g. the “locavorism”[2] or the “local food” movement. Snyder (2017) noted that the various currents in this field resulted in the development of “invasivorism” (“But as interest in food ethics, locavorism and foraging grew, the elegant logic of “invasivorism” hit a cultural sweet spot”). Starting in 2005, renown chefs proposed dishes using alien species and, in 2010, the U.S. National Oceanic and Atmospheric Administration (NOAA) launched its first campaign to encourage the consumption of IASs, titled “Eat the red lionfish”, in the Caribbean (Snyder, 2017). Each year, the Institute of Applied Ecology at the University of Oregon organises a culinary event for invasive species, the “Annual invasive species cook-off”, also known as “Eradication by mastication”, https://appliedeco.org/). Other approaches have developed, involving economic and commercial entities, for example certain chain stores such as Whole Foods in the United States, that now offer IASs in their aisles. Similarly, the State of Illinois exported 22 000 tons of Asian carp to China, generating revenues of 20 million dollars in 2010 (Snyder, 2017).

It would appear that these initiatives, though there were no clear commercial motives, played a non-negligible role in bringing to life economic sectors based on using IASs. However, the risks involved in these approaches are also evident. The promoters of “invasivorism” admit that, to date, there are no scientific studies demonstrating the effectiveness of human consumption in controlling IASs and that “There are a lot of small experiments going on but no large-scale data gathering” (Barnes, in Snyder, 2017).

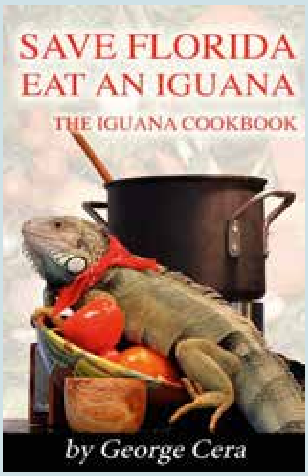


Figure 7. A cook book for iguanas (*Iguana iguana*), an IAS in Florida and the French Caribbean.

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2 • Local food (local food movement or locavore) is a movement of people who prefer to eat foods which are grown or farmed relatively close to the places of sale and preparation. (https://en.wikipedia.org/wiki/Local_food).

Red lionfish. © Jean-Philippe Maréchal (NBE)

Benefits and risks of IAS use

Economic, social and territorial benefits

The potential positive consequences (economic, social and territorial) are the main argument put forward by the promoters of projects targeting the use of IASs. For commercial projects, i.e. with the production of marketable goods, the main benefits expected by the promoters are revenues and positive consequences for the local area in terms of added value (gross production) and jobs. The incentive measures in favour of culling are generally presented as a means to raise the awareness of citizens to the IAS issue.

Compensation for loss of revenue

A reason often mentioned for commercial use of IASs is a desire to compensate losses of revenue suffered in different economic sectors. Losses are generally caused by a combination of adverse economic and environmental factors. Among the environmental factors, the introduction of an IAS is frequently mentioned.

For example, the **Chinese mitten crab** (*Eriocheir sinensis*) (see Figure 8), that was transported from Asia in the ballast water of ships, consumes the roe of fish having a high commercial value in Germany. Some 60 commercial fisheries on the Elbe and Havel Rivers were affected and the estimated losses amounted to 8.4 million euros over the period 1994 to 2004, i.e. 14 000 euros per fishery per year. At the same time, there is strong demand for Chinese mitten crabs for human consumption on the part of the Chinese community, given that exports from Taiwan and China are no longer possible due to diverse pollutions affecting the crabs and high costs. Revenues from the sale of crabs to the Asian markets over the same period was estimated at between 3 and 4.5 million euros, thus compensating a significant part of the lost revenues (Gollasch & Nehring, 2006).

Figure 8. Chinese mitten crabs are now a commercial product in Germany and the Netherlands. © Peter van der Sluijs

The **Red king crab** (*Paralithodes camtschaticus*) was intentionally introduced in the Barents Sea in the 1960s by Soviet authorities to provide poor populations in the north-western part of the country with a new resource. The species arrived in Norwegian waters as early as the end of the 1970s, however, it was only in the beginning of the 1990s that it became an issue due to the expansion of its range and its increased densities that created problems for commercial fisheries in that it became caught up in the gill nets and the longlines[3] used to fish cod and haddock. Given that the crabs have a high commercial value (up to 270 euros per kilogramme retail), the Joint Norwegian-Russian Fisheries Commission authorised commercial fishing of the species in 1993. In 2015, almost 500 active fishing vessels were registered in Norway and achieved revenues of 14 million euros plus exports of 36 million euros, thus more than compensating the loss of revenues that justified the decision to exploit the species (Sundet & Hoel, 2016).

That is also the case for the economic sector specialised in crayfish that has developed throughout Europe. Native crayfish have been fished and consumed in Europe for thousands of years, but the outbreak of crayfish plague in Italy in 1860 permanently modified the situation for crayfish farming in Europe. The disease, caused by a fungus (*Aphanomyces astaci*), resulted in massive mortality rates for crayfish throughout Europe. To compensate for the virtual disappearance of native crayfish, a German fish farmer introduced the **Eastern crayfish** (*Orconectes limosus*) in 1890. The species was later introduced in France in the Cher department in 1910. This initial introduction was followed by many others over the 1900s in order to replace the native crayfish that had

3 • A longline consists of a main line to which secondary lines with baited hooks are attached at regular intervals. This system is equivalent to a set of lines arranged in regular intervals.

disappeared. Sweden launched a programme to establish the Signal crayfish (*Pacifastacus leniusculus*), a species that was placed in 206 lakes and rivers in the country from 1960 to 1982 (Fjälling & Fürst, 1984). Introductions of the species in numerous other European countries followed.

The Red swamp crayfish (*Procambarus clarkii*) was introduced in Spain in the 1970s and rapidly became a product exploited commercially and exported (Gaudé, 2012) (see Figure 9). The success of the introduction and the commercial use of the species enabled Spain to cover the commercial losses caused by the collapse of the native crayfish populations, namely the white-clawed crayfish (*Austropotamobius pallipes*). The rapid expansion of the species' range and the exponential increase in the population numbers enabled the economic sector to recover it footing as early as 1981 (Gaudé, 2012).

Figure 9. Red swamp crayfish sold by a major French brand of frozen food, that were fished in fresh waters in Spain (Extremadura, Andalusia). © DR

In France, projects to make commercial use of Red swamp crayfish put forward the same arguments. According to the National Committee for Freshwater Commercial Fisheries, the creation of an additional resource for professional fishermen could reduce the difficulties due to "poor access to resources" and would constitute an alternative to the regulated species (Stolzenberg, 2016). That is particularly the case for European eels (*Anguilla anguilla*) that are now in critical danger of extinction (IUCN France *et al.*, 2010; Jacoby & Gollock, 2014) and are covered by a management plan to reconstitute the European populations. The plan includes measures to sharply reduce catches by prohibiting almost entirely the fishing of silver eels (the adults returning to the sea) by commercial fisheries, restrictions on the numbers of professional fishermen and a shortened fishing season (Onema, 2010).

Revenue creation and more active job markets

Commercial use of IASs can also be a source of jobs in areas where they are exploited, for the harvesting, transformation and sale of the products and by-products.

For example, after the year 2000, there were eight companies in Andalusia producing red swamp crayfish, employing 700 people and generating revenues of over 13 million euros each year for the local economy (Gaudé, 2012). During the 27 years following its introduction in southern Spain, over 40 000 tons of crayfish were sold for total revenues of 250 million euros (Gaudé, 2012).

In Ethiopia, two cooperatives farmed ***Prosopis juliflora*** (an invasive Mimosoid) on 396 hectares and produced 188 246 bags of charcoal that were sold for 133 000 dollars and represented 233 509 days of work for local farmers (see Figure 10). The 396 hectares were then freed and produced high yields of sesame, forage crops and vegetables for household consumption and sale (Admasu, 2008 in Borokini & Babalola, 2012).

Figure 10. Commercial use of Prosopis wood in the Karur region of India. In the French overseas territories and notably on Reunion Island, Prosopis trees are an invasive alien species (Soubeyran, 2008). © P. Jeganathan

In Brazil, the integrated-management programme for the *Tubastraea coccinea* and *Tubastrea tagusensis* corals (Sun Coral project) (see Figure 11) includes a section for the sale of corals by the local inhabitants around the Bay of Rio de Janeiro. The programme improved the revenues of 86% of the families active in collecting and selling the species (Creed *et al.*, 2017).

Figure 11. *Tubastraea coccinea* is a coral species that originated in the Indo-pacific region, but has now spread widely around the world. The species is dominant in reef habitats in the Bay of Rio de Janeiro in Brazil. It has become a commercial product in the framework of the Sun Coral Project integrated-management programme. © Maraguary

In their study on the economic consequences of IASs in Europe, the authors (Kettunen *et al.*, 2009) highlight the very limited amount of information on the financial benefits drawn from IASs. Among the examples mentioned are the **Red king crab** in Norway (see page 20) and the **Japanese littleneck clam** (*Ruditapes phillipinarum*), which represented revenues of 178 million euros in northern Italy in 2005, making it the marine species generating the most economic value in the country.

Incentive measures encouraging the capture and/or la consumption of IASs can generate a source of proteins for local populations. They can also produce non-negligible economic benefits in certain countries and in the French overseas territories.

Ecological benefits

In addition to the economic, social and territorial benefits mentioned above, projects for the use of IASs may also produce a number of ecological benefits that are often presented as a second argument in favour of a win-win approach by the project promoters. It should be noted however that most of these benefits have never been effectively assessed and still require study to confirm their value.

Direct benefits for ecosystems and biodiversity

Reduced impacts on the natural environment

Studies in New Zealand have shown that certain commercial projects have effectively produced ecological benefits. An assessment was carried out on three hunting campaigns for commercial purposes on introduced mammals, namely the **European red deer** (*Cervus elaphus*), the **Himalayan Tahr** (*Hemitragus jemlahicus*) (for the sale of the meat) and the **Common brushtail possum** (*Thrichosorus vulpecula*) (for the sale of the fur) (Parkes *et al.*, 1996). The commercial project for the European red deer had a notably positive effect on the alpine grasslands of northern Fiordland (in the SW section of the Southern Island of New Zealand) by reducing the herbivorous pressure and assisting the natural restoration of the environment (Rose & Platt, 1987).

However, the results are less favourable in wooded areas where most plant species recovered a satisfactory level of abundance, except for the most vulnerable species (Rose & Platt, 1987) (see Figure 12).

Figure 12. On the small island of Leprédour in New Caledonia, the introduction of deer and rabbits resulted in the destruction of the vegetation cover and in major soil erosion. © New Caledonia Nature Conservatory

Concerning the European red deer, the objective of restoring forests to their initial state (structure and composition), i.e. that prior to the invasion, could not be achieved. The disturbances to the ecosystems were so severe that the reduction in the population densities was not sufficient on its own to allow a complete restoration of the forests (Coomes *et al.*, 2003, in Barrière & Colyn, 2008). In addition, the effort put into culling the animals depends on the international market prices which can fluctuate widely over time. That was effectively the case in New Zealand and, as a result, the deer population increased when the hunting campaigns, notably those using helicopters, were no longer profitable (see Figure 13).

Figure 13. Commercial hunting of European red deer in New Zealand involved significant technical means to produce results, including helicopters to approach the deer in the most isolated areas. © University of Otago

Positive results were also noted in mountainous areas due to the commercial hunting of the Himalayan Tahr, following a 90% reduction in the population. The work done for the marketing of the Common brushtail possum did not produce any ecological benefits because the project was too small in size and was carried out over short time periods and with insufficient hunting effort (Parkes *et al.*, 1996).

Concerning the results of capture bounties, ecological benefits have been observed in the United States, in Louisiana with the *Coastwide Nutria Control Program*, set up to regulate the nutria population in 2002. At the start of the project, the bounty for a tail was set at four dollars, but was increased to five dollars in 2006 to encourage a higher number of culls. Over the period from 2002 to 2012, 318 000 nutria were captured each year and the surface area of farm land damaged by the species dropped from 323 square kilometres to 24 km² (Coastwide Nutria Control Program, 2016).

Legal incentive measures authorising large numbers of culls were also effective in the State of Maryland. The proliferation of nutria, introduced in the State in 1943 and given the lack of predators, had resulted in serious damage to the littoral marshes (disappearance of vegetation, landslides and erosion due to tidal action in the weakened areas). In 2002, a study on the feasibility of eliminating the species estimated that the degradation of wetlands by nutria caused an annual loss of revenue of four million dollars and that the annual losses would exceed 30 million dollars by the year 2050 (Delage, 2017). The relatively small population in 2002 (approximately 100 000 animals) meant that objectives to eradicate the species were feasible. The first phase of the project, managed by the Maryland Department of Natural Resources and the Maryland Fish & Wildlife Conservation Office, consisted of authorising a large number of culls by the general public and land owners, using a wide array of techniques (traps, guns, dogs, etc.), but without offering capture bounties (prohibited in the State of Maryland) (Delage, 2017). Once the nutria population had been reduced, the work was done exclusively by public employees and dealt with detecting the animals, which had become more rare and consequently more difficult to detect. The positive results of this first phase made it possible in 2003 to increase the available resources through the signing of the *Nutria Eradication and Control Act* that authorised a budget of four million dollars each year for five years in order to eradicate the species from Chesapeake Bay and Delaware Bay. By 2016, over a total surface area of 80 000 hectares, the density of the nutria population had been reduced virtually to zero and 125 000 hectares of wetlands were undergoing natural restoration (US Fish and wildlife service, 2016) (see Figure 14).

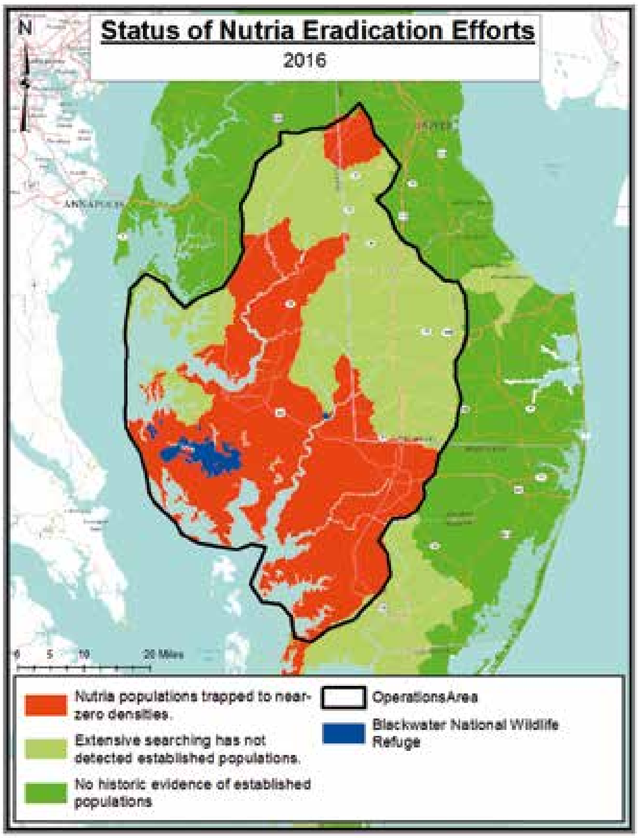


Figure 14. Map of the efforts to eradicate nutria in Maryland. Source: U.S. Fish and Wildlife Service, 2016.

Shifting anthropogenic pressures from certain native species

A potential ecological benefit was mentioned concerning the commercial use of ***Prosopis juliflora*** in East Africa and in Yemen. The latter country is confronted with a severe decline in the available wood due to the great pressure weighing on the native species of acacia for the production of firewood and charcoal. Commercial use of Prosopis would reduce the anthropogenic pressure on the native species and slow, at least locally, the spread of Prosopis (Geesing *et al.*, 2004). On the other hand, commercial use could lead to increased numbers and densities of Prosopis, and consequently the dispersal of a species that has an impact on the local biodiversity.

The same argument is used for **Typha** (*Typha australis*) in Senegal. According to Hellsten *et al.*, 1999, commercial use of Typha established in the natural environment produces 65 000 tons of charcoal per year, covering 15% of the demand in the country. After studying the same situation, Caro *et al.* (2011) estimated that the production of 42 000 tons of charcoal from Typha would "save" three million trees. In Mauritania, the promoters of a similar project[4] explained that an alternative source of charcoal would contribute to the fight against the illegal cutting of forests and would reduce the emissions of greenhouse gases, given that "*a ton of charcoal from Typha would emit seven tons of CO_2 less than an equivalent amount of charcoal*". However, the actual ecological benefits of these measures have not been assessed.

The agronomic use of **Common slipper shells** (*Crepidula fornicata*) in the bays of Saint-Brieuc and Cancale was also presented by a local defence committee as an alternative to extracting shell sands from Lannion Bay to produce calcareous soil conditioners ("Collectif Le peuple des dunes en Trégor" defence committee, 2013). However, the State Council rejected the appeal, indicating that it "*was not shown that there is a credible alternative to the use of the sands*" (F. Viard, personal publication, 2017).

Indirect benefits for ecosystems and biodiversity

Raising awareness about IAS issues

Programmes with incentives to cull IASs often include efforts to inform on and raise awareness concerning the problems caused by invasive species (see Figure 15). To achieve significant results, the managers of these programmes must mobilise and raise the awareness of the general public, which in turn must engage and feel a sense of responsibility. These efforts are similar to those made in projects to manage populations and calling on the participation of volunteers or projects involving the general public in citizen-science programmes[5] (Nuñez *et al.*, 2012).

To achieve their objectives, awareness-raising campaigns must be coordinated and implemented by local networks, they must set educational objectives that go beyond IAS management alone, propose a new outlook for the future

4 • " In Mauritania, a harmful plant becomes a source of energy. Using Typha, an invasive, highly detrimental plant for local inhabitants, to produce charcoal reduces deforestation and CO_2 emissions, and creates jobs", the title of an article in Le Monde, dated 9 September 2015.
http://www.lemonde.fr/planete/article/2015/09/09/en-mauritanie-une-plante-nuisible-devient-source-d-energie_4750054_3244.html#42yd7LFqrqxtaM5r.99

5 • Citizen science is defined as "programmes to collect information involving the public in the framework of a scientific project" by the French initiative for citizen science, 2012.

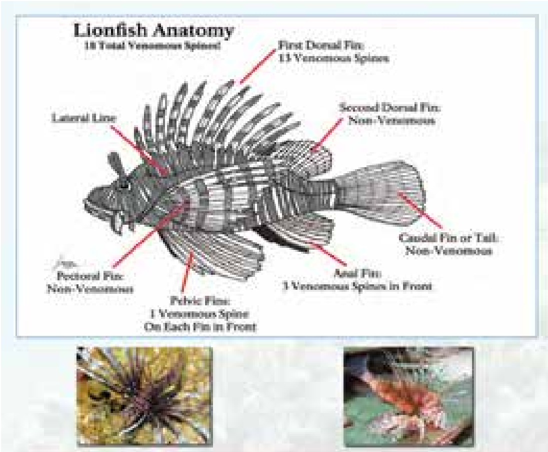


Figure 15. Example of an educational document on the red lionfish, intended for children, as part of the national "Junior Ranger" programme in the United States. © US National Park Services

and remain in regular contact with the participants so that they continue to feel involved (Gourmand, 2015, in Sarat *et al.*, 2015a). These campaigns may represent a means to reach parts of the public that are not commonly involved in environmental issues and thus constitute a further advantage of awareness-raising efforts (Nuñez *et al.*, 2012). However, their effectiveness must still be assessed and incentives may produce unexpected results (see the box).

"YOU HAVE TO SEE IT TO BELIEVE IT." POPULAR BELIEFS CONCERNING THE BURMESE PYTHON IN FLORIDA AND THE IMPLICATIONS FOR THE PARTICIPATION OF THE PUBLIC IN IAS MANAGEMENT OPERATIONS

In Florida, the *Python Challenge* is a multi-day event organised to encourage hunters to capture Burmese pythons (*Python bivittatus*) and raise awareness about IAS issues (see Figure 16). In 2016, 1 000 hunters participated in the competition for one month and 106 pythons were captured (http://pythonchallenge.org/), however the actual impact of this type of project on the population dynamics of pythons must still be assessed (South Florida Water Management District, 2017). Surveys were carried out by a team of researchers on the participants (n = 660) and on non-participants (n = 77) to determine if the event achieved its main objective of raising awareness on the ecological impacts of Burmese pythons in Southern Florida (Harvey *et al.*, 2015). A majority of participants declared that they were highly concerned by the topic. This level of concern increased in step with the degree of environmental awareness, observation of pythons in the natural environment, the age of the participant and if the participant was a woman. On the other hand, the level of concern decreased with the number of participations in the competition, i.e. people regularly in contact with the species in the framework of the competitions were found to be less concerned with the ecological impacts of the species. The authors concluded that the effectiveness of incentive programmes to manage python populations must still be assessed and recommended prudence in designing the parts of programmes involving the participation of the general public.

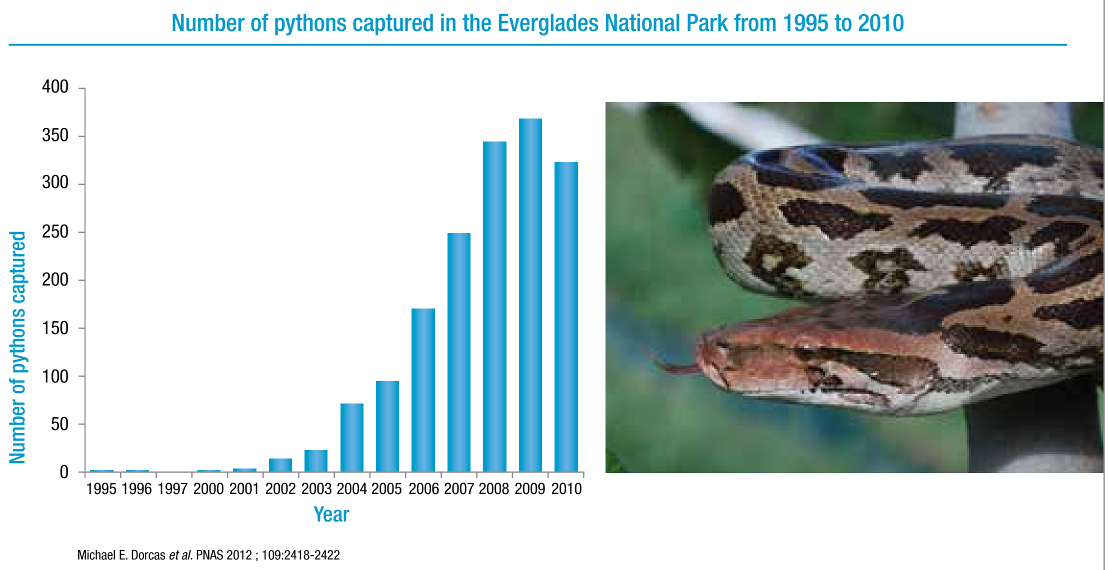


Figure 16. The Burmese python was released intentionally by breeders in the Everglades National Park in Florida in the 1980s. © Pratik Jain. Since its introduction, the number of captures in the natural environment has increased steadily and the species is responsible for the decline in numbers of native mammals (Dorcas *et al.*, 2012).

Efforts to raise awareness of IAS issues are, however, very rarely included in commercial projects concerning IASs found in the natural environment, essentially because commercial projects do not require the direct involvement of the general public, but rather the simultaneous presence of a market and demand for the product. In Spain, Gutierrez-Yurrita *et al.*, 1999, found that the level of awareness concerning IAS issues on the part of professional fishermen fishing the **Red swamp crayfish** was very low. In this study, 80% of the fishermen questioned were of the opinion that poaching of crayfish had no negative impacts on the environment and that their activity was beneficial in that it represented a means to limit the development of the species. A majority (69%) also thought that the fishing equipment used did not have any impact on other species (birds).

Other, more recent programmes involving commercial use of IASs, such as the Sun Coral project in Brazil and the FORIS programme (Removing barriers to invasive species management in production and protection forest in South-east Asia) have included among their objectives training activities and awareness raising concerning biological invasions and their impact on the environment. In Brazil, ten years after the launch of the Sun Coral project, 93% of coral hunters felt more concerned by environmental issues and better informed on biological invasions and their negative impact on the environment. The project also encouraged the organisation and involvement of local authorities in protecting marine environments (Creed *et al.*, 2007).

IAS detection

According to Nuñez *et al.*, 2012, programmes encouraging the culling of IASs (and particularly those promoting the consumption of IASs) can, if informational campaigns are set up, contribute to improving the detection of IASs. Efforts to inform the public (brochures, public meetings, internet sites) facilitate identification of the species and of the organisations involved in their management (for example the *Eattheinvaders* site in the United States, see Figure 18). This means of identifying IASs increases the intensity of observations and results in earlier detection, enhanced mapping of species and improved understanding of IAS population dynamics over time.

Figure 17. An example of the informational and awareness-raising methods used by the Observatory of the marine environment in Martinique in the framework of its programme to control the red lionfish. © OMMM / DEAL

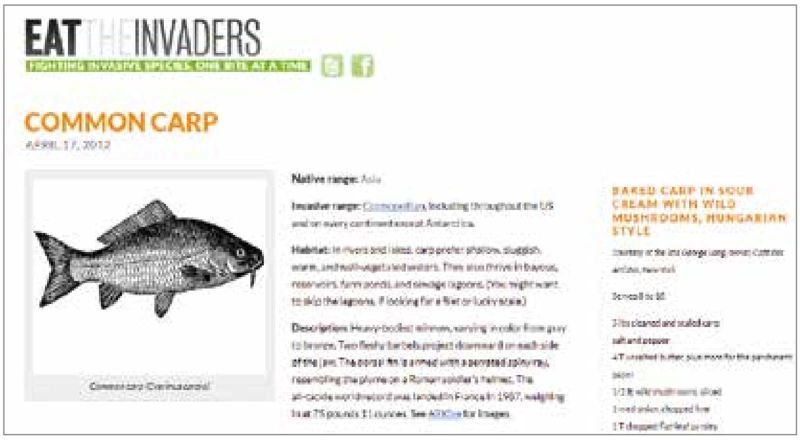


Figure 18. An example of a fact sheet, available via the internet, concerning a species targeted by a programme encouraging people to eat IASs. Each species is described with information on its ecology, range, introduction history and environmental impacts. Along side the fact sheet is, of course, a recipe on how to cook the species. © eattheinvaders.org

This approach is used, for example, by the Observatory of the marine environment in Martinique in the framework of campaigns to encourage the public to cull the Red lionfish (*Pterois volitans*) (see Figure 17). Informational kits are distributed to diving clubs and stores, and marking/capture kits are provided in the framework of efforts to monitor species movements. Videos, brochures and posters are made available to the public, as well as a regularly updated set of maps on the dedicated internet site (www.poissonlion-antillesfrancaises.com) showing the sites around Martinique where the red lionfish has been detected and/or captured.

Commercial projects to use IASs rarely include efforts to raise the awareness of the general public. For this reason, they contribute less to early detection and rapid responses.

Gaining knowledge on IASs

When accompanied by scientific studies, programmes to make use of IASs can contribute to improving the available knowledge on the species. This knowledge may deal with their introduction history, their distribution in the area where introduced, the population dynamics, information on the effectiveness of tested culling techniques, etc.

For example, the feasibility study for commercial use of Chinese mitten crabs in the Thames River, ordered by DEFRA (U.K. Department for the Environment, Food and Rural Affairs) and carried out by a team of researchers from the Natural History Museum in London, produced information on the distribution of the species in the river and collected data on its reproduction as well as on its population structure and dynamics (see Figure 19). This work also centralised the data on monthly captures of the species and served to test different capture protocols (Clark *et al.*, 2008). Finally, the feasibility study included ecotoxicological assessments of Chinese mitten crabs because precautionary measures are absolutely required prior to its consumption.

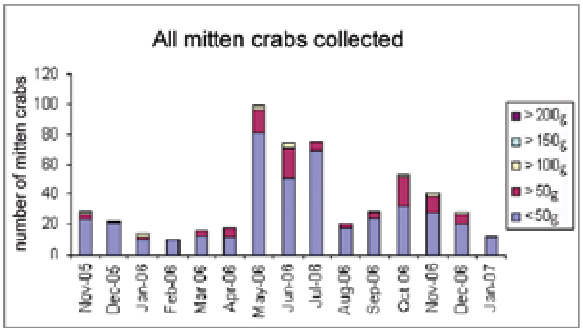


Figure 19. An example of the data collected on the population structure of Chinese mitten crabs during the feasibility study on the consumption of the species by Clark *et al.*, 2008.

Very complete scientific studies have been carried out on Asian carps introduced in the Mississippi and Illinois river basins (the Bighead carp *Hypophthalmichthys nobilis* and the Silver carp *Hypophthalmichthys molitrix*). The studies, run by researchers and public institutions, involving stakeholders from the professional sectors, aimed to determine the potential measures by the U.S. government and the fishing industry to reduce the risk of seeing the Asian carps disperse toward Lake Michigan and Lake Erie (Garvey *et al.*, 2012). The studies generated a great deal of information on the biology and the ecology of the species. The movements of Asian carp populations were analysed using telemetric techniques and revealed both the factors influencing upstream migration and the renewal rate of populations arriving from downstream. The densities and biomass of fish populations (both native and alien) were estimated using a hydroacoustic method. The mortality rates and reproductive capacities of Asian carps were determined in order to assess the resilience of the populations to the planned culling efforts. Long data series were analysed to determine the impact of the carps on native fish and to assess the risks involved if they were to spread to the Great Lakes. Finally, nutritional and ecotoxicological tests were run because there were projects to market the species.

The programme for integrated management of ***Tubastraea*** corals (Sun Coral project), launched by the University of Rio de Janeiro and the Brazilian Biodiversity Institute, included not only objectives concerning the control of the species, commercial use by local inhabitants and awareness raising about biological invasions, but also objectives in terms of gaining new knowledge on the biology and ecology of the species. An assessment run ten years after the start of the project showed that it has contributed significantly to gains in scientific knowledge and had produced over 70% of all the studies on the species in Brazil (Creed *et al.*, 2017, see Figure 20).

The participation of Ifremer in a project to harvest Common slipper shells off the Normandy and Breton coasts generated better understanding of the colonisation and dispersal dynamics of the IAS, and also produced targets for the commercial activity (Blanchard & Hamon, 2006) (see the box on page 42).

To date, commercial projects rarely take place in conjunction with scientific studies targeting new knowledge on IASs, particularly when the projects are managed by players in the given economic sector who do not attempt to bring in researchers and institutional stakeholders.

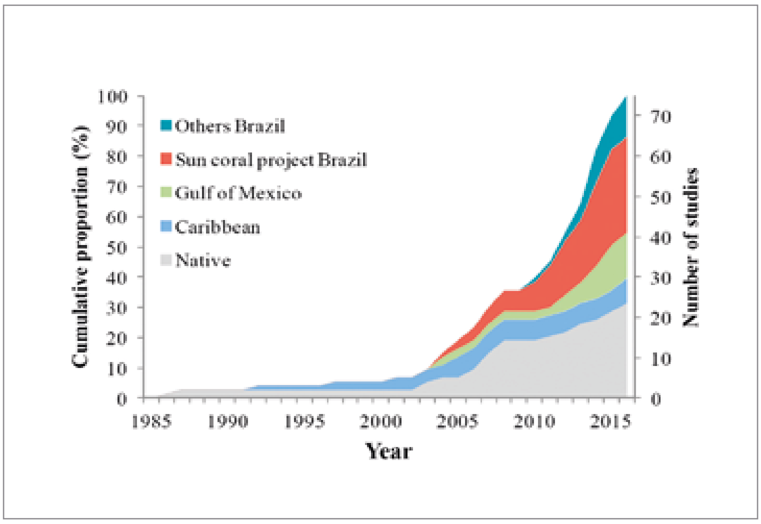


Figure 20. Number and cumulative proportions of studies carried out in the framework of the Sun Coral project and other contexts, by region. See Creed *et al.*, 2017.

Summary of projects identified in France and abroad

Type of use / Benefit	Incentive measures	Commercial use
ECONOMIC, SOCIAL AND TERRITORIAL BENEFITS		
Compensation for loss of revenue	Partial compensation in certain southern countries and in certain overseas territories	YES
Jobs and revenue, more dynamic local economy	Indirect benefit through jobs to coordinate and manage programmes	YES
ECOLOGICAL BENEFITS		
Reduced impacts on the natural environment	Yes in some cases, must be demonstrated in others	Yes in rare cases, must be demonstrated in others
Shifting anthropogenic pressures from certain native species	Possible, but must be demonstrated	Possible, but must be demonstrated
Raising awareness about IAS issues and earlier IAS detection	YES	In certain cases, when in conjunction with training
Gain knowledge on species biology and ecology	Yes in some cases, if in conjunction with scientific studies	Yes in some cases, if in conjunction with scientific studies

RISKS

A number of projects to make use of IASs have been successful both economically and ecologically, however many others have been failures and can result in a waste of time and resources (Nuñez *et al.*, 2012). If projects are launched without a number of precautions and without taking into account important ecological, economic, social and health factors, they may turn out to be counter-productive and create numerous risks.

Ecological risks

In order to determine if use of an IAS is a suitable means to manage the species in a given area, it is first necessary to understand its population dynamics and to have sufficient information on its biology and ecology (Pasko & Goldberg, 2014). That information includes the population structure, survival and reproduction rates, sex ratio, growth rates and various density-dependent processes (population composition and size, biomass, fertility and reproduction rates, intraspecific competition, etc.) and their fluctuations over time. In addition, IASs participate in a network of interactions with other species, both native and introduced, in the local area. An understanding of these interactions (e.g. competition, predation) is a prerequisite in organising effective use of an IAS without creating risks for the ecosystem. More generally, this knowledge is required for all types of IAS-management projects.

Biological overcompensation and ecosystemic effects

When population dynamics and density-dependent processes are not taken into account prior to starting a project, the culling of species without a well defined management and planning strategy can produce unexpected consequences.

Culls of IASs in the natural environment in the framework of projects targeting use (both incentive measures and commercial uses) generally target specimens of value for direct human use. Examples are the largest Asian carps (for the quantity of fish meat and prestige among sport anglers) (see Figure 21), the European green crabs (*Carcinus maenas*) during the moulting season (these crabs are consumed when their shell is soft) or sexually mature Chinese mitten crabs (people consume the gonads). These uses concern very specific age classes and reproductive stages, and take place only during certain times of year, all of which is counter-productive to effective management of a given species.

Figure 21. The largest Asian carps (in the photo, a silver carp in Portugal) are caught by anglers for consumption and for trophies. © Magiccity

For plants, culls may concern exclusively those parts of use, for example the leaves (e.g. Kudzu, *Pueraria lobata* (see Figure 22) or Garlic mustard, *Allaria petiolata*) or the fruit (pods of *Prosopis juliflora*, berries of *Japanese silverberry*, *Eleagnus umbellata*). If there are no instructions to harvest the entire plant, "partial" culls leaving on site the parts not deemed to be of any value may enable the plant to survive, to reproduce and even to disperse, depending on the species and its reproductive system (seeds, rhizomes, etc.). The risks involved in partial culling are highly variable in that it takes place at precise moments during the year (bud break, flowering, fruition).

Partial culling therefore constitutes an irregular pressure that may not reduce the population of the species, but may, on the contrary, stimulate the population dynamics.

Figure 22. Young Kudzu leaves are eaten as salad or cooked as a vegetable. © Doctoroftcm

For example, scientific studies on commercial use of Asian carps in the North of the United States have shown that culling targeting exclusively the large fish cannot reduce the populations of the species. A reduction would require culling all age classes (Garvey *et al.*, 2012).

These results were confirmed by Tsehaye *et al.* (2013), who estimated that an effective reduction would require that over 70% of the population be culled each year, that the efforts address all population groups and that greater effort should be put into culling Silver carps, a species that has higher reproduction rates than Bighead carps. According to these researchers, an industrial sector and market for small fish (organic fertiliser, food and fish oil) would be required to enable commercial uses of the species to achieve the necessary culling objectives.

Excessive culling targeting a single population group can assist the survival of other groups (Zipkin *et al.*, 2009), with as a result an increase in the overall number of individuals in a population. This density-dependent phenomenon, called biological overcompensation, has been observed in plants (Buckley *et al.*, 2001; Pardini *et al.*, 2009), insects (Moe *et al.*, 2002; Nicholson, 1957), mammals (Faithfull & Frankston, 2005) and fish (Zipkin *et al.*, 2008). In all the cases studied, an increase in mortality in the target population provoked an increase in the overall number of individuals, because the reduction in the number of mature individuals was compensated by higher survival and reproduction rates of younger individuals, resulting directly from enhanced availability of resources.

For example, intensive culling of a closed population of Smallmouth bass (*Micropterus dolomieu*) in a North American lake (Little Moose Lake) over a period of seven years led to an increase in species abundance, due essentially to the greater number of juveniles (Zipkin *et al.*, 2008). Incentive measures (capture bounty) to cull the Red fox (*Vulpes vulpes*) in Australia in the years 2002 and 2003, targeting a 20% reduction in the population, also produced counter-productive results. The reduction in the number of individuals generated an increase in the available resources for the remaining animals, thus enhancing reproductive results (a larger number of cubs per litter and higher survival rates) and eventually increasing the population (Faithfull & Frankston, 2005). In Guadeloupe, Martinique and the islands in the north of the Caribbean, it has been observed that culling large Red lionfish or Green iguanas (*Iguana iguana*) produced an imbalance in the reproductive and territorial hierarchy on certain sites, with as a result improved reproductive results for the species (Chalifour, personal publication, 2017).

Concerning plants, studies carried out on Garlic mustard (*Allaria petiolata*) (see Figure 23), an invasive alien plant that colonises understories and alluvial plains in North America, showed that management work placing excessive importance of culling the plants during the "rosette" stage (plants in their first year) could produce counter-productive results and cause a local increase in the density of the species (Pardini *et al.*, 2009). The "mature" plants are culled in view of consuming the leaves, unfortunately the incentives do not take into account the above ecological considerations and no advice is ever given to uproot the entire plant (Pesaturo, 2014).

Figure 23. *Alliaria petiolata* in the understory of a wooded area near Toronto, Canada. © Invasive weed of the Day - https://raymorepark.wordpress.com/2013/05/07/invasive-weed-of-the-day-garlic-mustard/

The use of ***Prosopis juliflora*** to produce charcoal also entails a risk of higher population densities (Witt, personal publication, in Delage, 2017). When the trees are cut, a large number of sprouts appear on the trunk that can be cut in turn and on which still more sprouts will appear, etc. This technique results is high densities of trees in a given area that, over time, produces less biomass, becomes difficult to access for livestock and humans, and ends up being no longer used. A few years later the trees in the area produce seeds and become once again factors in the spread of the species. Charcoal production is not sufficient to manage Prosopsis unless the cut trunks are treated with a herbicide or if the root system is entirely removed. What is more, the creation of dense, monospecific areas blocks the establishment of native plants and consequently reduces the local specific diversity.

On Réunion Island, Minatchy *et al.* (2017) showed that the number of sprouts on trunks of Cattley guava (*Psidium cattleinanum*) was greater in the humid, tropical forests in the mountains three years after the commercial cutting of the trees.

The alga ***Undaria pinnatifida***, which originated in Asia and was later introduced to Europe, Australia and New Zealand, has high value because it is marketed for human consumption under the name Wakame. Following its introduction in Europe, it was cultivated along the Breton coasts in France and off Galicia in Spain starting at the end of the 1980s. More recently, its cultivation was authorised in certain regions of New Zealand. More precisely, it may be harvested on artificial substrates (in marinas and "farms") and, when it has landed on the shore, in areas considered "not sensitive" to the harvesting. On the other hand, harvesting is not authorised in the natural environment, unless in conjunction with specific programmes (Ministry of Agriculture and Forestry, Biosecurity New Zealand, 2010). The purpose of these restrictions is to reduce the risk of destroying or impacting local algae and avoiding even greater proliferation of Wakame (Epstein & Smale, 2017). The knowledge gained on this species, notably during attempts to eradicate the alga from a nature reserve in Tasmania shortly after the year 2000, made clear that it is very difficult to eliminate it (due essentially to the existence of the microscopic resistance stage, i.e. the gametophytes) and that the disturbances caused by commercial harvesting could, depending on the season, the algae harvested, the level of disturbance, etc., even accelerate the colonisation dynamics (Hewitt *et al.*, 2005).

Biological overcompensation can reduce the effectiveness of programmes for uses targeting control of IAS populations over the long term (Pasko & Goldberg, 2013; Nuñez *et al.*, 2012).

Another type of risk concerns the new disturbances that IAS use can create in ecosystems. On Réunion, the disturbances caused by commercial operations with Cattley guava facilitated the establishment of three new heliophilous IASs (*Lonicera japonica, Strobilanthes hamiltonianus* and *Persicaria chinensis*) (Minatchy *et al.*, 2017). This risk was also evaluated in the framework of projects to use Common slipper shells (see the box on page 42), on the basis of an empirical study and models developed in Brest Bay. The large bay benefits from limited eutrophication in spite of tremendous inputs of nitrates from nearby human and particularly agricultural activities. This observation was linked to a great abundance of common slipper shells that play a role in maintaining the ratio of silicates to dissolved nitrates. If the ratio falls, major changes in ecosystems occur and in particular diatoms (algae with a siliceous exoskeleton) are replaced by non-siliceous micro-algae such as the toxic dinoflagellates. Common slipper shells may in effect protect the bay from eutrophication processes. Excessive exploitation of the species in the natural environment could disrupt the ecosystem at the expense of diatom populations and result in blooms of certain toxic micro-algae (Laruelle *et al.*, 2005).

Intentional and accidental introductions in the natural environment

If the management of an IAS gravitates toward its use as an economic resource, one consequence may be increased dispersal of the species to areas where it was not yet present. For example, people living in areas where the species is not present may introduce it to gain easier access to the resource or to create a profitable commercial operation.

Intentional introductions may cause rapid increases (greater than natural dispersion) in the range of a species that was initially introduced accidentally. The marine alga, ***Undaria pinnatifida***, was introduced accidentally in the Thau Pond (Southern France) in 1971. The positive outlook for its commercial use as a food source (known as Wakame) led to its intentional introduction for cultivation in Brittany at the start of the 1980s. In spite of studies warning of the risks, the alga rapidly escaped from the farms where it was cultivated and colonised numerous man-made substrates (marinas) and natural habitats along the Breton coast (Floc'h *et al.*, 2006; Epstein & Smale, 2017).

It is already will known that the marketing of alien crayfish has significantly accelerated the dispersal of the species and increased the number of introductions in European rivers. For example, in Spain and Portugal, the projected profits from selling Red swamp crayfish rapidly incited rice farmers to introduce the species in other regions, e.g. the rice fields in the region of Valence in 1978 and the Ebre Delta in 1979 (Guttiérez-Yurrita *et al.*, 1999). These introductions were not limited to the mainland, the species was also introduced to numerous islands, including the Azores (1993), the Balearics (1993) and the Canaries (1997) (Guttiérez-Yurrita *et al.*, 1999).

These introductions, in conjunction with the intrinsic dispersal capabilities of the species, resulted in its establishment throughout the Iberian peninsula by the end of the 1990s (see Figure 24). Spain is certainly a major commercial source of red swamp crayfish, however it must be noted that the trade in living specimens imported from Asia, the United States and Kenya is responsible for a vast majority of the introductions in the U.K., France, Germany and Switzerland (Henttonen & Huner, 1999).

Figure 24. Spread of red swamp crayfish in Spain and Portugal. See Guttiérez-Yurrita *et al.*, 1999.

Illegal introductions of invasive alien crayfish have been reported in numerous countries and documented proof has been available in some cases. In Sweden, the government launched massive introductions of **Signal crayfish** starting in 1967 to compensate the economic losses due to the decline in the populations of noble crayfish (*Astacus astacus*). Bohman et ses collègues (2011) studied the links between the development (deemed exponential) of the signal crayfish and the illegal introductions of the species in Sweden. The results would indicate that the spread of signal crayfish was probably due to the illegal introductions that worsened the already dangerous situation for noble crayfish. In the region around the Varmeln Lake in Sweden, 94 illegal introductions of signal crayfish were noted over the period 2000 to 2006 (see Figure 25). For Sweden as a whole, 117 illegal introductions were recorded for the period 2007 to 2009. In many cases, these introductions took place in aquatic environments where programmes to preserve the noble crayfish had been set up (Edsman, 2015).

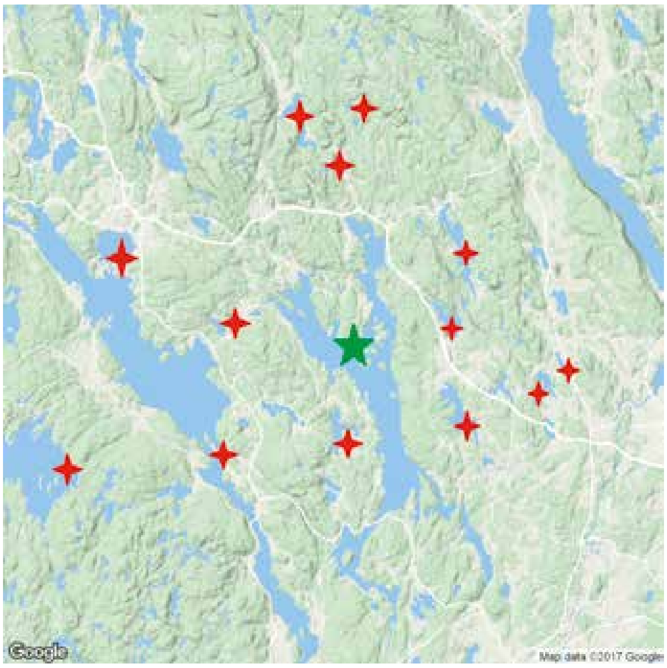


Figure 25. Map of illegal introductions of signal crayfish in the region around the Varmeln Lake in Sweden. The green star marks the initial introduction zone for commercial purposes in 1994. The red stars mark the illegal introductions in the natural environment observed in 2004. See Edsman, 2015. © Google maps 2017

Illegal fish stocking is an international problem and has resulted in numerous introductions of IASs in the natural environment, which can have significant adverse impacts on native species and the environment (Moyle & Light, 1996 ; Johnson *et al.*, 2009). On the basis of the data available in the United States, it is clear that illegal fish stocking has facilitated the dispersal of numerous species, such as **Smallmouth bass** and **Rock bass** (*Ambloplites rupestris*) (Jackson, 2002). In Montana, the Department of Fish, Wildlife and Parks listed over 500 illegal introductions of 49 species of fish in 300 water bodies over the period 1997 to 2007 (Dickson, 2014). According to (Rahel *et al.*, 2004), 50% of the illegal introductions were done by citizens where the main motivation was sports fishing. For a majority of the fish species, the initial introductions were carried out legally by the public authorities. However, once a species was present in the natural environment, illegal transfers by citizens and the colonisation of new water bodies, whether assisted by humans or not, constituted the main introduction pathways (Rahel *et al.*, 2004).

ILLEGAL INTRODUCTIONS OF FISH AND CRAYFISH IN FRANCE - A RECENT CONCEPT IN FRENCH LAW

In France in the 1800s, experiments on introducing alien species were widely encouraged by the National Acclimation Society. The development of the technique for artificial reproduction of trout in 1843 led to numerous attempts to introduce new fish species for aquaculture and recreational fishing. According to Keith & Allardi (1997), of the 26 fish species introduced in France over the 1800s and 1900s, only two were intended for aquaculture (*Acipenser baeri* and *Oncorhynchus kisutch*), compared to ten for recreational fishing, five for biological control, the remainder consisting of accidental introductions or out of simple scientific curiosity. Concerning crayfish, the introductions of *Pacifastacus leniusculus* in Sweden in the 1960s raised considerable enthusiasm throughout Europe and numerous introduction trials were launched. "I*t was during the first international symposium on freshwater crayfish held in Austria in 1972 and in light of the trials run in Sweden since 1960 that the advantages of* P. leniusculus *became evident to the French crayfish experts participating in the meeting*" (Arrignon *et al.*, 1998) (see Figure 26). From that point on and without any legal restrictions, the species was introduced in France easily and in large quantities. "*Between 1973 and 1977, 18 000 juveniles were used in acclimation trials for* P. leniusculus *in the Haute-Savoie, Ain and Yonne departments. Some of the juveniles transited through the INRA stations on Lake Geneva or were experimented with at INRA and it was the crayfish that escaped that formed the basis of the current population in the lake*" (Arrignon *et al.*, 1998).

The legal concept of introductions is recent in the French legal system. Prior to 1984, the law prohibited the introduction of "particularly harmful" fish and crustaceans (article R432-5), including the black bullhead (*Ameirus melas*), the Chinese mitten crab and the pumpkinseed (*Lepomis gibbosus*). Subsequently, the 1984 Fisheries law, in conjunction with the decrees dated 8 November and 17 December 1985, defined the concepts of "represented" species (i.e. those already present) and those "likely to provoke biological disturbances", and established lists that are still in effect today. It should be noted that among the "represented" species were a number of alien species, for example pikeperch *Sander lucioperca*, largemouth bass *Micropterus salmoides*, etc., whose introduction, similar to the other species listed, does not require an authorisation (on the condition that the specimens come from certified fish farms). Concerning crayfish, the law stipulates that introductions are prohibited except for three native species and *Astacus leptodactylus*. At that time, article L432-11 stipulated that the live transport of the prohibited crayfish was prohibited without an authorisation. In the 2006 Law on water and aquatic environments, that prohibition was lifted because it was seen by lawmakers as an obstacle to trade in those species and trade was seen as a means to manage the species. That being said, the transport of certain species remains subject to an authorisation in order to protect native species. That is the case for the decree (21 July 1983) protecting native crayfish and requiring an authorisation for the sale and transport of the red swamp crayfish (Sarat *et al.*, 2015a).

Figure 26. Advertisement from 1983 encouraging the introduction of signal crayfish (*Pacifastacus leniusculus*).

Most of the introductions of alien fish and crayfish up to 1984 cannot, in fact, be considered illegal. But subsequently, it is possible to list a few species that have been introduced illegally, intentionally or not, in open waters since 1985, the date of the decree listing the species represented in French rivers. For example, the Albanian roach (*Pachychilon pictum*) was released accidentally during restocking operations of gudgeons imported from Greece, Macedonia or ex-Yugoslavia (Keith *et al.*, 2011; Pascal *et al.*, 2006). Other species were introduced prior to 1985, but were subsequently dispersed. An example is the Asp (*Aspius aspius*), observed in the Rhine since 1976 and first captured in Alsace in 1988 (Pascal *et al.*, 2006; Keith *et al.*, 2011). Its introduction (via canals or by human intervention) must still be explained (Pascal *et al.*, 2006; Keith *et al.*, 2011). Starting from the Rhine, the species travelled upstream the Meuse and Moselle Rivers, but was also dispersed secretly to various points in France and invaded the lower and mid Loire River in the beginning of the 2010s (Keith *et al.*, 2011; Poulet, personal publication, 2017). The topmouth gudgeon (*Pseudorasbora parva*), first observed in France in the Sarthe department in the beginning of the 1980s, was probably introduced accidentally at the end of the 1970s as a "stowaway" among other species intended for fish farms (Allardi & Chancerel, 1988). The grass carp (*Ctenopharyngodon idella*), whose lack of reproduction in France has been noted (Télétchea & Le Doré, 2011), is marketed due to its capacity to consume large amounts of aquatic plants. Even though its introduction is authorised only in certain types of water body (decree dated 20 March 2013), it is now found in numerous places, including in rivers. Finally, other species are used illegally in ponds for recreational fishing, for example certain sturgeon (*Acipenser transmontanus*, *Acipenser gueldenstaedii*, etc.) and striped bass (*Morone saxatilis*) (Poulet, personal publication, 2017).

Generally speaking, use of a species increases the risks that it will be transported and dispersed by humans. The dispersal of species may take place over great distances. For example, the gathering and sale of the pods of *Prosopis juliflora* in Kenya create the risk that the species will spread to neighbouring countries (Delage, 2017).

Pathogen transmission

There is also a significant risk that pathogens carried by marketed IASs will also be dispersed from one country to another (Witt, personal publication in Delage, 2017). This phenomenon was observed following the introductions of crayfish in European rivers, notably in Spain and Sweden. In Spain, the introduction of the Signal crayfish in the natural environment was not preceded by impact studies and the risk of spreading crayfish plague (Aphanomycosis) was not taken into account, in total disregard for the recommendations contained in the Bern convention, the Habitats Directive, and those made by EIFAC (European Inland Fisheries Advisory Commission), IUCN and the International Association of Astacology (Guttiérez-Yurrita *et al.*, 1999). The introductions were carried out without any sanitary precautions and resulted in the disease spreading to wide sections of the country and causing high death rates among white-clawed crayfish (see Figure 27).

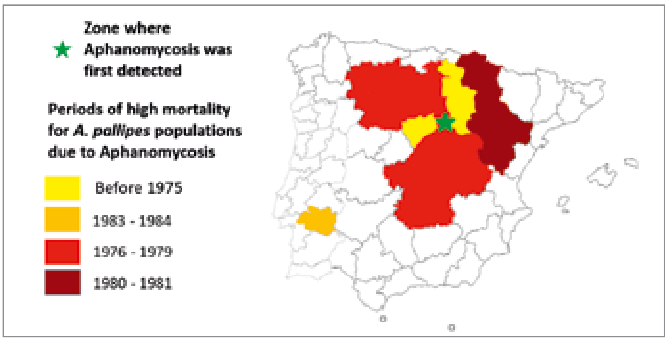


Figure 27. The spread of *Aphanomyces astaci* in Spain and Portugal. The green marks the zone where the disease was first detected. The colour code indicates the years in which the highest mortality rates of *Austropotamobius pallipes* were caused directly by *Aphanomyces astaci*. See Guttiérez-Yurrita *et al.*, 1999.

In Sweden, the illegal introductions of Signal crayfish were also the cause of the spread of crayfish plague in the country, in spite of the sanitary precautions taken to check whether the crayfish imported from North America were infected or not with the disease (Edsman, 2015) (see Figure 28).

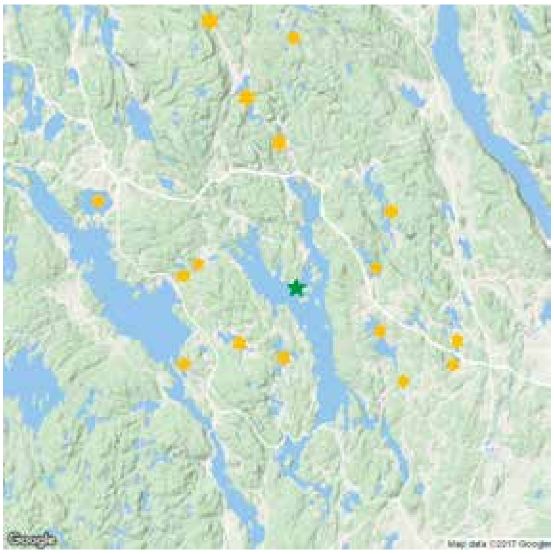


Figure 28. Map of crayfish populations affected by crayfish plague in the region around the Varmeln Lake in Sweden. The green star marks the initial introduction zone of the signal crayfish for commercial purposes in 1994. The yellow dots mark the sites affected by crayfish plague in 2004. See Edsman, 2015. © Google maps 2017

Efforts to maintain and disperse species to ensure long-term availability of the resource

When an IAS has become an economic good, it becomes difficult to maintain the objectives targeting a reduction in population numbers, to say nothing of eradication (Nuñez *et al.*, 2012). The economic dependence that can result from the use of an IAS will encourage people to at least maintain the species in the natural environment and even to grow/breed it (see the box). This is known as a perverse effect of good intentions.

Incentive measures offering capture bounties must be carefully regulated to avoid undue profits that can result in the dispersal of the species and an increase in population numbers.

THE COBRA EFFECT - A POLITICAL AND ECONOMIC THEORY BORN OF THE UNEXPECTED CONSEQUENCES OF A CAPTURE BOUNTY

A campaign to reduce the rat population of Hanoi was launched in 1902 by the French colonial authorities and became a classic example of the cobra effect (Vann, 2003). A bounty for each rat tail was offered by the authorities to reduce the risks to human health (including the plague) caused by the proliferation of rats at that time. The bounty paid was one "centime" (0.01 franc) for each rat tail collected (it had been decided that the entire dead animal would represent too much work for the civil servants in charge of collecting the rats and distributing the bounties). From the start, people brought in thousands of rat tails. The authorities were very happy with the success of the incentive measures to cull the rats, but soon reports began to come in concerning increasingly frequent sighting of rats in the city with no tail. The authorities soon learned that the rats were not being killed, but were left alive so they could continue to reproduce, and that rat farms had sprung up in the area around Hanoi. After discovering the large-scale, organised cheating of the system, the colonial authorities immediately halted the bounties for rat tails.

An identical reaction on the part of inhabitants was observed in India at the same time concerning bounties paid by the British authorities for cobras captured in Delhi. Rather than hunting the snakes, the inhabitants rapidly established snake farms after realising that the bounties largely exceeded the cost of raising the animals. As soon as the authorities became aware of the situation, the bounty programme was halted. The cobras suddenly lost all monetary value and the farmers released them to the environment. This episode lies at the origin of the "cobra effect", a theory[6] developed by Horst Siebert, a German economist, that is used in the economic and political fields to characterise a solution to a problem that only makes the situation worse, even though the original intentions were good.

In Spain, proposals were made by the National Fisheries Institute in order to "*reconcile the economic use of the red swamp crayfish with the environmental issues*" (Conde & Domínguez, 2015). The idea was to raise male Red swamp crayfish in authorised farms, located in areas where the crayfish already existed in the natural environment, and to sell them live. According to the project promoters, raising red swamp crayfish in a controlled setting would reduce not only the risk of biological invasion (given the single sex raised), but also the illegal marketing of the species because a clear legal base would exist for its sale. However, raising a single sex of red swamp crayfish does not eliminate all risk and it is important to note that farms must be equipped with systems to prevent evasion of the animals in order to avoid any new release to the natural environment. Farms must be monitored and inspected by the authorities with heavy penalties for offences to dissuade from dispersing the species to the natural environment and exploiting it illegally. This project would appear difficult to implement, notably in terms of the monitoring and inspections on the installations (Delage, 2017).

6 • https://en.wikipedia.org/wiki/Cobra_effect

In Norway, the government set up a dual management system for **Red king crab**. The system is based on the creation of two geographic fishing zones (see Figure 29). The first is an "open" zone, without quotas, where the objective is to maintain a strong capture effort in order to limit the spread of the population. The second fishing zone is subject to a quota to ensure the sustainable use of the species and the creation of a fishing activity intended to compensate the loss of revenue from the traditional activity due to the introduction of the species in the Barents Sea (see page 20) (Sundet & Hoel, 2016). The initial assessments revealed certain limits to this dual management system, e.g. in the "sustainable" fishing zone the high density of crabs that overflows into the adjacent zones and the arrival of crabs from the zone in Russia, where there has not been a strategy or effort to control the species since 2007 (Sundet & Hoel, 2016). Monitoring of the populations did not reveal an increase in the abundance of crabs in the regulated zone, however the species did continue its spread to the north (Sundet & Hoel, 2016).

The strategy for this project, i.e. develop a commercial activity while attempting to limit the spread of the species to areas outside of the zones where it is highly abundant, is certainly interesting, but did not meet the ecological objectives initially set to limit the spread of the population.

The **Signal crayfish** was released in Lake Geneva in 1976, in Thonon-les-Bains, following breeding trials at the INRA applied hydrobiology unit (Dubois *et al.*, 2006). Today, the species is considered "invasive" in Lake Geneva (Commission internationale pour la protection des eaux du Léman, 2004), however it was rapidly perceived as an economic resource and commercial fisheries received the necessary authorisations to catch it. Signal crayfish today represent on average 3% of revenues for the commercial fisheries in Alpine lakes (FranceAgriMer, 2018; Direction générale de l'environnement du canton de Vaud, 2017), which represents a potentially valuable complement, but nothing more. The species' numbers also fluctuate (see Figure 30) and catches are currently fairly low, resulting in an even lower contribution to revenues (FranceAgriMer, 2018). That being said, the species is still present in the lake.

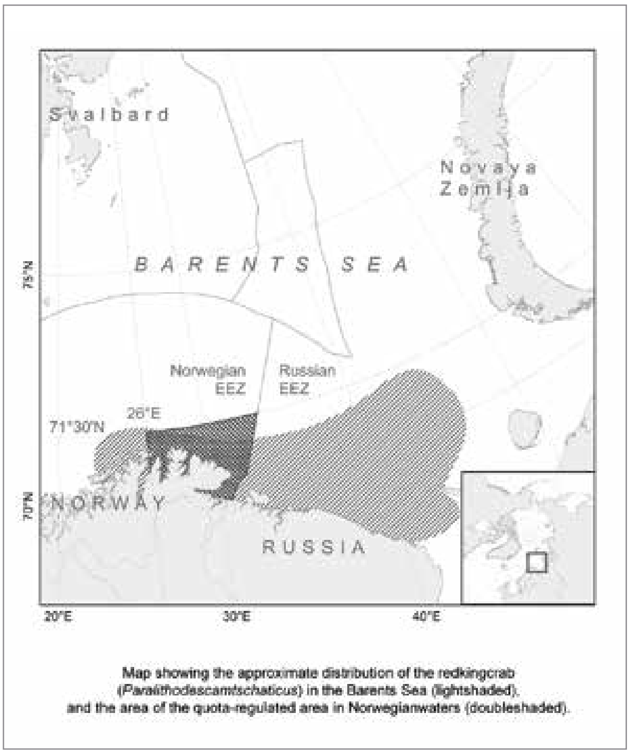


Figure 29. Map of the "sustainable" fishing zone set up by the dual management system for red king crab in Norway (see Sundet & Hoel, 2016).

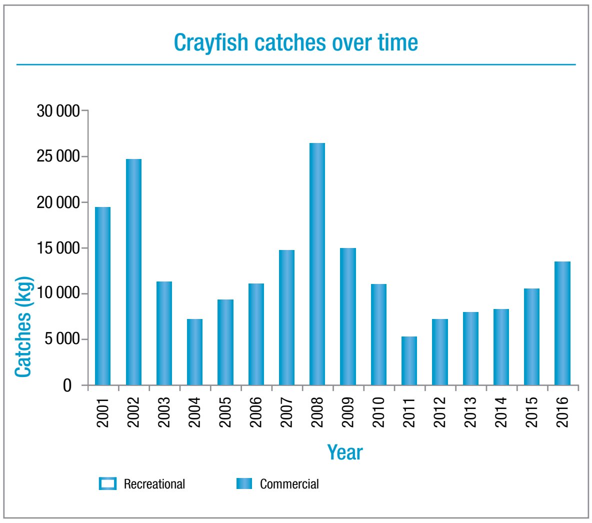


Figure 30. Quantities of signal crayfish caught in Lake Geneva from 2001 to 2016 (see la Direction générale de l'environnement du canton de Vaud, 2017).

In France, the signal crayfish is listed in the Environmental Code as a "species likely to provoke biological imbalances". The conditions governing fishing in the lake are laid out in a Franco-Swiss agreement (Decree 2002-405 dated 20 March 2002 on fishing in Lake Geneva). Transport of live animals is prohibited, except for commercial fisheries and under certain conditions contained in a prefectoral order. These crayfish, that represent an acute risk for the environment and particularly for the remaining populations of native crayfish, are transported alive throughout France as "Lake Geneva crayfish" and have been found still living in large grocery stores in the Vosges department. In the same area, a population of signal crayfish was subsequently found in the natural environment, which would suggest that customers purchasing living crayfish in the stores released them to aquatic environments in order to ensure their reproduction (Collas *et al.*, 2005). The local offices of the French Biodiversity Agency (formerly Onema) also noted that signal crayfish had been transported from Lake Geneva and released to the natural environment (Collas *et al.*, 2007). It obtained proof of direct transfers from Lake Geneva to private lakes in the Doubs, Jura and Vosges departments (Collas, personal publication). The commercial fishing of signal crayfish in Lake Geneva thus resulted in major dispersion of the species throughout France and particularly to the north-east section of France (Collas *et al.*, 2005), in spite of prohibitions on the marketing and sale of the species by European regulation 1143/2014.

Impacts on non-targeted species

IAS management involving their use can also impact native species. The populations of non-targeted species can be impacted directly, e.g. by being trapped, or indirectly, e.g. by disturbances arising from greater human presence. The impacts are all the greater if culling is done by people without sufficient information or who have not received sufficient training.

In the U.K., the feasibility study on commercial use of the Chinese mitten crab (*Eriocheir sinensis*) underscored the risks of accidental capture of eels in Fyke nets (Clark *et al.*, 2008). During the tests on the nets, 2 013 fish were caught, of which 1 397 were eels, i.e. almost 70% of the captures were accidental. It was clear that commercial fishing of the Chinese mitten crab in the Thames River would have a major impact on the eel population. A number of recommendations were made, including the use of nets with a 40 x 40 mm mesh to enable eels to escape, the development of pheromone traps and the granting of fishing rights exclusively to licensed professionals to allow the authorities to run inspections and monitor the impact of the activity on the eel population. The project did not receive final approval by the U.K. authorities (the Non-native species secretariat) due to the impacts on eels (Clark, personal publication in Delage, 2017).

In France, accidental captures of eels were noted during tests run on commercial fishing for Red swamp crayfish in the Grand-Lieu Lake (Loire-Atlantique department). In order to effectively control the population of red swamp crayfish, the fishing should take place all year, including during the time when the season for eels is closed, in which case the use of the standard Fyke nets to capture the crayfish would be illegal. For this reason, it was necessary to develop special equipment that allowed the eels to escape (Belhamiti *et al.*, 2015). Accidental catches of European pond turtles (*Emys orbicularis*) were also noted in the Camargue area, in the Vigueirat marshes (Lambret, 2010). Consequently, the diameter of the entry to the Fyke nets used to capture the crayfish was modified (Lambret, 2010) (see Figure 31). However, great attention must be paid to the operating conditions of the Fyke nets because, depending on the tension of the netting, the mesh size and therefore the selectivity of the net is modified (Beaulaton, personal publication, 2017). This also means that more regular inspections must be carried out, which occupy a non-negligible number of personnel in charge of policing the environment.

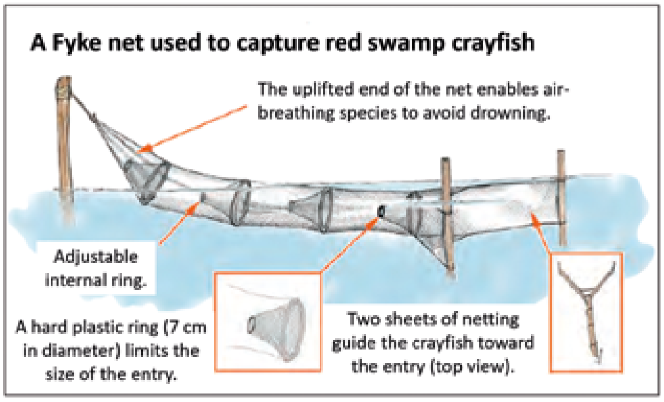


Figure 31. A modified Fyke net used to capture red swamp crayfish in the Vigueirat marshes. See Lambret, 2010.

In Ireland, accidental captures of European otters have been observed in the Fyke nets used for recreational fishing of various species, including crayfish (Poole *et al.*, 2007), however no notable impact on populations has been noted. These risks of collateral damage must be taken into account when preparing commercial-fishing projects for IASs that involve the more intensive use of special equipment than for recreational activities (fishing all year, higher density of nets in the environment).

Incentives for trapping, notably for the mandatory efforts against Nutria and Muskrats and when non-selective means are used, can have detrimental consequences for native species, particularly if specific techniques, training and instruction are absent. In France, selective and non-lethal cage traps are the most common type of trap, which limit the impact on non-targeted, native species such as beaver, otter, mink, the European polecat, etc. Trappers are required to check their traps daily. The conibear trap is also used to kill invasive alien rodents. Its use is prohibited in areas where beaver, otter and European mink are known to live.

Economic and social risks

Economic dependence (creation of a market)

Economic use of IASs would appear, a priori, to run counter to the principles governing the management of the species, i.e. a policy aiming to permanently reduce the development of the population in order to maintain the impacts at an acceptable level. To reconcile these two objectives, IASs must be considered a non-renewable resource, a notion not compatible with the economic rationale of a return on investment, economic development and growth (Delage, 2017).

The commercial objectives are often very far removed from the ecological reality. That is notably the case when the project is to create a local market *ex nihilo*. It may be a very long and difficult task to market an IAS and have it accepted for consumption or use by a population that is not at all familiar with it. That was the case for the Chinese mitten crab in the Netherlands and Germany, and for the Green crab in Canada.

The time required to create a dynamic and profitable market differs from the time required for the propagation of a species. On the one hand, establishing an economic activity takes time (for example, the market for the Blue catfish (*Ictalurus furcatus*) in Virginia has begun to grow 20 years after its launch), even if the time can be shortened by creating producer-to-market schemes and direct sales, on the other, IAS populations can spread rapidly.

If a local market does not exist, the promoters of the project can attempt to export the IASs to the countries or geographic areas that habitually consume the species. However, more or less considerable investments become necessary to supply the foreign markets, including product preparation (freezing, drying, etc.), packaging, storing, shipping, inspections on quality, etc. These industrial processes involve additional financial investments and require a sustainable resource to become profitable. The result is a need to maintain the abundance of an IAS to ensure its long-term marketability, which runs directly counter to the ecological need to control the IAS. In addition, the cost and effort to capture an IAS rises in step with the reduction in the population numbers. t is necessary to foresee these results and to plan for a decrease in revenues, while developing strategies to exit the activity to avoid any dependence on the IAS resource.

COMMON SLIPPER SHELLS, AN EXAMPLE OF THE RISKS INVOLVED IN SHIFTING FROM AN IAS MANAGEMENT PROJECT TO A SUSTAINABLE COMMERCIAL PROJECT

In France since 1998, several commercial projects have been launched involving common slipper shells (*Crepidula fornicata*), a mollusc from North America. Repeatedly introduced in Europe since the end of the 1800s, the species has become an IAS since the 1970s in several large French bays in Brittany and Normandy where oyster fishing and shell fishing in general represent important economic sectors. The species competes for space and probably for nutrients with other commercial species, in particular scallops in Saint-Brieuc Bay and Brest Bay, and oysters at Cancale and Marennes-Oléron. It also creates difficulties for fishing using towed gear.

The objective of the first project to make economic use of the species, launched in 2001 by the Association to harvest and market common slipper shells in northern Brittany, was to considerably reduce the numbers of slipper shells in the Saint-Brieuc and Mont Saint-Michel Bays, thus freeing space for commercial shellfish. Where high densities of slipper shells exist, recruitment of young scallops is hindered. Removal of the slipper shells, even if no use is made of the shells, would have a positive impact on scallop fishing (Frésard & Ropars-Collet, 2014). However, slipper shells consist essentially of calcium carbonate, which means they can be used to produce a calcareous soil conditioner commonly used in agriculture. The project was monitored by Ifremer for a period of three years (2002-2005) to assess the impact on the marine environment (Blanchard & Hamon, 2006). The results showed that the species recolonised the fished areas very quickly. Eradication of the species was not possible. In addition, the fishing technique hindered the restoration of the sea bottom to conditions conducive to the return of scallops in areas where high densities of slipper shells had grown. Ifremer underscored the importance of regularly removing the slipper shells from newly colonised areas (Blanchard & Hamon, 2006). But for financial reasons, the project was halted in 2015.

A number of other projects have attempted to use slipper shells as a source of food for humans. Among those projects, one of the first, launched by the town of Cancale in 1996, was abandoned due to the difficulty of extracting the edible part from the shell. Since 2008, the OptiCrep project, launched by Brixeta and Atlantic Limpet Development, have produced over 1 000 tons of the food annually. Called "sea tidbits" and the "new treasure from Cancale Bay", the slipper shells are marketed once removed from the shells and frozen, at a price of approximately 2 500 euros per metric ton. The shells are also used, as initially planned, as a calcareous soil conditioner. Management of slipper shell populations is not an objective of the OptiCrep project. On the contrary, the project promoters highlight the objective of the sustainable use of the resource. "*In this area, the resource is abundant, however we harvest only the 10% annual increase in the stock. Under these management conditions, we fully respect the resource. Due to its low impact on the environment and respectful approach, our fishery has been approved by the Mister Goodfish programme that encourages responsible fishing*" (Atlantic Limpet Development, 2017).

Integration of IASs in the local culture

Use of IASs may lead to their integration in the local culture. A consequence of integration may be a lessening of the disturbance caused by the IAS, with as a result social opposition to certain management projects (Nuñez *et al.*, 2012).

A number of studies have shown that, for certain species marketed as food, human societies tend to be prudent and to reject new types of food. To overcome that obstacle, food-industry companies use various techniques, for example bringing the food regularly to the attention of consumers (advertising, price reductions, etc.), highlighting the merits and advantages of the product, etc. For a management programme based on IAS consumption to be effective, the product must become part of the preferences and eating habits of the target consumer group, which can lead to the progressive integration of the IAS in the local culture, but also result in a counter-productive situation. A number of examples exist in continental France, namely Nutria, also called the "Marsh hare" in the Poitevin marshes to facilitate the sale of the *pâté*, Common slipper shells now called "Sea tidbits" (see Figure 32) and, in the overseas territories, the Brazilian pepper tree (*Schinus terebenthifolius*) celebrated as the "Rose berry" in New Caledonia (see Figure 33 a and b), and the Javan rusa, which even made it onto the 1 000 Pacific franc bill from 1969 to 2014 (see Figure 34). On Réunion Island, the fruit of the Cattley Guava (*Psidium cattleianum*), a small tree that can form dense single-species thickets that push out the native species, now plays an important role in local traditions because it is eaten and has an annual event in its honour. The Signal crayfish is also called the Californian red-clawed crayfish (see Figure 26) in order to confuse consumers who do not distinguish between native and alien crayfish (the noble crayfish, native to France, is called the red-clawed crayfish in French) and convince people that anything called a "crayfish" is native.

Such examples are not limited to France. In Venice, Italy, the Japanese littleneck clam has been renamed the "authentic clam" in order to justify its regular commercial use[7].

Figure 32. Common slipper shells are harvested in the Saint-Brieuc and Mont Saint-Michel bays. The species is marketed as "sea tidbits" to facilitate its integration in the eating habits of consumers. © P. Morris

Figure 33 a et b. The Brazilian pepper tree, whose "rose berries" are celebrated and consumed in New Caledonia. © New Caledonia Nature Conservatory

7 • An ethnology thesis by Florence Ménez in 2015, titled "The clam parable - ontogenesis of an inter-species attachment in the Venetian Lagoon. An ethnographic study of its biographic story" deals specifically with the social integration of the Philippine clam in the Venetian Lagoon. The study looks at the categories that enabled the clam to shift from a wild and foreign "dioxin clam" into a "native" and even a "national" clam (Ménez, 2015).

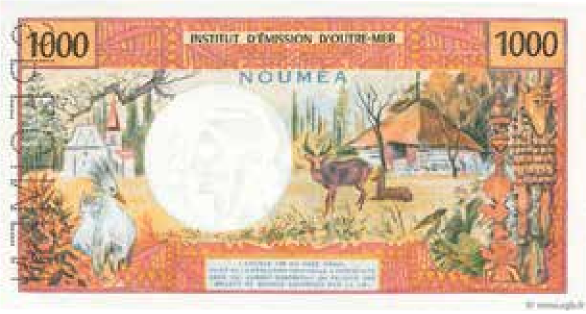


Figure 34. A 1 000 CFP bill, valid until 2014, showing a Javan rusa. © www.cgb.fr

One means to avoid the cultural integration of IASs may be to constantly remind consumers that the objective is to control IAS populations in order to limit the adverse impacts on the environment, the economy and human health.

Incentives to use IASs and their integration in the local culture may also have negative consequences for native species. The European red deer was introduced in Argentina and Chile a century ago for hunting. It has produced major adverse effects, but is also an economic resource for tourism and sport hunting. To maintain the economic benefits, the governments of the two countries have set up hunting quotas designed to preserve the size and density of the deer populations. In Patagonia, some farmers hunt or poison guanacos (*Lama guanicoe*), a native species, to ensure that it does not compete with the European red deer (Lambertucci & Speziale, 2011). In New Caledonia, the Javan rusa, introduced in 1870, is both a species incorporating high social, food, economic and cultural values, and one of the seven priority IASs targeted for control measures.

The cultural integration of an IAS, that may come about due to its use, risks creating opposition to any management programmes. For example, in Kenya, a biological-control programme against Prosopis had to be halted by the authorities because several companies, but also NGOs, had convinced the population that the trees, the “green gold” of Africa, could contribute significantly to the local economy (Witt 2013). On Réunion Island, the debates continue concerning the Cattley Guava (also called “red gold”) (see Figure 35) between the managers of natural environments, the producers and the consumers of the fruit (Piccin & Danflous, 2013).

Figure 35. The fruit of the Cattley Guava are in high favour with the local population and sold in small trays along roads. © J.-Y. Meyer

Illegal use of IASs that have become an economic resource

Illegal uses of IASs in the wake of projects targeting their use is a risk that must not be neglected. Illegal uses have frequently been observed for invertebrates, such as the red swamp crayfish and the Japanese littleneck clam.

In Spain and Portugal, the highly diverse regulations governing Red swamp crayfish complicate the socio-economic context of the species. In Spain, the central government has authorised fishing and marketing the species, but the regional governments allow only recreational fishing, except in the south of the country where it is an industrial activity. In Portugal, commercial activities and notably the transport of live animals are forbidden. The first cases of illegal activities in Spain and Portugal were reported in the 1990s (Gutiérrez-Yurrita *et al.*, 1999) . They were the consequence of a major dry period in the Spanish region of Guadalquivir, which severely impacted the production of red swamp crayfish and incited the fisheries to poach the species in Portugal. The captured animals were brought back alive to Spain where they were conditioned and sold (Guttiérrez-Yurrita *et al.*, 1999).

Similar situations were observed in the U.K., where commercial fishing of Signal crayfish is authorised in England, but not in Scotland and Wales. Concerning incentive measures (capture bounties), cases of illegal trapping (non-approved traps and without authorisation) have been reported in England (Peay, personal publication, 2016).

In Venice, pollution from nearby industrial zones led to the prohibition of fishing for clams (Japanese and native) in the lagoon at the end of the 1990s (Ménez, 2015). High demand from consumers and the easy profits resulted in the development of an illegal economic sector for clams and the emergence of informal fishing cooperatives where the crews were called "Ciurma"[8]. According to Ménez, 2015, "*At night, the lagoon became a lawless Wild West. The most productive sites were located near the industrial zone and the road and train bridges* […]. *A fishing session lasted approximately 90 minutes and took place three or four times per week.*" In addition, the technique used to collect the clams (severe agitation of the bottom) was prohibited because it caused severe environmental damage by stirring up the lagoon bottom and leaving great quantities of sediment in suspension. A million cubic metres of sediment were estimated to have been lost each year from the lagoon (Osservatorio naturalistico, 2006, in Ménez, 2015).

In France, the Japanese littleneck clam in the Morbihan Golf is marketed. This commercial activity, estimated at over four million euros in 2001, represented the largest percentage of revenues for the fishing sector in the area (Peronnet *et al.*, 2001, in Lesueur, 2002). The frequent poaching on the Sarzeau site is done by fishermen without a license, but also by those with the necessary license. The former are in direct competition with the commercial fisheries given that they fish in restricted areas and sell their products. The professionals are themselves accused of not respecting the regulations (shell sizes, fishing zones, equipment used). This illegal activity, carried out at night, is difficult to assess and to control (Lesueur, 2002).

In Portugal, the Japanese littleneck clam is currently fished in the Tagus estuary. Following a severe reduction in the numbers of the native clam, *Ruditapes decussatus*, fishing of the species was prohibited, however the authorised fishing of the Japanese littleneck clam enables the illegal fishing of the native clams. The authorities have encountered difficulties in enforcing the prohibitions because the inspectors have often not been trained to recognise the morphological differences and cannot distinguish the two species of clams sold on the market (see Figure 36) (P. Chaino, personal publication, in Delage, 2017). A further difficulty lies in the fact that the clams interbreed, thus producing offspring with intermediate morphological characteristics (Hurtado *et al.*, 2011).

Figure 36. Morphological differences between the European clam and the Japanese littleneck calm. Source: WORMS – World register of Marine Species © Natural History Museum Rotterdam

Private profits and social costs

Another consequence of the economic use of IASs is "privatizing profit and socializing costs". In most of the projects for IAS use, private companies make the profits while the species continues to incur costs due to its multiple impacts and the expense of management, costs that are borne by the public authorities and consequently by taxpayers and the local population.

8 • An Italian word from the Genoan dialect, meaning all the slave or voluntary rowers in a ship, and by extension, now a derogatory term for noisy, effusive louts. Definition from Ménez, 2015.

This phenomenon, concerning the economic use of alien trees, was criticised in Africa. For example, Witt (2013) noted that most of the benefits from the production of charcoal using the wood of the Prosopis tree went to foreign investors, whereas the local communities, directly impacted by the proliferation of the species, drew very few benefits.

The economic dependence that results from the commercial exploitation of an IAS makes it difficult, if not impossible, to implement an effective management strategy.Black wattle (*Acacia mearnsii*) was introduced to South Africa in the 1800s with plans for its commercial use (see Figure 37). The species turned out to be highly invasive with negative consequences for biodiversity, water reserves and the stability of riparian ecosystems, thus creating costs for the country, but profits for the forestry industry. A study (Wit *et al.*, 2001) ran a cost-benefit analysis on the species for South Africa as a whole. It showed that the benefits drawn from marketing *Acacia mearnsii* would most likely not compensate the management costs and urgently recommended a detailed comparison of the profits made by the private companies and the costs borne exclusively by taxpayers. The authors also suggested that the private companies should contribute significantly to financing not only the management measures, but also research programmes, for example on the biological control of the species. In 2013, the indispensable management costs for black wattle continued to be borne exclusively by taxpayers (Witt, 2013).

Figure 37. Black wattle is marketed in South Africa. © F. & K. Starr

Further costs for public authorities must be taken into account when analysing the economic viability of commercial activities. They may consist of public grants to create a company, as well as financial assistance to maintain the viability of the project if the species becomes less abundant in the natural environment and/or funding for an "exit strategy" if revenues fall too far. Finally, it the project is halted totally or even partially, the costs may include the payment of social benefits to the former employees (unemployment benefits, grants to assist in finding work, etc.).

It is absolutely necessary to clearly define, prior to the start of projects, the responsibilities of the promoters of projects for the economic use of IASs. This is all the more necessary when projects receive public funding.

Health risks

Contamination of products intended for human consumption

For projects targeting IAS products intended for human consumption, ecotoxicological analyses are absolutely required to avoid any health risks. These issues arise notably for the marketing of invertebrates and certain fish.

For example, in Germany in 1995 and 1998, the ecotoxicological studies run prior to the launch of projects to market Chinese mitten crab from the Elbe and Havel Rivers revealed levels of contamination exceeding the applicable standards for HCB, HCH, DDT and methoxychloride (Delage, 2017). The species is currently marketed and attempts have been made to export it to Taiwan and China where, due to pollution, the crabs have become rare and, consequently, expensive. But the Chinese health authorities require clear traceability of the products to avoid fraud (i.e. the sale of contaminated crabs). Attempts to export living crabs have also been blocked by the Chinese authorities via quarantine rules. A commercial project for Sea lampreys (*Petromyzon marinus*) in the North American Great Lakes was abandoned due to contamination by heavy metals (the concentration of mercury exceeded EU standards by a factor of four, i.e. 1.3 ppm compared to the 0.3 ppm limit set by EU standards (Gunderson, 1998)).

Similar health considerations have been raised in the U.K. The feasibility study on the marketing of Chinese mitten crabs from the Thames River estuary revealed high levels of dioxins and PCBs. Even though the crabs are consumed over a short period of the year (three to four months when the crabs are sexually mature), the study authors were of the opinion that the quantity of pollutants absorbed would not exceed the permissible daily dose, but did recommend caution for children and pregnant women (Delage, 2017). This crab species can also carry a parasitic infection caused by lung fluke (the flatworm *Paragonimus westermani*). The analysis showed that the crabs from the Thames estuary were not contaminated by *P. westermani*. However, the Chinese mitten crab may carry *Vibrio parahaemolyticus*, a bacteria that can cause severe cases of gastroenteritis. High concentrations of the bacteria may be present during the summer months and at lower concentrations during the autumn months when the crabs are consumed. For this reason, consumption of raw or slightly cooked crab may represent a significant health hazard.

The **Blue catfish** in the Chesapeake Bay (United States) has been marketed by commercial fisheries for over twenty years. The catfish represents the end of the food chain and consequently concentrates pollutants, notably PCBs. Only juveniles may be sold as food because they are less contaminated. Sale of the fish is limited to those measuring less than 81 centimetres, which limits the possibility of taking action against all the biological stages of the population and modifying the population dynamics, while also reducing the profitability of the fisheries (Delage, 2017).

In New Caledonia, a commercial project is exploring the possibility of marketing the **Giant African snail** (*Lissachatina fulica*) for human consumption and to feed animals. This large snail originated in East Africa and was introduced to New Caledonia in 1972 (Gargominy *et al.*, 1996). The species is an intermediate host to *Angiostrongylus cantonensis*, a nematode responsible for eosinophilic meningitis, and humans risk contamination if they eat raw or insufficiently cooked snails. Only three to ten cases of the disease are reported each year in New Caledonia, however the risks are not negligible for young children (Barrière, personal publication, 2017).

In continental France, a study spanning the entire Loire river basin provided quantitative data on the bioaccumulation potential of **Alien crayfish** (*Orconectes limosus*, *Pacifastacus leniusculus* and *Procambarus clarkii*) (Lemarchand *et al.*, 2013, in Basilico *et al.*, 2013). The authors studied almost 500 crayfish, looking for approximately 50 chemical compounds including the main pesticides in the river, 16 PCB congeners and heavy metals (lead, mercury, cadmium, copper, arsenic) (see Figure 38). The results revealed systematic contamination of the crayfish by pesticides (essentially DDE, DDT and Lindane, at relatively low levels), PCBs (approximately 9 mg/kg for the three species) and, above all, heavy metals, in particular copper, cadmium and mercury. For a given substance, the average concentrations noted in the crayfish varied only slightly from one species to another or from one site to another. These results are indicative of systematic contamination, i.e. a "background noise". However, the variability from one crayfish to another would suggest that moults are a means to eliminate the pollutants.

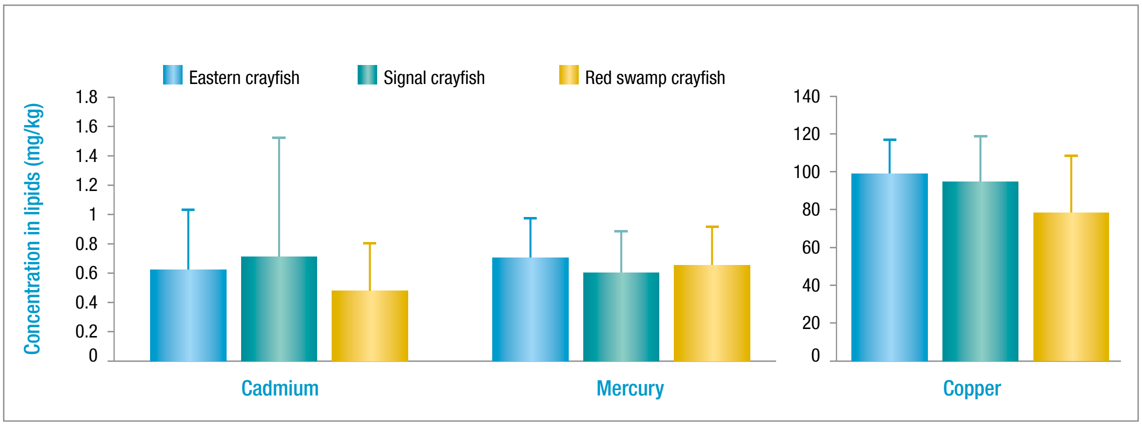


Figure 38. Average concentrations of heavy metals in invasive crayfish in the Loire River basin (mg/kg of lipids). According to Lemarchand *et al.*, 2013, in Basilico *et al.*, 2013.

Incentive measures encourage the culling and the consumption of Red lionfish in the Caribbean, however the presence of ciguatoxin in its flesh represents a serious risk. Ciguatera is a form of food poisoning caused by benthic micro-algae in coral reefs (from the *Gamberdiscus genus*). The micro-algae produce the ciguatoxin that is consumed by herbivorous fish and bioaccumulates, increasing the concentration levels (Robertson *et al.*, 2013). The red lionfish is a predator at the top of the food chain and thus likely to accumulate ciguatoxin. An analysis was run on the risk of ciguatera in the French Caribbean and the results indicated that a risk existed for Saint-Barthélemy and that further studies were necessary for Saint-Martin (Soliño *et al.*, 2015). The species is not marketed in Saint-Barthélemy or Saint-Martin (Observatoire du milieu marin de Martinique, 2017).

Accidents due to capture techniques

Incentive measures encouraging culling of IASs may create risks for people trapping, hunting or collecting them. The spines of the Red lionfish contain venom and accidents have occurred in the process of fishing and handling the animals (even when dead). Even though the venom is not lethal, medical care is necessary (Diaz, 2015).

Summary of projects identified in France and abroad

Type of use / Type of risk	Incentive measures	Commercial measures
ECOLOGICAL RISKS WITH CONSEQUENCES FOR SPECIES AND ENVIRONMENTS		
Biological overcompensation	YES	YES
Intentional and accidental introductions in the natural environment	YES	YES
Preservation and dispersal of populations to ensure the sustainability of the resource	YES, in certain cases if there are capture bounties	YES
Impacts on non-targeted species	YES	YES
Transmission of pathogens	No information	YES
ECONOMIC AND SOCIAL RISKS		
Economic dependence (creation of a market)	Possible, if the bounties represent a considerable percentage of revenues	YES
Contribution to IAS integration in the local culture	YES	YES
Illegal use of IASs that have become an economic resource	NO	YES
Private profits and social costs	NO	YES
RISKS FOR HUMAN HEALTH		
Contamination of products intended for human consumption	YES	YES
Accidents due to capture techniques	In some rare cases	NO

Black wattle. © G. Grisard

A real contribution to controlling biological invasions?

ANALYSIS OF SURVEYED PROJECTS

Surveyed projects

A bibliographical review and an international survey were undertaken to collect information on 39 projects targeting the use of 30 IASs in 19 countries (see Figure 39 and Table 2).

The actual number of projects around the world is far greater. The number of projects selected (39) is the result of the search criteria targeting essentially the species present in aquatic environments in France, Europe and other industrialised countries, plus a few other terrestrial species and specific cases in emerging countries selected to fill out the range of projects analysed. Finally, selection was also limited to projects providing enough information for the analysis purposes. The analysis method used for the project survey is presented in the annex to this document.

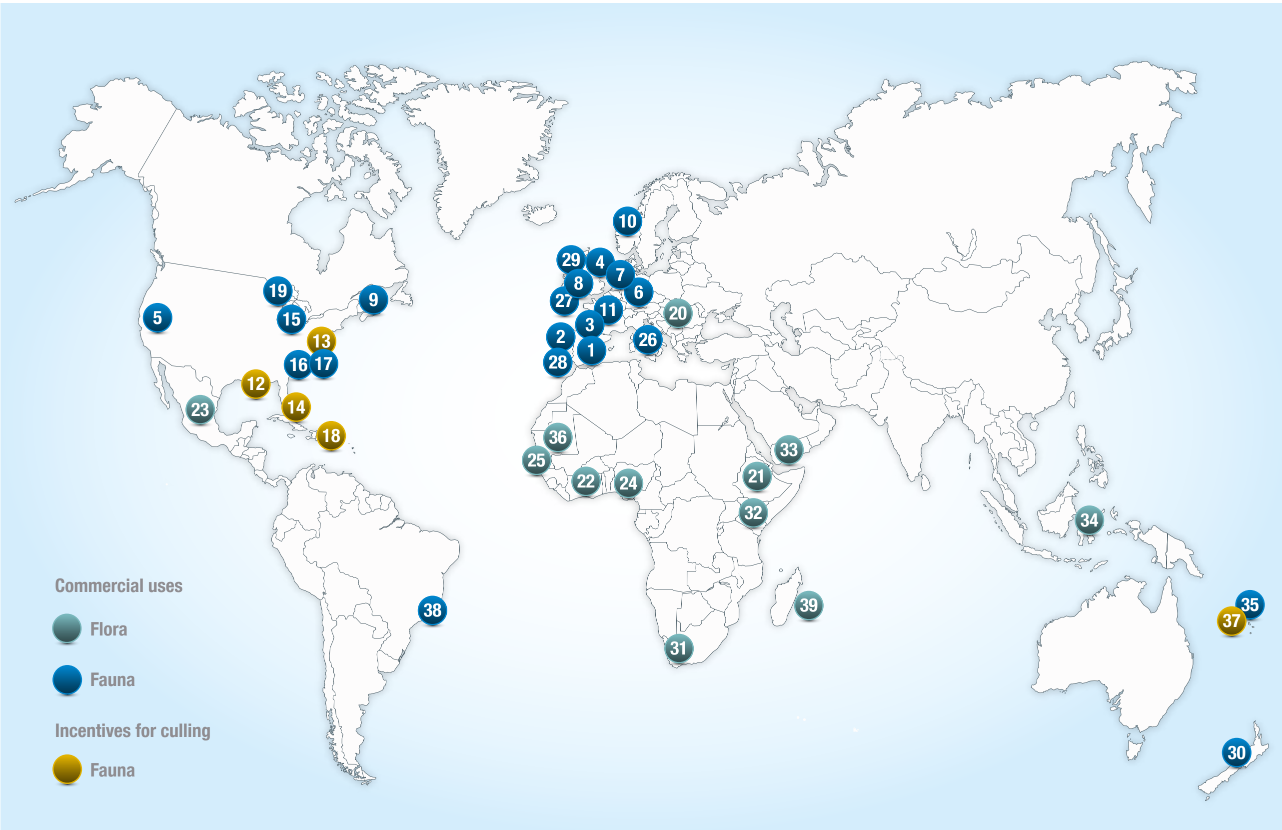


Figure 39. Geographic distribution of the projects listed in this report.

Tableau 2. List of projects targeting use of IASs.

1. Commercial use of red swamp crayfish in Andalusia I *Spain*
2. Feasible exploitation of the red swamp crayfish *Procambarus clarkii* in introduced regions I *Spain and Portugal*
3. Commercial use of red swamp crayfish (Action programme to gain knowledge, acquire control and make commercial use of red swamp crayfish by professional fisheries (Conapped)) I *France*
4. Commercial use of red swamp crayfish in Scotland I *United Kingdom*

5 Commercial use of red swamp crayfish in Lake Tahoe (California and Nevada) | *United States*

6 Commercial use of the Chinese mitten crab in the Elbe and Havel Rivers | *Germany*

7 Commercial use of the Chinese mitten crab | *Netherlands*

8 Commercial use of the Chinese mitten crab in the Thames Rivers | *United Kingdom*

9 Commercial use of the Green crab on Prince Edward Island | *Canada*

10 Commercial use of the red king crab (Norwegian management of an introduced species : the Artic red crab fishery) | *Norway*

11 Commercial use of common slipper shells in Cancale Bay (OptiCrep ALD / Brixeta) | *France*

12 Incentive programme to cull nutria in Louisiana (Coastwide Nutria Control Program) | *United States*

13 Incentive programme to cull nutria in Maryland (Chesapeake Bay Nutria Eradication Project) | *United States*

14 Incentive programme to cull Burmese pythons in Florida (Python challenge) | *United States*

15 Commercial use of Asian carps in Lake Superior (Lake Superior Aquatic Invasive Species Complete Prevention Plan) | *United States*

16 Commercial use of the blue catfish in Virginia (Maryland Invasive Catfish Policy) | *United States*

17 Commercial use of the Northern Snakehead in Maryland (National control and management plan for the Northern Snakehead) | *United States*

18 Incentive programme to cull the red lionfish | *United States and Caribbean*

19 Commercial use of sea lampreys in the Great Lakes of North America | *United States*

20 Commercial use of desert false indigo | *Hungary and Romania*

21 Commercial use of prosopis | *Ethiopia*

22 Commercial use of water hyacinth (Green keeper Africa) | *Benin and Niger*

23 Commercial use of water hyacinth (TEMA) | *Mexico*

24 Commercial use of water hyacinth (MitiMeth) | *Niger*

25 Commercial use of Typha wood for charcoal | *Senegal*

26 Commercial use of the Japanese littleneck clam in the lagoon of Venice | *Italy*

27 Commercial use of the Japanese littleneck clam in the Golf of Morbihan | *France*

28 Commercial use of the Japanese littleneck clam | *Portugal*

29 Commercial use of red swamp crayfish in England | *United Kingdom*

30 Commercial use of the European red deer, the Himalayan tahr and the common brushtail possum | *New Zealand*

31 Commercial use of black wattle | *South Africa*

32 Commercial use of prosopis | *Kenya*

33 Commercial use of prosopis | *Yemen*

34 Commercial use of *Acacia nicotila* and *Mimosa pigra* (FORIS programme – Removing barriers to invasive species management in production and protection forest in Southeast Asia) | *Cambodia, Indonesia, the Philippines and Viet-Nam*

35 Commercial use of the giant African snail in the Pacific overseas territories | *Pacific community countries (including New Caledonia and French Polynesia)*

36 Commercial use of Typha wood for charcoal | *Mauritania*

37 Hunting and trapping bounties for Javan rusas and wild boar | *France (New Caledonia)*

38 Commercial use of *Tubastrea coccinea* and *Tubastrea tagusensis* corals in the framework of the Sun Coral Project integrated-management programme | *Brazil*

39 Creation of an industrial sector for commercial use of Cattley guava (*Psidium cattleianum*) on Réunion Island | *France (Reunion Island)*

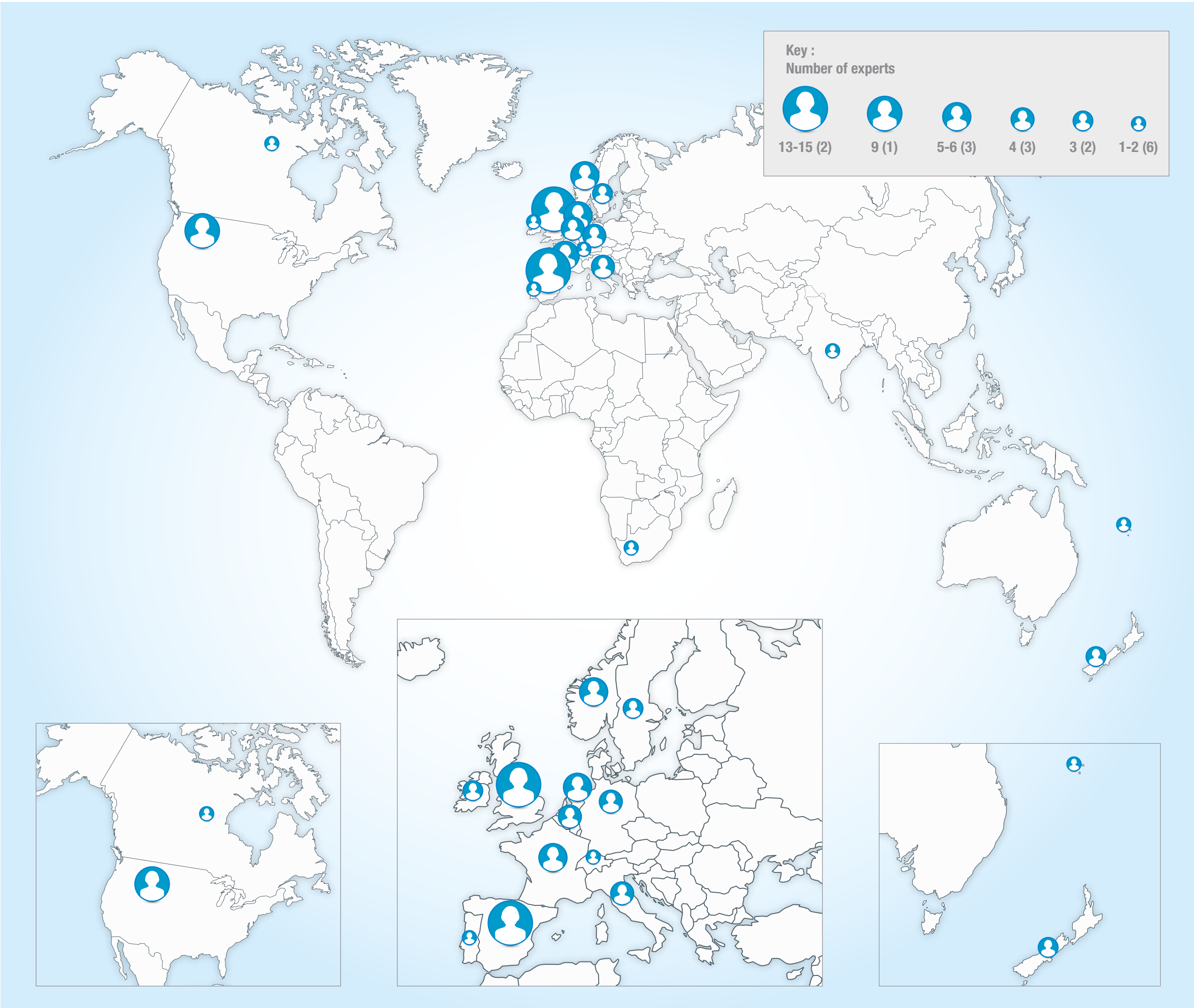
Experts and resource persons

A total of 84 experts from 18 countries were contacted and 47 responded (response rate 56%) (Table 3 and Figure 40).

Tableau 3. Country and number of experts contacted (see Delage, 2017).

Country | Number of persons contacted			
South Africa | 1	Spain | 13	Norway | 5	Sweden | 3
Germany | 4	France | 6	New Zealand | 3	Switzerland | 2
Belgium | 4	India | 1	New Caledonia | 2	United Kingdom | 15
Canada | 2	Ireland | 2	Netherlands | 6	International | 1
United States | 9	Italy | 4	Portugal | 1	
TOTAL | 84			

Figure 40. Geographic distribution of the resource persons contacted for the international study (see Delage, 2017).



Analysis of the surveyed projects

Species

A majority of the projects for IAS use (both incentives for culling and commercial uses) concerned fauna (27 out of 39 projects, i.e. 70% of projects) and particularly invertebrates (17 out of 39 projects, i.e. 44% of the total) (see Figure 41).

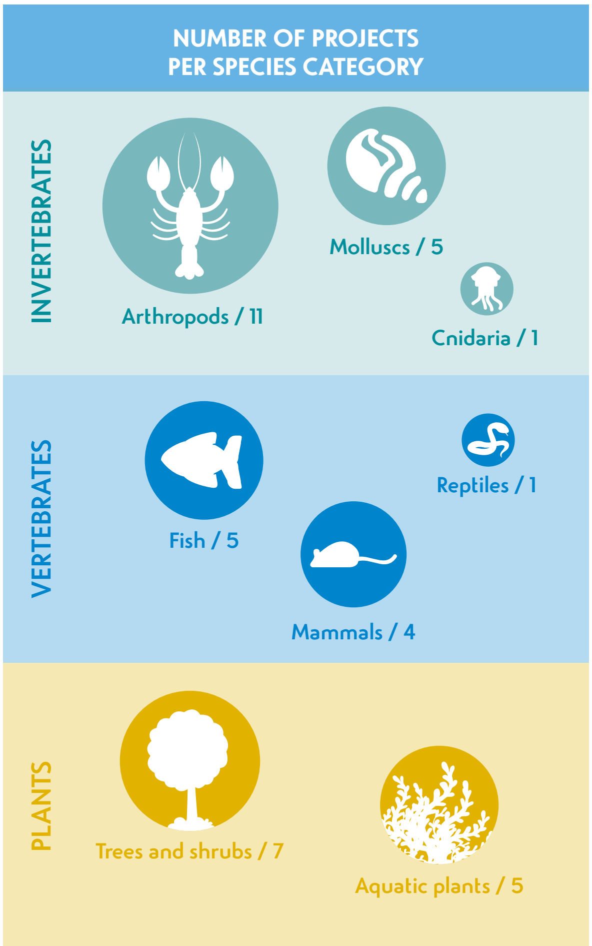


Figure 41. Number and category of species involved in projects for IAS us.

The results of the analysis show that projects addressing invasive alien fauna are dominant in the northern hemisphere, whereas projects targeting the use of invasive alien plants are more often observed in the southern hemisphere, particularly in Africa. For projects on the commercial use of plants, the distribution between trees/shrubs on the one hand aquatic plants on the other is fairly well balanced.

Project status

A vast majority (69%) of the surveyed projects are parts of programmes that are still ongoing (see Figure 42). Most started in the 2000s, however the oldest projects were launched in the 1970s or 1980s (e.g. marketing of North American crayfish in Europe, commercial hunting of mammals introduced to New Zealand).

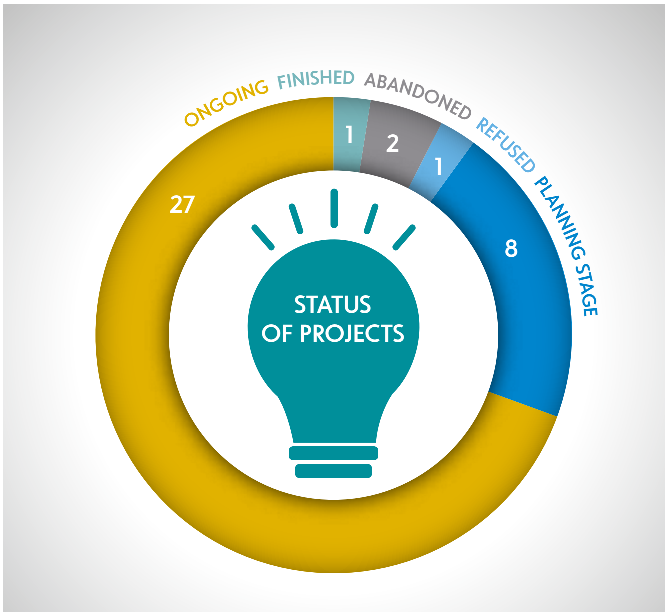


Figure 42. Status of projects.

Only one programme has been finished and fully assessed, namely the Nutria programme in Louisiana (Coastwide Nutria Control Program 2016). Given the positive results of the culling incentives, originally planned for the period 2002 to 2007, the programme has since been regularly assessed and renewed annually (Normand, 2016) (see Figure 43).

Technical and economic reasons are generally the cause for abandoned projects. For example, the attempt to market Sea lampreys from the Great Lakes in North America did not succeed due to the degraded taste of the exported products (freezing the product over the time required to export it to Europe altered the taste), to technical difficulties in marketing the species in tin cans and, finally, to health risks (levels of mercury in the fish from the Great Lakes exceeded applicable standards in the European Union (Gunderson, 1998)). In New Zealand, commercial hunting of the European red deer using helicopters was abandoned when the hunting and transportation costs became disproportionate with the sale price of the meat. The activity also had difficulties in competing with farmed venison (Parkes *et al.*, 1996). Commercial use of the Common brushtail possum did not produce any significant decrease in the population densities of the species or sufficient economic results. Social pressures may also be a reason why projects are abandoned. In New Zealand, commercial hunting of the Himalayan tahr, set up in 1971, was halted and prohibited from 1983 to 1994 due to pressures exerted by local hunters (Parkes *et al.*, 1996).

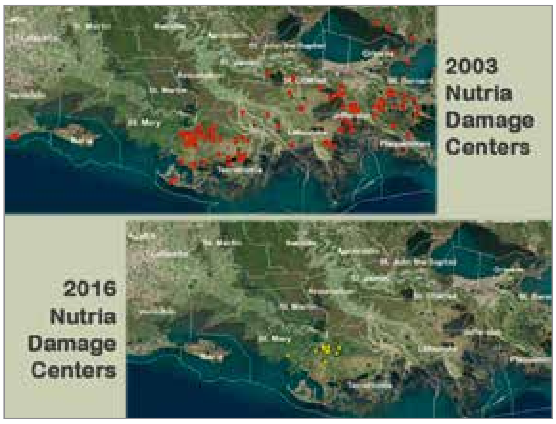


Figure 43. Results of the management programme for nutria in Louisiana. Map of sites where damages were observed at the start of the programme in 2003 and in 2016. (See Normand, 2016).

Main motivations

Of the 39 projects for IAS use discussed here, five consisted of incentive measures without any commercial objectives, whereas 34 had clear economic objectives. Of the 34 projects, 33 planned to develop markets for the products. Only one project, the *Tubastrea* corals in Brazil, has as its main objective the control of the species, with in addition the possibility of additional revenue for the local population.

The motivations leading to projects targeting IAS use may be grouped in several categories (Delage, 2017). In some cases, several motivations are combined to enhance the value of the project.

The objectives of the five projects comprising incentive measures included protection of biodiversity, via a limitation of IAS impacts on native species and the restoration of natural environments, plus a return of profitable local activities (fishing, hunting, hiking, etc.).

Among the 34 commercial projects, a prime objective is to compensate for lost revenue, in some cases caused directly by the arrival of the IAS in an environment where it competes with native species offering high added value. A second objective often mentioned in conjunction with the lost revenue concerns the creation of jobs at different stages in the commercial process (harvesting/culling, transformation, sale of by-products, etc.).

Health reasons are raised in relation to the commercial use of Typha and Water hyacinth (*Eichhornia crassipes*) in Africa because the two plants can block water courses, resulting in stagnation, the proliferation of mosquitoes and the development of a malaria hazard.

Generally speaking, projects targeting IAS use would not appear to be sufficiently integrated in the overall strategies for IAS management. The only projects with exclusively ecological objectives are those consisting of incentive measures. Commercial projects regularly highlight positive ecological effects among the objectives, but the actual results are rarely assessed. Among the 34 commercial projects, over half (20 projects) explicitly mention a double objective, i.e. "economy and ecology" (see Figure 44). The remaining projects present IASs as economic pests (impacts on other commercial species) or health hazards (stagnation of aquatic environments) and do not mention any ecological objectives in addition to the economic.

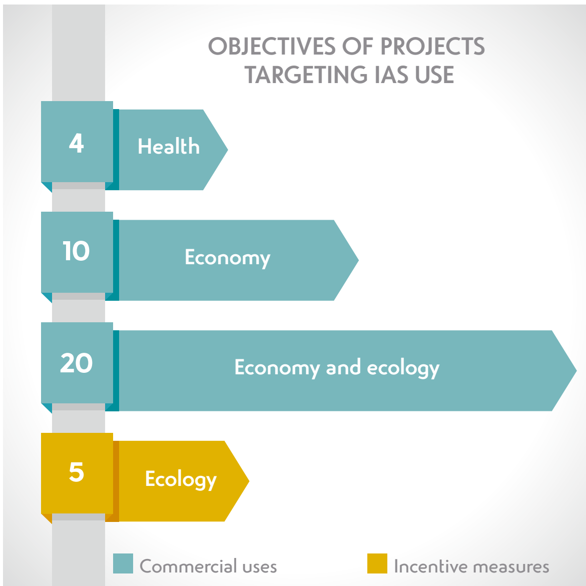


Figure 44. Objectives of projects targeting IAS use.

Scientific monitoring and assessment of projects

To date, commercial projects highlighting a double objective, both "economy and ecology", have not been sufficiently organised in scientific terms. Only three of the surveyed projects include studies on the population dynamics of the target IASs, even though such studies are indispensable to measure the effectiveness of culling and to avoid any counter-productive effects, e.g. biological overcompensation.

Monitoring of the work done has gained in regularity. Out of 17 projects, the culled specimens were (more or less rigorously) monitored in 13 projects. Monitoring of the ecological impacts of projects is still uncommon given that only four commercial projects implement scientific protocols to access their ecological effectiveness (United States, New Zealand, Brazil and Southeast Asia). The development of indicators and monitoring methods is, however, planned for some projects still in the planning stages, and work is also being put into methods capable of targeting all the development stages of species and the priority intervention areas, e.g. for red swamp crayfish in France.

The system to monitor catches of Asian carps in the Great Lakes of North America stands out as an example in that it comprises a complete scientific programme (Garvey *et al.*, 2012) including:

- a study on the size distribution within the population including a measurement of their average length;
- measurement of the abundance indices (CPUE) ;
- measurement of fishing effectiveness by marking individual fish;
- monitoring of species migration using acoustic transmitters;
- formulation of a fishing strategy to determine the size and biomass of fish that must be caught to halt the growth of the population.

The programme to manage the *Tubastraea coccinea* and *Tubastrea tagusensis* coral populations (Sun Coral project), which includes marketing of the corals by the local population around the Rio de Janeiro Bay, is also exemplary. After ten years of implementation, a complete assessment of the programme was run (Creed *et al.*, 2017). The assessment included monitoring of the distribution of coral populations, development of a protocol to quantify changes in the density of the target corals and in the benthic community, and in-depth monitoring of the work to cull the species.

On Réunion Island, Minatchy *et al.* (2017) carried out an ecological assessment of the commercial use of the Cattley guava. After the project had been running for three years, floristic surveys were run on the farmed areas in the humid, tropical forests in the mountains and on control plots. Abundance-dominance indices were calculated and the degree to which the Cattley guava had invaded the zone was measured.

Market studies, on the other hand, were frequently run for commercial projects (27 out of 34), as were studies on the development of transformation processes (18 out of 34) and studies on the nutritional value of species and their chemical contamination (5 out of 34).

Incentive programmes to cull species generally collect annual data on culls and the number of authorisations granted, but rarely any information on the effectiveness of the culling effort. An example of a complete monitoring programme is that for the Nutria eradication project in Louisiana, which included annual culling data for each type of environment, culling method and geographic zone for the entire duration of the project (2002 to 2012). Damage monitoring was carried out in parallel to assess the effectiveness of the eradication project (Hogue & Mouton 2012) (see Figure 45).

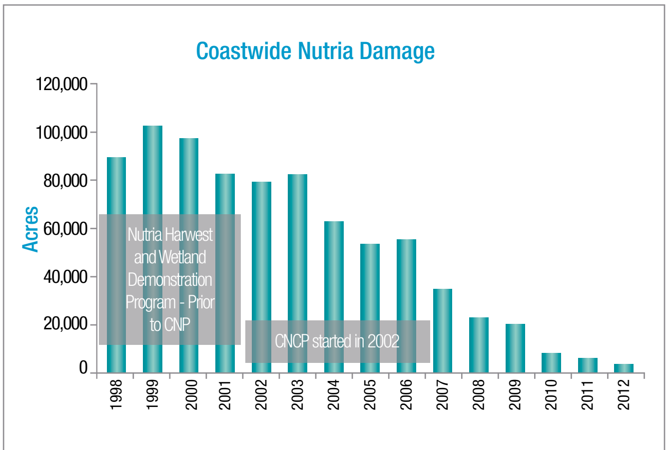


Figure 45. Damage monitoring to assess the effectiveness of the nutria eradication project in Louisiana. See Hogue and Mouton, 2012.

Integration in a comprehensive management strategy

Generally speaking, commercial projects are only infrequently integrated in comprehensive strategies for IAS management. There are exceptions however, for example the commercial project for Northern snakeheads (*Channa argus*) in Maryland, that is part of a national management plan (National control and management plan for members of the Snakehead family, 2014), and the management plan for Asian carps in Lake Superior (United States), that is part of a more general programme targeting all biological invasions in the gigantic body of water (Lake Superior Aquatic Invasive Species Complete Prevention Plan).

The Sun Coral project is also part of a comprehensive management strategy. It includes an array of objectives, notably the preservation and restoration of colonised marine environments, the provision of additional revenues for the local population, enhanced knowledge on the biology and ecology of the species, the development of new management techniques, enhanced environmental awareness and education, and finally contribution to establishing regulations and a policy to prevent and manage invasions by the coral species (Creed *et al.*, 2017) (see Figure 46 a and b).

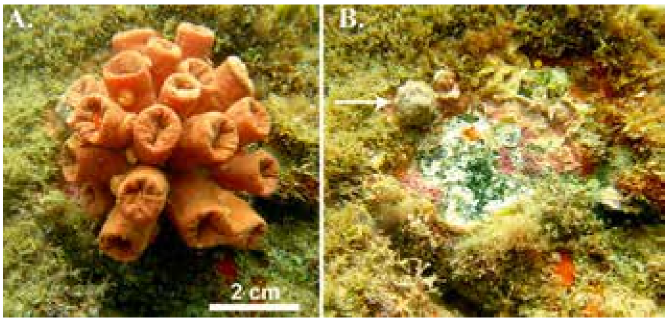


Figure 46 a et b. A protocol for manual culling was devised in the framework of the Sun Coral project. Coral collectors were trained to limit the impacts of culling on other species, for example, the gastropod shown by the arrow in Figure 46 b.

In Southeast Asia, the FORIS programme (*Removing barriers to invasive species management in production and protection forest in Southeast Asia*) is active in four countries (Cambodia, Indonesia, Philippines and Viet-Nam). Commercial use of Alien mimosas is integrated in a comprehensive management strategy that comprises a number of objectives, including the creation of national IAS policies, interregional cooperation, IAS management in forests, informational efforts, and monitoring and assessment of IAS impacts.

Collaborative efforts and types of partnerships

Among the 39 surveyed projects (including both incentive measures and commercial uses), 26 are run by public institutions, an NGO or a research organisation and 12 by private companies (see Figure 47). A women's cooperative in Africa runs the remaining project. Projects involving incentive measures are proposed exclusively by public institutions. Commercial projects are run essentially by private companies and in some cases by public institutions and NGOs.

Figure 47. Main categories of project initiators.

Collaboration between categories is fairly frequent and mentioned in 28 of the 39 projects. The most common are collaborations between public institutions and research organisations (14 projects), those between national governments, public institutions and private companies (four projects) and finally those between private companies and research organisations (three projects). NGOs are often involved in commercial projects in less developed countries, in conjunction with the local populations (production of biomass and crafts), with five projects in Africa, one in Brazil, one in Europe and one in Canada.

Four projects involve more than five types of partner (public institutions, professional organisations, research organisations, local governments, NGOs, cooperatives, etc.). Work groups federating these different participants are also mentioned in a number of projects (catfish in Virginia, nutria in Maryland, *Tubastraea* corals in Brazil).

Regulatory framework

It is often difficult to access information on the regulatory framework for commercial projects. However, in a number of countries, regulations governing certain IASs in commercial projects are not particularly rational. For example, in Canada, the **Green crab** is listed as an IAS, however, its import, transport, possession and release are not prohibited. It is simply subject to inspections (DORS 2015-21 regulation). In the United Kingdom, Chinese mitten crabs may be imported legally. In France, common slipper shells and the Japanese littleneck clam have no legal status and are not covered by any regulations.

Other species are more strictly regulated. In the United States, it is prohibited to import, transport and release **Asian carps** to the environment (Asian Carp Prevention and Control Act). The **Northern Snakehead** is listed as a pest in Maryland, Delaware, Virginia and Washington DC on the basis of the federal Lacey act, which prohibits the import, export and trade of the species between the States without authorisation (see Figure 48).

For fauna in general, most culling operations in the natural environment require an authorisation provided by the authorities (permission to capture, approval of traps, fishing and hunting permits, etc.). That is the case, for example, for Asian carps in the Great Lakes, the **Blue catfish** in Florida and the **Red swamp crayfish** in France. In other countries, the culling and sale of IASs is authorised, however, it is prohibited to release them to the natural environment. That is the case for **Signal crayfish** and **Red swamp crayfish** in the Netherlands (Koese, personal publication, in Delage, 2017).

Figure 48. Northern Snakeheads are listed as pests in some of the United States. © Brian Gratwicke

Regulations are not, however, always consistent within a given country. The U.K. illustrates this aspect well. Commercial fishing, the detention and the transport of Signal crayfish are legal in England, but not in Scotland or Wales. Regulations are not always consistent between neighbouring countries. For example, in Portugal, all commercial use (including the transport of live animals) of red swamp crayfish is strictly prohibited, but is authorised by the central government in Spain and is authorised in a limited number of cases in France. These inconsistencies in the regulatory frameworks can lead to illegal introductions and use of IASs.

In the EU, these differences between the Member States should fade over time in step with the implementation of European regulation 1143/2014 on the prevention and management of the introduction and spread of invasive alien species of Union concern. All the species listed as being of Union concern (Implementing regulation (EU) 2017/1263) are prohibited from sale in the Union, in addition to the prohibitions on their introduction in the natural environment, transport, detention, breeding and cultivation. All commercial projects for an IAS on the list must be authorised by the European Commission (article 9 in European regulation 1143/2014).

The regulations governing certain activities (fishing, hunting, etc.) are in some cases not well suited to IAS use in some projects. That is the case for the **Red lionfish** in certain Caribbean countries where its capture (spearfishing) is not only authorised, but encouraged, however only with snorkelling equipment. Unfortunately, the species is difficult to hunt and scuba equipment would be required for effective hunting (see Figure 49). As a result, the regulatory framework hinders any real efforts to capture the species. The Sun Coral project in Brazil also reported difficulties in identifying the cognizant State agencies in order to obtain the necessary authorisations for commercial operations. The Ecology ministry and the Fishing and Aquaculture ministry designated each other as responsible for granting the operating permits and marketing authorisations, which led to interruptions in the culling work, affecting the revenues of the local populations and finally hindering implementation of the existing regulations (Creed *et al.*, 2017).

Figure 49. Capture of a red lionfish in Saint-Martin. © RNN Saint-Martin

Awareness raising, information and training

Of the 39 surveyed projects, only twelve (30%) mentioned efforts to raise the awareness of the general public, involved persons and/or professional participants. This type of information is not easily obtained, except for projects consisting of incentive measures, which all include "awareness raising" efforts. Informational campaigns have been launched for commercial fisheries and the general public in the framework of the commercial project concerning the blue catfish in Virginia and the management plan for northern snakeheads in Maryland included an informational effort. Concerning plants, an information and awareness-raising section is included in the commercial projects for alien mimosas in Southeast Asia (FORIS programme).

Some projects organise training courses and awareness-raising sessions. An example is the commercial project for Typha in Senegal and Mauritania. Mention is also made of training courses resulting in professional certifications, for example the management programme for Asian carps in the Great Lakes. The training for professional fishermen includes techniques on how to handle Asian carps without danger, information on administrative aspects (permits), management of a commercial fishing fleet, collection of production data and its transfer to other groups of project participants, etc.

The Sun Coral project in Brazil has clearly defined objectives concerning raising awareness of biological invasions and environmental issues. Over the period 2006 to 2016, 289 interventions to raise awareness were carried out (in schools, training for environmental technicians, videos, posters, brochures, stands at public events, guided visits, workshops, etc.), informing over 143 000 people (Creed *et al.*, 2017).

The FORIS programme organised training sessions for students in Cambodia (see Figure 50). The main objective was to raise awareness concerning the issues involved in biological invasions and to teach management techniques for Mimosa pigra. A total of 389 students participated in the training sessions in 2016 (FORIS, 2016). Training programmes for fisheries were also mentioned in the framework of the commercial project for Red swamp crayfish in France (Stolzenberg, 2016).

Risks mentioned by the contacted experts

The experts contacted during the preliminary study carried out by IOWater expressed numerous concerns about economic uses of IASs. A few examples are presented next page.

Public Awareness Raising on IAS

To fulfil the objectives of Component 3: National Capacity Building and Institutional Support, and Component 5: Information and Awareness Programme, during the No-Cost Extension, the FORIS Cambodia Project team provided successive trainings at private universities in provinces surrounding the Tonle Sap Lake comprising Kampong Chhnang, Pursat, Kampong Thom and Siem Reap in June 2016. The 4-province trainings gathered 389 participants (with 200 females). The purpose of the training is to increase and promote public awareness particularly university students and teachers, and government staff at provincial levels on the aspect of IAS management particularly the target Mimosa pigra. FORIS Cambodia Project has applied a various combination techniques at the pilot site and shared the experiences with the participants. The training materials were produced and conducted based on the designed Training Modules and results of the Experimental Trial derived from the Pilot Site. Leaflets and posters were distributed to all participants, and Stand posters were also displayed during the courses. Questionnaire for pre and post assessment was designed and applied as well to measure the level of understanding of these university students and government staff.

Figure 50. Examples of training sessions in the framework of the FORIS programme. © FORIS

Arne Witt, CABI, coordinator of IAS programmes in Africa and Asia

> *By promoting invasives for utilization, you are creating a "perverse incentive" – you are trying to sell something that is inherently bad for the environment as something valuable and useful. Utilization can form part of an integrated management strategy, but on its own it is doomed to failure because the goal is not to deplete the resource."*

Stephanie Peay, School of Biology, Faculty of Biological Sciences, University of Leeds, U.K.

> *Regarding economic and social use [...] exploitation of signal crayfish [...] is regarded as one of the incentives for further illegal introductions. Studies have provided some evidence for compensatory growth of crayfish following depletion by trapping, together with evidence of influx from adjacent areas.*

Sonia Vanderhoeven, Belgian biodiversity platform

> *There is a major risk of creating needs exceeding what the management system can supply.*

Richard Shaw, CABI

> *Our experience is that commercial exploitation can be counter-productive if not very carefully managed.*

François Tron, Conservation International

> *Economic incentives to harvest invasive alien species may:*
> - *create movements in favour of dense and widely spread IAS populations, causing greater impacts on biodiversity and ecosystem services;*
> - *increase opposition by the public and industry to maintaining IAS populations at low abundance and impact levels;*
> - *contribute to social conflicts concerning access to the resource;*
> - *shift public environmental funding to commercial projects whose environmental impact has not been systematically assessed.*

Lennard Edsman, Swedish University of Agricultural Sciences

> *Scientific people in Sweden are not advocating commercialisation as a management option at all. They are against it. Reality has shown that it has promoted the spread and the negative effects, made things worse, rather than controlling the spread and decreasing negative effects.*

Bram Koese, Naturalis, the Netherlands

> *In the Netherlands, commercial fisheries takes place on two invasive crayfish (Procambarus clarkii and Procambarus acutus) and the Chinese mitten crab (Eriocheir sinensis). I don't think that the ecological benefits are the primary objective of both fisheries, although some fisherman would sell it that way.*

CONCLUSIONS OF THE ANALYSIS ON THE SURVEYED PROJECTS

In spite of the relatively high number of projects targeting IAS use presented here, their success in managing the species remains to be seen. The numerical data suggesting any success in limiting IAS population numbers is sparse at best. This finding echoes that presented by Pasko and Goldberg in 2014. The proposed and actually implemented scientific assessment methods are fewand far between. Projects with clearly stated recommendations and/or warnings concerning negative consequences are uncommon. At the same time, many experts have highlighted the risks and difficulties in implementing and managing projects.

In spite of the knowledge now available on the risks involved and the very small number of projects that have shown positive results, only a minority of current projects take into account the recommendations that have been made and fewer yet are part of a comprehensive strategy for IAS management (see Table 4).

A number of positive aspects may, however, be noted, particularly the large percentage of projects involving numerous partners, notably national governments, economic players and research institutes, and the efforts to raise awareness of IAS issues that are now part of many of the most recent projects.

The analysis must distinguish between projects consisting essentially of incentive measures and those targeting commercial activities. The main promoters in the former are public institutions, in a partnership with research organisations, citizen's groups and local governments. These incentive projects are components in comprehensive management strategies, have strictly ecological objectives, include efforts to raise awareness and are monitored (though some of the data could be collected more regularly). The ecological benefits of a majority of the incentive projects are not particularly evident, however the environmental risks involved are far less serious than those for commercial projects.

The participation of State services and researchers in planning and formulating the objectives of projects would appear to play an essential role in reducing as much as possible the environmental impact of all types of projects targeting IAS use, i.e. both incentive projects and commercial projects.

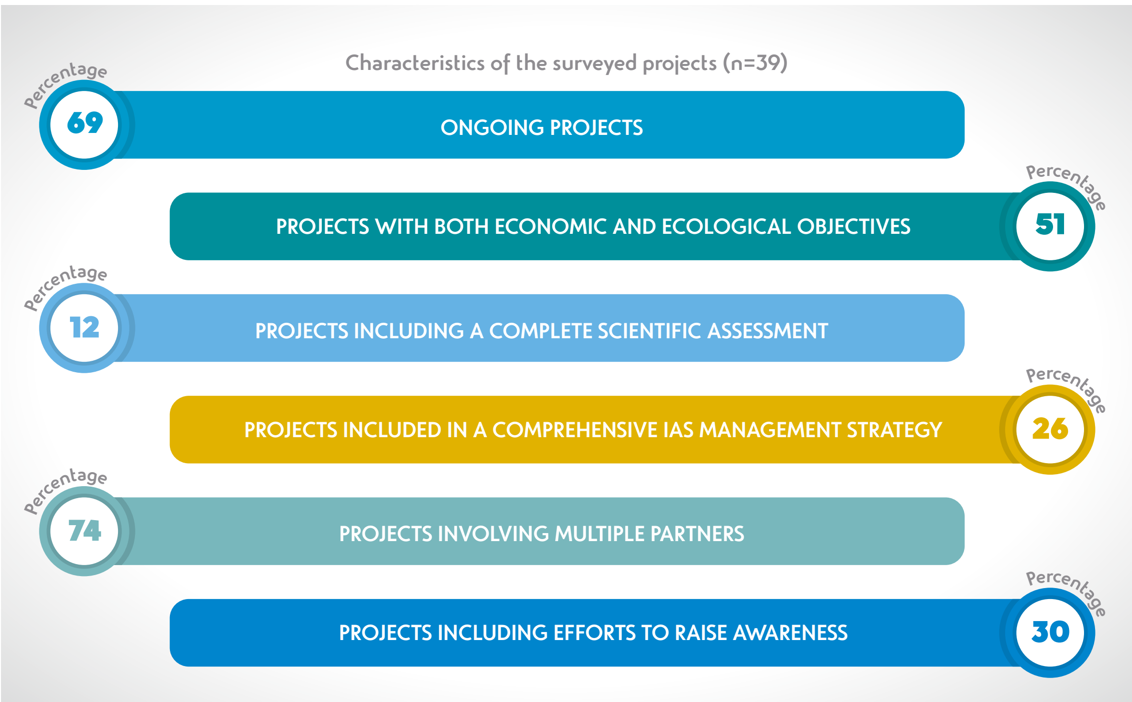


Tableau 4. Summary of some of the information drawn from the analysis of the surveyed projects.

Water hyacinth (*Eichhornia crassipes*) and water cabbage (*Pistia stratiotes*) are two species of floating, aquatic plants. Their attractive appearance is the main cause of their dissemination across the planet. They are considered invasive in most of the French overseas territories (a colony is shown here in the town of Saint-Gilles les Bains on Réunion Island). © G. Peltre

The two species have been observed sporadically in certain natural environments in continental France, however they rarely resist winter conditions. Prudent policy would dictate special surveillance of the two species and interventions to manage any colonies that may develop during the summer (shown here is water hyacinth observed in 1998 in a shallow body of water in the Golf of Seignosse (Landes department) © A. Dutartre and colonisation of the Rhône side-canal by water cabbage in 2016 (Gard department). © J.-P. Reygrobellet, SMAGE

Management of water primrose in the Brière regional nature park. © L. Bélier

Points requiring attention and proposal of a framework for project design

The observed effects and the need to manage IASs are a source of significant difficulties for stakeholders in territories confronted with the problem. Over the last few years, advances in scientific knowledge have contributed significantly to better understanding invasions, to better assessing their impacts and to designing corrective measures, however, numerous difficulties, ecological, economic and political, remain.

Widely established and locally abundant IASs constitute large quantities of available and renewable biomass. For this reason, they are in some cases seen as a new, exploitable resource and a potential source of economic profits. Commercial IAS projects are often presented as a win-win solution offering both ecological and economic benefits. The many examples presented here show that though there may be economic benefits in some cases, the ecological benefits are almost never assessed and the numerical data on the rare successes are extremely limited. On the other hand, a wide array of unwanted, negative effects run counter to the management objectives for the target species and, more generally, to the objectives of territorial strategies for IAS management.

These negative effects include:

- an increase in the risks of species dispersal and accidental introduction (escape during transport) and/or intentional introduction (targeting an increase in the abundance of the IAS in the natural environment or even breeding/cultivation of the species);
- impacts on non-targeted species and transmission of pathologies;
- efforts to maintain IAS populations in view of increasing profits and ensuring access to the resource;
- confusion between the commercial value and the patrimonial value of species, resulting in counter-productive situations for IAS management (misleading information targeting the general public and creating a positive image of the species) and in conflicts of interest;
- privatizing profits and socializing the costs incurred by IAS management;
- creation of economic dependence on the resource.

The analysis of the surveyed projects presented here shows that commercial uses of IASs do not represent a panacea for the difficulties in managing biological invasions. To minimise the risk of failure, commercial IAS projects must be part of a comprehensive management strategy based on clear ecological objectives and necessarily including efforts to prevent introductions in the natural environment, surveillance measures, data acquisition and the mobilisation of all stakeholders in IAS issues.

Asian knotweed is useful for agricultural purposes (composting and methanisation) and for the pharmaceutical industry (extraction of resveratrol). © J.-P. Reygrobellet, SMAGE

In spite of the considerable risks involved, proposals for commercial IAS projects continue to be made in France and in numerous other countries. They are presented as local opportunities for certain socio-professional categories confronted with economic difficulties. In the years to come, this type of proposal will likely increase in number and the projects will target an increasing spectrum of IASs, most of which are not regulated. It is highly probable that some of those projects will be poorly designed and may even cause unforeseen environmental harm and damage to biodiversity.

To date, preventive measures (an environmental assessment tailored to the identified risks of dispersal to the natural environment) are required by European regulation 1143/2014[9] before initiating a commercial IAS project. However, this recent environmental regulation would appear to be virtually unknown and rarely observed by project managers. In addition, the public authorities do not enforce it and do not run inspections. What is more, it applies to a very small number of species, i.e. the 49 species on the European list last updated in 2017.

For all the above reasons, the potential consequences of such projects for the environment have not been identified and virtually no sources of information are currently available for decision-makers and stakeholders. That is why a framework would appear necessary to **correctly identify the issues and risks of commercial IAS projects**, prior to their launch, to ensure that they do not harm the environment.

The purpose of the analytical framework proposed here is to provide technical assistance to all organisations required to produce an opinion on an IAS project. It should not be seen as a rigid, step-by-step procedure, but rather as a guide for study on the issues raised by projects, by identifying points requiring attention in order to avoid significant risks for the environment and to ensure a rigorous assessment of the ecological benefits.

This framework consists of a series of issues and the corresponding points requiring attention concerning:

- the available knowledge on the species targeted by the project;
- formulation of the project objectives and its integration in a comprehensive strategy for IAS management;
- identification and forward-planning of risks, and the ecological assessment of the project;
- the collaboration of multiple stakeholders and the selection of partners.

Awareness of the points requiring attention achieved by analysing this series of issues should make it possible to produce a detailed and reasoned opinion on a project. The delivered opinion may include requests for additional information on the overall design of the project, its objectives, the justifications presented and/or the actual operating conditions of the future project, in order to fill out an initial assessment.

In its current form, the framework presented on the following pages **does not constitute a simple method to quantify the quality of a project based on the identified points requiring attention**. This is because the potential diversity of projects is so great, in addition to the diversity of local situations in which commercial projects may be undertaken, that it would be difficult, even imprudent, to propose a quantification method that would necessarily impose excessive simplification. It is up to each organisation producing an opinion to prioritise the various criteria listed here on the basis of the available knowledge of the local area, the situation created by the IAS and the issues involved in its commercial use in the framework of the given project.

9 • Article 9.4.f.g.h European regulation (EU) 1143/2014 (22 October 2014); article R .411-40 §II / 6° French Environmental Code, resulting from decree 2017-595 (21 April 2017).

ISSUES AND POINTS REQUIRING ATTENTION

1 KNOWLEDGE ON THE SPECIES TARGETED BY THE PROJECT

Is the species both alien and invasive?

- If the species is already listed as alien and invasive in the area targeted by the project, then it definitely falls under the analysis proposed here. If the species is not alien, then the project should be analysed using a different framework.
- If the species is not considered alien and invasive in the area targeted by the project, but it is in a nearby or adjacent territory (e.g. a neighbouring river basin or country, or a close biogeographic region), it is likely to become alien and invasive in the target area. In this case, the best management strategy for the area is to analyse the risks and to intervene as early as possible to limit the spread of the species or even to eradicate it

What is the distribution and abundance of the species in the area targeted by the project?

- Knowledge on the range of the species in the project territory is the indispensable starting point in determining the viability of the project and the basis for later assessments of its results. The precision of any data provided in the project documents on the distribution of the species with respect to all the available data may represent a favourable factor in analysing the project. If the species is established in high densities and it is easy to trap or gather, the commercial use of the species may represent a worthwhile management technique.
- If, however, the species is widely established, but with low densities, a commercial project will be difficult to set up and rarely profitable. If the species is established only in certain spots and in low densities, a commercial project, whose profitability is based on obtaining large quantities of the species, will not achieve its objectives and will not constitute an effective management technique. In this case, it is highly doubtful that a commercial project is a viable solution.

Is it easy to identify the species?

- If the species is difficult to identify by people in the field (for example, it requires an expert opinion or a genetic analysis), there is a major risk of confusion with native species whose populations may be endangered by a commercial project.
- If the species is easy to identify and cannot be confused with a native species, the risk of confusion is lower and inspections on project operations are easier.
- Identification of the species by the environmental police is clearly necessary for all inspections on the project site, during transportation and at the point of sale (stores, etc.). If identification of the species is difficult, the inspection personnel have not been trained or there is a chance of misidentification with a native species, there is a high risk of non-observance of the traceability and detention conditions, and a risk of illegal operations (e.g. use of a native species). In this case, the project managers may be required to obtain certified means of identification that can be presented during inspections and thus confirm the compliance of the inspected goods with the legal requirements.

Is the species found on sites that are difficult to access or on private property?

- If that is the case, the project will encounter difficulties in accessing the resource and/or may disturb or cause damage in preserved areas. The operations will take place only in the areas where the resource can be culled and transported, which means that the objective of reducing the population over the entire range of the species will not be reached. If access is easy, that would represent a favourable factor for the viability of the project.
- If the species is present on private property, the necessary operating permits may not be granted and culling will not be possible over the entire target area. However, if the project lists the precise means of obtaining the necessary permits for the private property, that would represent a favourable factor for the viability of the project. In the absence of the permits, it will not be possible to reduce the population numbers in line with the objectives and the species may reoccupy the exploited areas by migrating from those not covered by the project.

To what degree is the species capable of dispersal?

- Kowledge on the dispersal capabilities of the species is critical in determining the risk of dispersal created by commercial IAS projects. The level of risk rises in step with the dispersal capabilities of the species (that are directly correlated with its reproductive mode and capabilities) and the measures required to mitigate dispersal also become increasingly difficult to implement. The risk is increased even further when the target species is present in a biotope offering numerous ecological connections (e.g. areas with continuous plant cover, wetlands, rivers, etc.).
- If the risks of dispersal are high, it is necessary to ensure that each step in operations (capture, transport, transformation, storage, transport to point of sale, storage and transfer to the final place of use) does not increase the risks of dispersal and that the confinement measures are suitably implemented at each step.

Has study been put into the population dynamics of the target population?

- Knowledge on the population dynamics of the species (fecundity, age of sexual maturity, mortality rates, population strategy, etc.) is indispensable in view of setting up a culling strategy capable of meeting the set ecological objectives. Insufficient culling pressure on only a part of the population (e.g. the largest specimens or a single stage in the reproductive cycle) or a part of each specimen (a part of a plant) may not have any effect on the population dynamics or may even stimulate the growth of the population (biological overcompensation). Commercial operations may consequently have no effect on the population of the target IAS or even be counter-productive..

Is the target IAS a carrier of parasites and/or pathogens?

- If the species is a potential carrier of parasites and/or pathogens, its commercial use may increase the dispersal of the latter and consequently seriously impact ecosystems. If there is a clear risk, prophylactic measures are required at each step in operations. If prophylactic measures are not taken, project operations will, in all likelihood, increase the prevalence of parasites and/or pathogens.
- Analysis of the health risks raised by the target species is a prerequisite for all commercial projects.

2 PROJECT OBJECTIVES AND INTEGRATION IN A COMPREHENSIVE MANAGEMENT STRATEGY

Has a market study been carried out for the project?

- A market study provides information on the project viability and profitability, and on the factors that can impact the project. For a commercial IAS project, the study must also supply reasoned arguments justifying the selected economic model (products, transformation methods, distribution circuits, etc.) and how it can reduce the ecological risks of the project. In the absence of a market study, there is no guarantee concerning the economic viability of the project and consequently a risk of economic failure, of insufficient species management and even of its increased dispersal.

Does an "exit strategy" exist for the project?

- In that the main objective must be the reduction in the population numbers of the target species, the project must have identified and anticipated the consequences of that reduction in the area covered by the project. An end to the project must be anticipated and an exit strategy is required to adapt to the reduced profitability that will necessarily occur when the ecological objectives have been reached. Other profitable activities must have been identified before the launch of the project in order to compensate for the reduction in the target resource. In their absence, there is a high risk of economic dependence, of efforts to maintain the IAS population and of IAS dispersal. The project initiators should, in some cases, present the exit strategy in detail before proceeding with the project.

Have the implementation costs of the project been assessed?

- It is necessary to compare the costs and benefits of a commercial project with those of more standard management techniques. A cost-benefit analysis, which consists of comparing the project costs with its potential benefits, may be an extremely useful element in the overall assessment of the project and should, in some cases, be required of the project initiators. If a cost-benefit analysis is run, it must include the gains and losses for the natural environment, factors that are rarely taken into account in evaluating marketable goods and services, notably because they are more difficult to calculate. In order to obtain correct results from the cost-benefit analysis, it is necessary first to have identified the environmental, health, economic and social risks involved in the project.
- If the costs of the project are greater than for standard management techniques and/or the results of the cost-benefit analysis are not favourable, the viability of a commercial project must be questioned.

Have the project objectives been clearly expressed?

- It is essential that the ecological objectives (a reduction in the population of the target IAS, an improvement in the biological diversity of the local environment, etc.) be sincere, realistic and a central priority of the project.
- If the objectives of a commercial project focus on the potential economic benefits or if the ecological objectives are mentioned, but imprecisely and in little detail, the project will produce few or even no environmental benefits and will not serve as a means to manage the population of the target IAS.

Is the commercial project part of a comprehensive management strategy?

- A comprehensive management strategy is required to reach the objective of reducing the target IAS population. That objective cannot be reached by a commercial project alone. It is necessary to integrate the project in a larger, multifaceted strategy set up in collaboration with an array of partners and consisting of preventive work, monitoring, regulation and awareness raising in order to enhance the ecological functioning of the environment and reduce the risks of damage to it by the project.
- In the absence of an effective and comprehensive management strategy, the objective of the project becomes personal and opportunistic economic gain.

Does the project include training and efforts to raise awareness?

- Training of employees and informing on IAS issues are important means to prevent biological invasions, i.e. intentional or accidental introductions and dispersals, transmission of pathogens, etc. Operational personnel should be trained on implementing specific biosecurity measures during the work, e.g. decontamination and cleaning of equipment, confinement of specimens, identification of batches, etc., which all serve to reduce the corresponding risks. In their absence, the potential risks for the environment are greater.

Does the project include a charter of good practices?

- A charter of good practices, drafted with all the participating stakeholders (private companies, State services, managers of natural areas, local governments, etc.), formally lists the rules required to ensure smooth operations and to achieve the ecological objectives of the project, while limiting the risks for the environment. It is binding on the project managers and on the other participants in the commercial activity (transporters, transformers, resellers, etc.). Non-compliance with the charter may result in the rescindment of the operating permits.

3 IDENTIFICATION AND FORWARD-PLANNING OF RISKS, AND THE ECOLOGICAL ASSESSMENT OF THE PROJECT

Have the potential negative consequences of the project been identified and are the necessary means available to counteract them?

- The potential negative consequences (ecological, economic, health) of the commercial project must be clearly identified. Identification must address all aspects, both potential and certain, temporary and permanent, of the entire project (all operations, all geographic sectors, from culling in the field to the final sale, including transportation and transformation) and must be included in the project documents prior to the launch of operations.
- The means required to foresee and limit the identified consequences must be available to ensure that the project avoids harming the environment and produces positive ecological results. If negative ecological consequences are known to exist but are not mentioned in the project documents or are not addressed in detail, and no means are proposed to counteract them, the sincerity of the ecological objectives of the project is doubtful and the risk of serious ecological consequences is high.

Is there a risk of the IAS dispersing beyond the area covered by the project?

- If there is a past history of the species being intentionally dispersed by humans (fishing, hunting, etc.), the risks are high and increase even further if the species has commercial value. In addition, if the species is transported live to the processing site or is sold live, or if its release to aquatic environments is authorised, the risk of dispersal and/or of intentional/accidental introduction is high. For plants, care must be taken to avoid the dispersal of propagules (seeds or plant fragments that can develop into a new plant).
- The risk of plants spreading is even higher in areas close to the project that have not yet been colonised by the species. The potential consequences are even worse if the nearby areas contain threatened native species.
- The pathogens and parasites potentially carried by the IAS must be taken into account when analysing the dispersal risks.

Are the culling sites for the target IAS precisely identified?

- A precise geographic description of the culling sites, including lot numbers in the Land Register, is essential in order to delimit the project area and later assess the effectiveness of operations.
- Inclusion of the Land Register data in an official document (e.g. the prefectoral authorisation) makes it possible to check that the work is effectively done on the designated project sites, that no illegal operations are undertaken and that all project sites are culled in compliance with the culling plan contained in the project documents.
- In order to avoid any risk of dispersal, the project area should be limited to the range of the IAS.

Do project operations endanger the conservation status of native species and/or of the natural environment?

- All environmental impacts of project operations must be taken into account. For example, sustained trapping work, due to the presence of humans and the passage of vehicles, could disturb the local fauna (during periods of reproduction, nest building or rest, etc.), modify the environment (compact soil, increase the turbidity of aquatic environments, etc.) and have negative consequences for the natives species in general.
- If culling methods (trapping, capture, harvesting) are not selective, there is a risk of capturing non-targeted species that may already be threatened and consequently of harming biodiversity. If alternative techniques are proposed to limit this risk, those techniques must have been subjected to a scientific assessment to ensure that they result in a significant reduction of the problem. The assessment must be impartial, i.e. all protocols, operations, analyses and conclusions must be validated or at least examined by a group of independent experts.
- In all cases, it is necessary to ensure that all fishing equipment and periods comply with the applicable regulations.

Does the project include measures to confine the target IAS, to prevent its dispersal and to ensure its traceability?

- These measures are required to prevent the dispersal risks inherent in commercial IAS projects. Their absence may lead to a lack of foresight and planning, and consequently to an increase in the dispersal risks and to failure of the ecological objectives of the project. Rigorous measures must be implemented in the field and at each step in operations (transformation, storage, transport) from start to end of the project. Their absence may result in the refusal to grant the operating permits.
- If the IAS is transported live, the risks of dispersal and/or of intentional/accidental introduction increase with the distance between the culling site and the storage/transformation/conditioning site(s). All the above sites should be listed in official documents (prefectoral authorisations) prior to the start of operations (particularly transport and sale).
- If no standards are mentioned in the project documents concerning the confinement conditions on the storage, transformation and conditioning sites, there is an increased risk of dispersal and inspections are more difficult.
- Measures to identify and/or trace individual IASs or batches make it possible to effectively monitor the operations of commercial projects. The applicable standards should be mentioned in the official documents and require certain data (contact information of the project manager, routes used, batch numbers, culling dates and location, quantities, number of packages, etc.).

ISSUES AND POINTS REQUIRING ATTENTION

Does the project include the means to disinfect and clean equipment in order to avoid dispersal of the IAS and of diseases?

- Effective use of disinfection protocols for equipment reduces the risk of accidental dispersal of the species, of other organisms and of pathogens. If disinfection and cleaning protocols are not proposed, the project promoters are not sufficiently aware of the risk of dispersal and irreversible, negative impacts on the environment may occur.

In the framework of the project, do the culling efforts targeting the species address the entire population (all individuals)?

- Studies on the type and degree of culling required to reduce the IAS population are a key factor in preparing a culling strategy capable of attaining the management objectives set for the project. If the culling effort bears on a single age class or size, on a single sex or specific stage of development or reproduction, the work may fail to meet the objectives and even result in biological overcompensation.
- This risk of biological overcompensation is even greater if overcompensation has already been observed in the target species or taxonomically similar species.
- Concerning plants, if culling targets only a part of the organism, propagules left on site may enable the regrowth of the IAS population and consequently result in the failure of the management objectives.
- A clearly formulated culling strategy should exist before operating permits are granted.

Will the potential ecological consequences be scientifically assessed during the project?

- A scientific assessment and regular publication of information during the project (culling data, range monitoring of the target species, population dynamics of non-targeted species and particularly those impacted by the IAS, etc.) make it possible to monitor progress toward achieving the ecological objectives and determine whether to renew the operating permits.
- The scientific assessment must be based on rigorous monitoring techniques and protocols. To ensure their effectiveness and reliability, those techniques and protocols must be established and implemented by qualified organisations not linked to the project initiator.
- If the ecological consequences have not been identified and a scientific assessment is not proposed as part of the project, it will be impossible to check that the ecological objectives are met (or that there are no negative impacts) and the project will produce purely economic benefits (if it has been correctly calibrated).

4 COLLABORATION OF MULTIPLE STAKEHOLDERS AND PARTNERS

Does the project involve an array of partners?

- Bringing in all the stakeholders in IAS management, including State services, public agencies, managers of natural areas, researchers, local governments, etc., makes it possible to monitor the benefits, risks and progress toward the ecological objectives of the commercial project. If the project is being promoted by a single entity or by partners having exclusively commercial objectives, the ecological objectives are likely to be rather secondary and may not be taken into account at all.

Does the project include among its partners research organisations with know-how in biology and ecology, or in scientific fields using socio-economic analysis?

- Scientific participants (e.g. university researchers), brought in as independent partners, can provide valuable assistance by:
  - carrying out preliminary studies on the biology and population dynamics of the target species;
  - setting up the culling and monitoring protocols required to correctly assess the ecological effectiveness of the project;
  - assessing the positive and negative effects of the commercial operations on communities of non-targeted species;
  - participating in the socio-economic assessments of the project.
- The lack of scientific partners in a project enhances the risks of poorly defining the ecological objectives and the culling strategy, and of the ecological assessment being insufficient or totally absent.

Have the State services been contacted and their assistance requested?

- This type of project requires input from the State services in charge of biodiversity and all applicable regulations (Departmental Territorial Directorates, French Biodiversity Agency, National Agency for Hunting and Wildlife, etc.). They can check to ensure that the project complies with regulations and that it does not run counter to environmental policies and strategies on the local, national and international levels.

ANNEXES

Analysis method for the project survey

To assess the advantages and risks of IAS use as a means of species management, an initial phase of the work consisted of a survey of documented projects. The results of the survey were used in drafting this report. The International Office for Water, in a partnership with the French Biodiversity Agency, was selected to conduct the survey.

The objective was to find documented examples of IAS uses, primarily concerning aquatic species, in France, Europe and other industrialised countries. Specific examples of terrestrial species and projects in emerging countries were also included to fill out the analysis. Examples of incentive measures not targeting a commercial benefit (incentives for culling and capture bounties) were included in order to compare the two types of approach to IASs.

The following elements of information were sought for each of the projects in the survey:

- the project context;
- the positive results;
- the negative consequences;
- the risks of attempting to use aquatic IASs, for both the natural environment and the project initiators.

A review of the literature and inquiries to resource persons and both European and international experts provided the necessary information. Many of these people had already been identified by the National Work Group on Biological Invasions in Aquatic Environments (IBMA) and several had been contacted in 2014 and 2015 for the study titled Strategies of European countries for aquatic IASs[10] (in French), run by IOWater, in collaboration IBMA and the French Biodiversity Agency. Other contacts (authors, experts mentioned in studies, etc.) were identified progressively as the incoming information was processed.

Each person was contacted by email. The context and the objectives of the survey were presented and a number of questions were raised concerning the existence of projects to use IASs in the person's country, the effects on IAS populations, the methods employed to inspect the operations of IAS projects, the role played by research organisations and State services, and finally the monitoring systems used to assess the positive and negative impacts on ecosystems.

The information collected was subsequently organised in "project fact sheets" presenting each of the surveyed projects with the available information on:

- the target IAS;
- the local area;
- the problems caused by the species;
- the type, objectives and role (primary or secondary) of the IAS project in managing the population of the species;
- the context of the IAS project;
- the project initiator(s)/manager(s);
- the applicable regulatory framework (if it exists);
- the positive and negative consequences (economic, social and ecological) of the project.

Not all of the above elements were available for each of the surveyed projects.

The bibliographical review and the international survey collected information on 25 projects targeting the use of 18 IASs in 18 countries. Using the available information, 20 "project fact sheets" could be drafted.

Another 14 IAS projects filled out the survey by IOWater and are mentioned in this report. Consequently, a total of 39 projects served for the preparation of this report.

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MAIN ABBREVIATIONS

AFB: French Biodiversity Agency

APICAN: Agency for the Prevention and Compensation of Agricultural and Natural Catastrophes (New Caledonia)

CABI: Centre for Agricultural Bioscience International

CEN: Nature Conservatory (France)

CNRS: National Scientific Research Centre (France)

CONAPPED: National Committee for Freshwater Commercial Fisheries (France)

DAISIE: Delivering Alien Invasive Species Inventories for Europe

DDE: Dichlorodiphenyldichloroethylene

DDT: Dichlorodiphenyltrichloroethane

DDT: Departmental Territorial Agency (France)

DEFRA: Department for Environment, Food & Rural Affairs (U.K.)

DREAL: Regional Environmental Directorate (France)

EIFAC: European Inland Fisheries Advisory Commission

EU: European Union

FDGDON: Departmental Federation of Pest-Control Groups (France)

FORIS: Removing Barriers to Invasive Species Management in Production and Protection Forest in South-east Asia

FREDON: Regional Federation of Pest-Control Groups (France)

HCB: Hexachlorobenzene

HCH: Gamma-hexachlorocyclohexane

IAS: Invasive alien species

IBMA: National Work Group on Biological Invasions in Aquatic Environments (France)

Ifremer: French Research Institute for Exploitation of the Sea

IOWater: International Office for Water

IUCN: International Union for the Conservation of Nature

NGO: Non-governmental organisation

NOAA: National Oceanic and Atmospheric Administration (U.S.)

ONCFS: National Agency for Hunting and Wildlife (France)

Onema: National Agency for Water and Aquatic Environments (France)

PCB: Polychlorinated biphenyls

RNN: National nature reserve (France)

DEFINITIONS

Containment: Any effort to create barriers intended to significantly reduce the risks that the population of an invasive alien species might disperse and propagate beyond the invaded area.

Introduction: The transfer, initiated by humans, of a species outside of its natural range, by transporting any part of the species capable of surviving and subsequently reproducing (gametes, seeds, spores, eggs or other propagules). The transfer may occur within the borders of a single country or beyond. An "intentional introduction" takes place on purpose, targeting a specific objective (agriculture, forestry, livestock farming, ecological restoration, biological control, hunting, fishing, recreational activities, etc.). An "unintentional introduction" takes place by accident, through human activities, e.g. via maritime or air transport, ballast water in ships, etc.).

Invasive alien species (IAS): A non-native species whose introduction or spread represents a threat to or has a negative impact on biodiversity and the related ecosystem services.

Native species: A species naturally present in a given territory.

Invasive alien species (IAS) are acknowledged as one of the main causes of biodiversity loss worldwide. Due to their multiple impacts, these species threaten native species, natural habitats and the services provided by ecosystems, and can also harm economic activities and human health.

They create major problems for the areas where they are introduced, given the steadily increasing introduction rates, the constant and complex management policies required and the significant costs to taxpayers. On the other hand, when they have become established in natural environments, IASs can in some cases be seen as marketable resources, e.g. fish species, wood products, compounds for the pharmaceutical industry, etc.

Commercial uses of IASs are not, however, without risks for natural environments and they raise an array of questions concerning their potential consequences. A number of these questions concern the increased risks of dispersal of the target IAS and efforts to maintain IAS populations in colonised areas once the species have become a commercial item.

This study, carried out by the National Work Group on Biological Invasions in Aquatic Environments (IBMA), under the supervision of the IUCN French committee and the French Biodiversity Agency, comprises a wide array of examples and reviews the issues and risks involved in attempting to commercially exploit invasive alien species established in natural environments. An analytical framework and points requiring attention are also provided to assist organisations called upon to produce an opinion on projects involving the use of IASs, notably State services and local governments.

With the support of:

IUCN French Committee

GT IBMA
FRENCH NATIONAL WORK GROUP
for biological invasions in aquatic environments

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