ONEMA
The National Agency for Water and Aquatic Environments

Knowledge for action

Invasive alien species in aquatic environments

Practical information and management insights

Vol. 1 Practical information

Emmanuelle Sarat, Emilie Mazaubert,
Alain Dutartre, Nicolas Poulet
and Yohann Soubeyran (editors)

N°17

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RÉPUBLIQUE FRANÇAISE
Ministère de l'Écologie, du Développement durable et de l'Énergie

The French National Agency for Water and Aquatic Environments

Onema is a public agency operating under the supervision of the Ecology ministry. It was created by the 2006 Water law and launched in April 2007. Onema is the principle technical organisation in France in charge of developing knowledge on the ecology of aquatic environments and monitoring water status. Its mission is to contribute to comprehensive and sustainable management of water resources and aquatic ecosystems. The agency contributes to restoring water quality and attaining the goal of good chemical and ecological status, the objective set by the European water framework directive. Onema, with a workforce of 900, is present throughout continental France as well as in the overseas territories in the framework of the national interbasin solidarity policy. In carrying out its mission, Onema works closely with all stakeholders in the water sector.

The French committee of the International union for the conservation of nature

The French committee constitutes the network of French organisations and experts working for the IUCN and serves as a knowledge base and platform for discussion on biodiversity issues. This novel partnership comprises two ministries, 13 public organisations, 41 NGOs and over 250 experts grouped in special commissions and topical work groups. The committee addresses biodiversity issues in France and promotes French research and know-how internationally.

The IBMA work group

This book was drafted by the Biological invasions in aquatic environments (IBMA) work group that Onema and Cemagref (now Irstea) launched jointly in 2009. Its mission is to assist all water stakeholders working on the topic of invasive alien species (IAS) by facilitating access to new knowledge on IASs and developing management tools. Since 2014, the work group has been managed by the IUCN French committee and Onema.

This book continues the ***Knowledge for action*** series that makes new research findings and science-advice work available to professionals in the water and aquatic-environment sector (scientists, engineers, managers, instructors, students, etc.).

The book is available on the Onema site (www.onema.fr), in the Resources section, on the IBMA site (www.gt-ibma.eu) and at the national portal for "Water technical documents" (www.documentation.eaufrance.fr).

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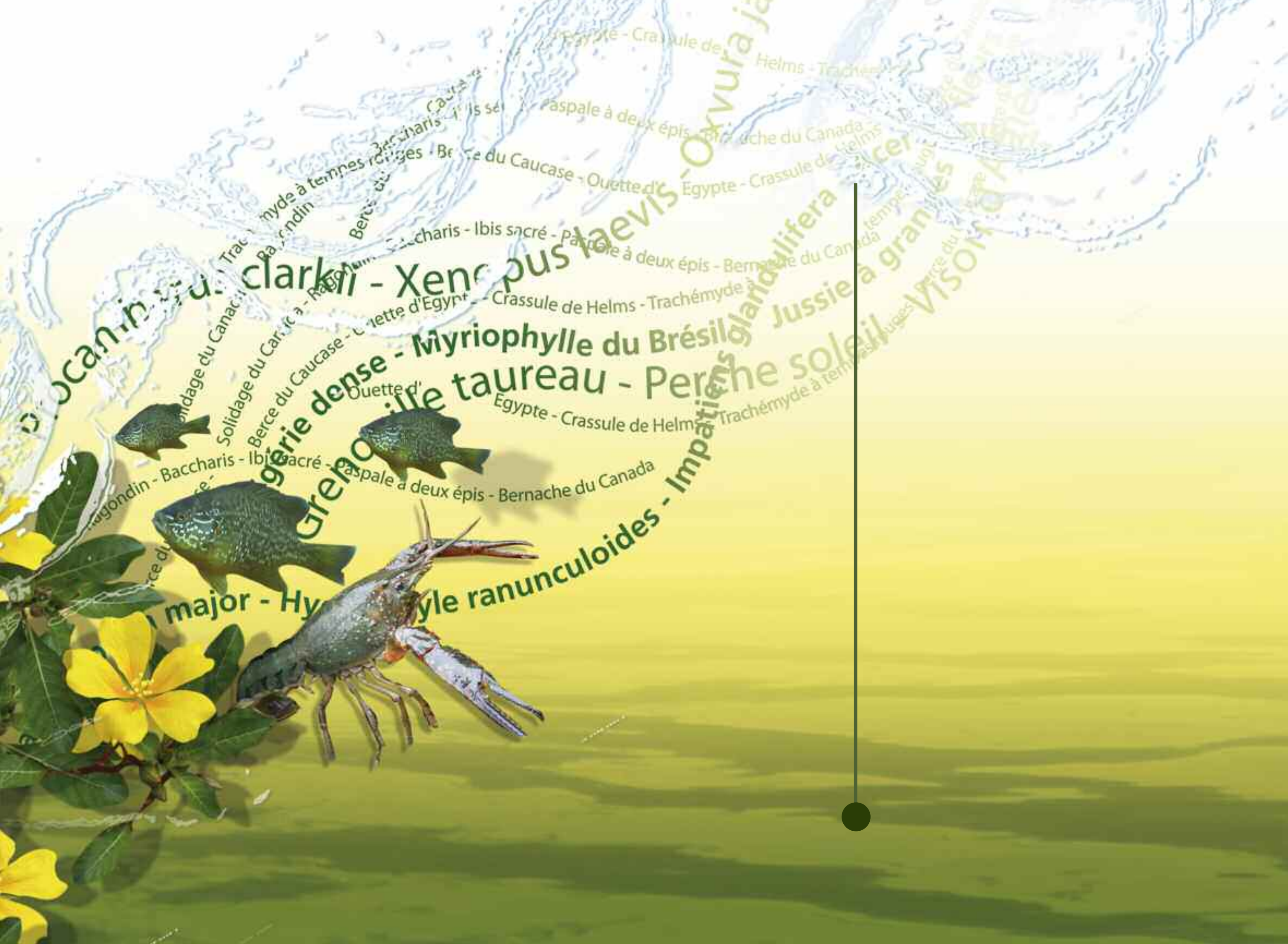

We wish to salute two colleagues who passed away in 2013, two valiant defenders of biodiversity whose work and research on biological invasions continues to help us to progress to this day.

Robert Barbault, a great promoter of convergence among disciplines involving biodiversity and the highly productive president of the scientific council for the INVABIO research programme, who was one of the initiators of this book. "*...If we could accept to think differently, i.e. look at the world in ecological terms, the hope of reconciling humans with nature might cease to appear utopian.*"

Michel Pascal, tireless traveller and unconventional researcher, nicknamed Ratator thanks to his innumerable island forays to attack ravenous alien rodent populations, even though they had never done him any particular harm. "*I am criticised as a jack of all trades. But that is precisely what I want to be, with a very broad knowledge base in order to better understand this world we live in.*"

Foreword

Invasive alien species (IAS) are acknowledged as one of the main causes of biodiversity loss worldwide. This issue is so important that the Convention on biological diversity decided to include it among its major lines of work 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 invasive alien species a major objective and a new regulation on preventing and managing their introduction and propagation was recently voted and entered into force in the beginning of 2015.

France as well is confronted with the situation and there are many examples in aquatic environments of both plants (water primrose, knotweed, etc.) and animals (crayfish, coypu, etc.). These species enter into competition with native species, modify the functioning of natural habitats and the services provided by ecosystems, affect economic activities and can even undermine human health. These problems have become one of the major concerns for the managers of natural areas and for policy makers, and the numerous media reports over several years have even begun to evoke regular echoes among the general public.

Over the past 15 years, a growing number of managers in areas spanning highly diverse administrative and geographic scales have entered the fray in an attempt to overcome the difficulties created by invasive alien species. Specific needs rapidly became apparent in terms of coordinating work, organising monitoring, assessing the impacts, establishing research programmes, defining strategies and producing effective results. This led to the creation of local work groups attempting to coordinate the many aspects of the overall problem.

It was in this context that the national Biological invasions in aquatic environments (IBMA) work group was created. Since 2009, the group has brought together over 40 people representing an array of stakeholders (managers of natural areas, researchers, associations, public organisations, State services and local governments) to set up and run various projects. Intended primarily for managers, the objective of the projects is to contribute, to date in continental France, to the development of information networks on all the issues raised by invasive alien species in aquatic environments, notably by making available the knowledge gained on these species. The IBMA internet site is an effective means of disseminating information. Management of the work group, initially assumed by a partnership between Onema and Cemagref (now Irstea), shifted to Onema and the IUCN French committee in January 2014.

The IUCN French committee has two main projects concerning invasive alien species, the first was launched in 2005 in the French overseas territories and the second consists of managing the IBMA work group with Onema. The committee also acts as a liaison with the IUCN on the international level and is in close contact with its Invasive species specialist group (ISSG) that provides data to assist in formulating the major international agreements.

Work at Onema on invasive alien species takes place on two levels, the first being financial and technical support for research projects to develop operational knowledge for IAS management. An example is the programme for the Louisiana crayfish in a partnership with INRA, CNRS and the Brière regional nature park, which resulted in the first national symposium on invasive crayfish and in publications presenting background information. On the second level, Onema provides its know-how to State services and to the Ecology ministry on issues concerning regulations and the management of invasive alien species, examples being Wels catfish, Asian carp and crayfish.

The objective of these two volumes in the Knowledge for action series, based on the work of the IBMA work group in conjunction with almost 100 contributors, is to contribute to the debates on how to manage IASs, to provide a general outline on current knowledge (volume 1) and a number of specific examples (volume 2) to assist managers of aquatic environments and policy makers in their respective tasks to better manage these species.

We hope that these volumes will be of use to the full range of stakeholders dealing with IASs, including managers of natural areas, the coordinators of territorial groups and policy makers. We further hope that they will contribute to raising awareness of the issues involved in managing invasive alien species in aquatic environments in France.

Sébastien Moncorps
Director of the IUCN French committee

Philippe Dupont
Research and development department, Onema

Brief outline

Invasive alien species (IAS) and their impacts represent a growing concern for the managers of natural areas. That is particularly true for aquatic environments where an array of stakeholders are now taking action. In parallel, public policies are coming into play on the national level and the European Union recently adopted a new regulation in this field.

What is the status of current knowledge on biological invasions? What is the applicable legal framework and what recommendations should be made?

In the field, which species are managers attempting to address? Which techniques are used, where and how, and what are the objectives and the results achieved?

These two volumes of the Knowledge for action series clearly present the situation and propose a scientifically based approach to assist environmental managers in setting up management projects. Though no "cure alls" currently exist, this volume offers highly useful information while attempting to address the specific aspects of each situation, including the site, the species to be managed and the necessary technical and financial resources.

Vol. 1 Practical information

The first volume presents the current situation concerning invasive alien species in aquatic environments in continental France.

Six chapters provide a detailed outline on:

- current scientific knowledge on IASs, including definitions, colonisation processes, impacts and topics for future research;
- current legislation and regulations addressing IASs on the international, European and national levels;
- IAS strategies and action plans, including the main participants and existing projects;
- the general approach to IAS management, i.e. prerequisite knowledge, prevention, monitoring and action taken;
- IAS management, including a presentation on the overall situation for interventions, a panorama of existing techniques, the management of waste and assessments of management work;
- the existing tools available to managers, e.g. coordination of projects, lists of species, databases, platforms for information exchange and collections of feedback from management projects.

Vol. 2 Management insights

The second volume is a collection of fact sheets on invasive alien species and management projects carried out in continental France and Europe.

A total of 26 fauna and flora species are covered in 52 examples presenting management projects, drafted in conjunction with the managers.

Each sheet includes descriptive information on species identification, biology and ecology.

The project-feedback information comprises:

- the organisation managing the project;
- a description of the project site with maps;
- the problems on the site and the issues at hand;
- the intervention techniques, e.g. the selected method, each operational step, schedules, technical constraints;
- project results and budget;
- the outlook following the project;
- efforts to promote the project and its results;
- available documentation and the contact person for more information.

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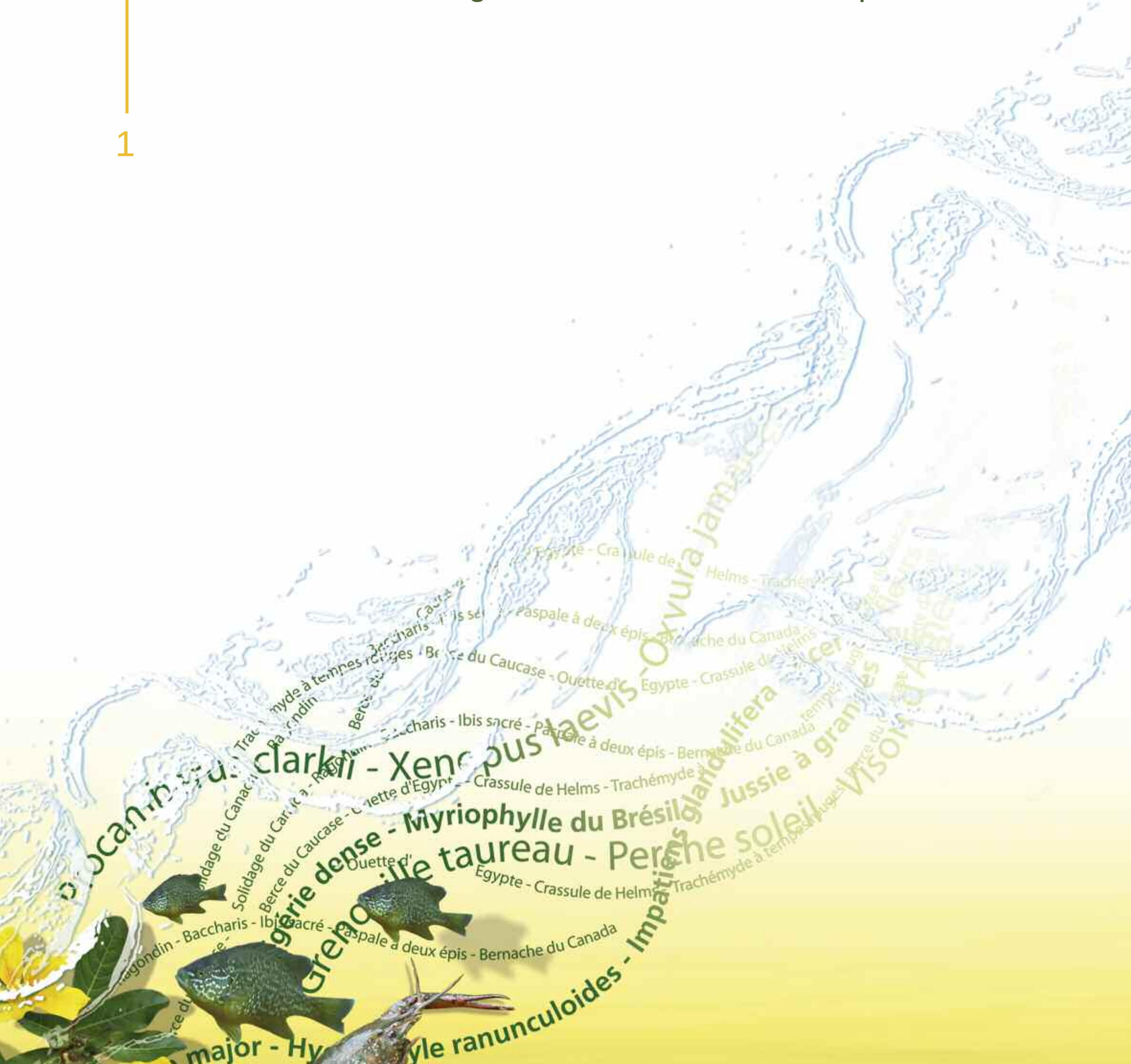
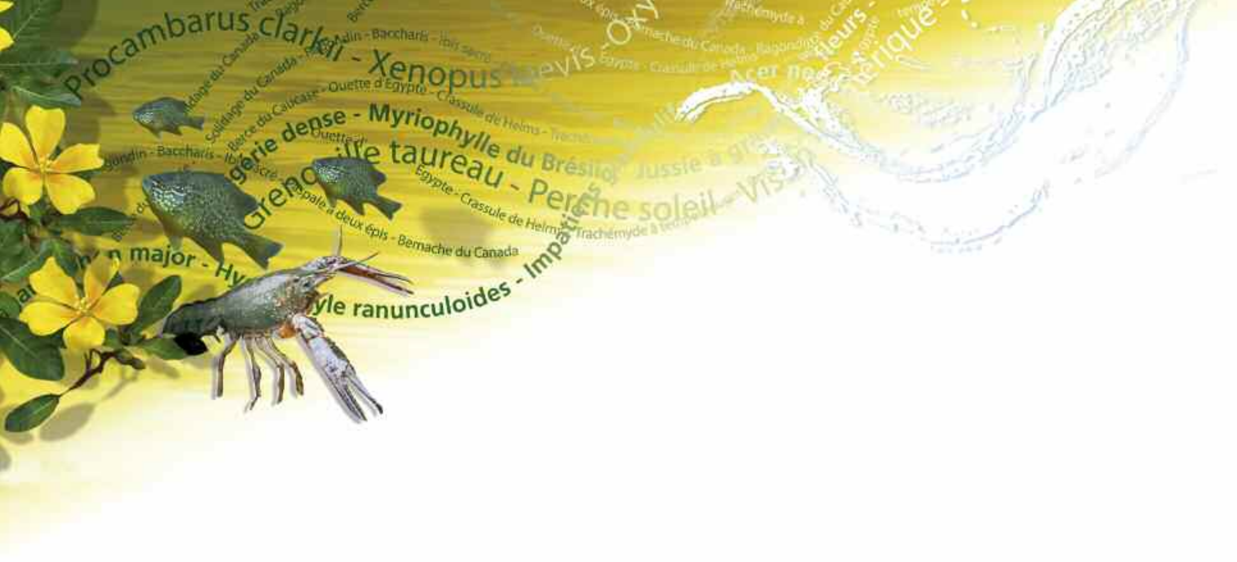
This chapter was drafted by:
Emmanuelle Sarat (IUCN French committee),
Alain Dutartre (independent expert, formerly at Irstea),
Emilie Mazaubert (Irstea).

With the collaboration of:
Jacques Haury (AgroCampus Ouest),
Isabelle Mandon-Dalger (Federation of national botanical conservatories),
Nicolas Poulet (Onema),
Yohann Soubeyran (IUCN French committee),
Eric Tabacchi (University of Toulouse).

General knowledge on invasive alien species

1





Basic concepts

Definitions

The many definitions of biological invasions have been listed in a large number of bibliographical references. The significant variations in the terms and expressions used are due in part to the different stakeholders involved and their many perceptions of the situations at hand (Menozzi, 2010; Lévêque *et al.*, 2012). That being said, certain definitions have achieved consensus on the international level, for example those proposed by the IUCN (2001) that were subsequently adopted by the Convention for biological diversity (United Nations, 2002) and in the regulation of the European parliament and of the Council on the prevention and management of the introduction and spread of invasive alien species (European parliament and Council, 2013)[1].

The definitions[2] proposed here consist of existing definitions and generally take into account two criteria deemed essential by the scientific community, managers and the public, i.e. the origin of the species and impacts incurred (Menozzi, 2010).

■ Invasive alien species

In this book, an invasive alien species (IAS) is a non-native or non-indigenous species whose introduction (by humans, whether intentional or not), establishment and spread threaten ecosystems, habitats and native species, and have negative impacts on ecosystem services and/or on socio-economic and/or health aspects (IUCN, 2000; Pyšek *et al.*, 2009; Genovesi and Shine, 2011; European parliament and Council, 2013).

Strictly speaking, it would be preferable to use the term “invasive alien populations” because the term “species” includes all populations, i.e. both those living in the original distribution range and those introduced to the new area (Pascal *et al.*, 2006). For this reason, it might be better to use a definition containing the word “population” rather than the word “species”. The above remark is all the more valid in that not all introduced populations will necessarily become invasive.

■ Native or indigenous species

A species is said to be native to a given geographic area over a given period when it is represented in that area by populations seen as long-standing at the beginning of that period. The species grows and lives naturally in the area without having been introduced by humans and their activities. The species may also be characterised by a distribution range that apparently does not depend on dispersal by humans.

1. The European regulation defines an invasive alien species as a non-native species whose introduction or spread represents a threat to or has a negative impact on biodiversity and the related ecosystem services.
2. An analysis of all the definitions pertaining to the issue of invasive alien species was carried out by the National museum of natural history (MNHN) (Thévenot, 2013). The document may be viewed on the MNHN site (natural heritage department): http://spn.mnhn.fr/servicepatrimoinenaturel/publications/rapports_spn.

■ Alien, non-native or exogenous species

A species, i.e. an individual or population, introduced intentionally or unintentionally by humans or their activities to areas outside its original distribution range. A species is said to be alien to a given biogeographic area over a given period when it was absent from the area at the start of the period, but subsequently colonised the area and established long-term populations. In other words, the species lives outside its natural distribution range.

■ Introduced species

A non-native species introduced intentionally or unintentionally to an area or part of an area where it had been absent up to that point.

■ Naturalised species

An introduced species encountering favourable ecological conditions for establishment that is sustainable over decades in the host area. The species reproduces and expands regularly in the new distribution range and maintains its presence over the long term, an example being *Hibiscus palustris* (see Figure 1). Specifically concerning plants, Richardson *et al*. (2000) proposed a fairly close definition, adding that these species can maintain their presence without any direct intervention on the part of humans or in spite of human intervention in natural, semi-natural or man-made ecosystems.

Figure 1

© A. Dutartre, Irstea

Hibiscus or Crimsoneyed rosemallow (Hibiscus palustris). Originally from North America, this plant grows near water and has large, highly visible flowers during the summer. It has been established for decades on a few sites in the Landes and Pyrénées-Atlantiques departments (SW France). It is mentioned in the interministerial decision dated 20 January 1982, in the "list of plant species protected throughout the country".

■ Pervasive or proliferating species

A pervasive species is defined in ecological terms as a native or non-native species in a given territory, that develops in abundance locally and rapidly expands its range. Aboucaya (1999) added as an additional criterion that the species colonises natural or semi-natural habitats. The definition of a proliferating species is similar to that of a pervasive species, i.e. rapid development in the number of individuals to the point that the species comes to dominate a given area. Though this definition does not exclude the concept, it does not mention the damage caused by the species.

The causes of pervasion or proliferation vary significantly depending on the origin of the species. Native species may become pervasive or proliferate following environmental changes in the occupied biotope (development work, eutrophication, climate change) or the environmental changes may also contribute to triggering an invasion by non-native species.

Box 1

Invasive or pervasive?

The terms "invasive" and "pervasive" do not have exactly the same meaning. Though they both pertain to the rapid development in the numbers of a species and its geographic expansion, the term "invasive" is generally used for populations that are not native to the given area, whereas the term "pervasive" can designate an introduced or a native species that suddenly begins to grow in numbers. In addition, certain experts speak of an invasive population only if it causes noticeable damage. Practically speaking, the two terms are often perceived as virtually synonymous, particularly given the fact that it is not always possible to determine if a population is native or the product of introduced individuals. (Pascal *et al.*, 2009).

Biological invasion

An invasion occurs when a species expands outside its natural distribution range and establishes one or more sustainable and autonomous populations, generally without any human assistance in the colonised environment. Three phases are generally observed, arrival, establishment and expansion (Kolar and Lodge, 2001).

Feral animal/population

A captive or domestic animal that has returned to a wild state. This definition is used particularly for mammals, e.g. feral pigs, goats, cattle, etc.

Table 1 shows the links between the various terms and can be used to compare two terms. For example, a native/indigenous species cannot be alien/non-native, introduced or naturalised. It may be pervasive or proliferating, but it cannot be invasive and alien.

Table 1 *Possible combinations of terms. According to Thévenot, 2013.*

If a species is... / Can it be...	Native or indigenous	Alien or non-native	Introduced	Naturalised	Pervasive or proliferating	Invasive alien
Native or indigenous		No	No	No	Possible	No
Alien or non-native	No		Possible	Possible	Possible	Possible
Introduced	No	Yes		Possible	Possible	Possible
Naturalised	No	Yes	Yes		Possible	Possible
Pervasive or proliferating	Possible	Possible	Possible	Possible		Possible
Invasive alien	No	Yes	Yes	Yes	Yes	

Semantic difficulties

■ Terminology

The study of biological invasions has generated a highly diverse set of concepts that are still under debate in the scientific community as well as among stakeholders (Lévêque *et al.*, 2012). This multiplication of terms and concepts has been identified as one of the factors slowing improvements in knowledge on the ecology of biological invasions (Falk-Petersen *et al.*, 2006) and also constitutes an obstacle to the integration of these issues in public policies and to intervention strategies. In addition, certain terms were defined taking into account specific taxonomic groups. This is a direct result of the relative paucity of multidisciplinary research and the high specialisation of researchers and naturalists, which in some cases can result in difficulties in understanding. That is occasionally the case between the animal and plant spheres (Falk-Petersen *et al.*, 2006) or concerning micro-organisms.

There is often confusion between the concept of proliferation and the alien nature of a species (Lévêque *et al.*, 2012). For example, some native species that proliferate locally are occasionally thought to be alien species. That is the case for river water-crowfoot (*Ranunculus fluitans*, see Figure 2), that can form thick beds similar to water primrose or water cabbage (*Pistia stratiotes*, see Figure 3) and hinder navigation, or the Great cormorant (*Phalacrocorax carbo*), that can do significant harm to freshwater fisheries, but is nonetheless a protected, native species.

Figure 2

a © Siebrand
b © A. Dutartre, Irstea

*Native Ranunculus species, such as river water-crowfoot (*Ranunculus fluitans*), can colonise large areas in favourable, river biotopes, modifying water flows and hindering navigation.*

Figure 3

© A. Dutartre - Irstea

*Water cabbage (*Pistia stratiotes*), is a floating, alien plant that is highly appreciated as an ornament in fountains. It can proliferate very rapidly, as shown above in 2003 in a periurban river in the Gironde department (SW France).*

The distinction is, however, important. Above and beyond the underlying regulatory issues that arise when preparing management work, there are numerous interactions between native species that are the result of long co-evolution and the existing communities can be disturbed by the arrival of new species (Strauss *et al.*, 2006a and 2006b; Ricciardi and Atkinson, 2004). The absence of co-evolution between an alien species and the host communities can explain an invasion (due to the lack of any possibility to compete) or its failure. However, recent research has shown that rapid evolutionary processes may take place within introduced populations, a clear indication of the complexity and of the possible changes in the relations between native and alien species.

For aquatic environments, Ricciardi and Atkinson (2004) submitted the hypothesis that the impact of an introduced species can be determined by the evolutionary and phylogenetic history of the invaded ecosystem. For example, an introduced species from a genus that is absent or not frequent in the host ecosystem, and consequently has a different evolutionary history, may produce impacts that are seen as more negative than those of an introduced species from a genus already widely present in the same ecosystem.

■ Different geographic areas

The alien or native nature of a species may also depend on the geographic area under consideration. Theoretically, a species should be seen as introduced only in areas lying outside its past or present natural distribution range. A native species is thus considered alien when it is transported outside of its original range and even invasive if it proliferates in the new environment (Beisel and Lévêque, 2010). Introductions may take place between countries or within a single country, but between two distinct biogeographic regions. In both cases, the population is considered alien in the host environment. For this reason, a given species may be considered native or alien depending on the geographic area under consideration (Poulet, 2010).

That is the case, for example, of the marsh frog (*Pelophylax ridibundus*), whose natural distribution range spans a vast zone in Eurasia. In the western part of this range, in France, the species is considered native in the eastern section of the country around Lake Geneva and down the Rhône valley (Neveu, 1989). The species was also introduced to numerous French regions, including Bretagne (Brittany). As a result, the status of the marsh frog can change depending on the geographic area under consideration. It is native to Eastern Europe and a large part of continental France, but is alien in Bretagne.

A further example is the common nase (*Chondrotoma nasus*), a fish species native to Central Europe that is present in the Rhine basin. As early as 1860, the species could disperse, via navigation canals, to the Rhône, Seine and Loire River basins where it is considered alien (Keith *et al.*, 2011). That is also the case of the butterbur (*Petasites hybridus*, see Figure 4), that grows along rivers in the Massif Central and in the eastern section of France, but is considered a potential invasive species in Bretagne (Haury *et al.*, 2010; Quéré *et al.*, 2011).

Figure 4

© TeunSpaans

*The butterbur (*Petasites hybridus*).*

■ Introduction dates

In addition to the geographic factors, further criteria concern the dates and reference periods selected in determining whether a species is native or non-native to a given area. The distribution of a species at a given date or period serves as the reference point on the basis of which the movements of the species are then analysed in order to set their status. In continental Europe, transfers of species by humans, both intentional and unintentional, started several thousand years ago, a fact that can make it difficult to determine whether a species is native or non-native in a given area (Simberloff *in* Pascal *et al.*, 2006).

In continental France, numerous zooarchaeological studies on certain species have revealed whether they were present prior to the start of the Holocene (10 000 years ago), i.e. the end of the last glacial period and the start of the first known introductions (Pascal *et al.*, 2006). Selection of the Holocene as the reference point means that certain species are considered native, when in fact they are alien, for example house mice (*Mus musculus*) or the common pochard (*Aythya ferina*, see Figure 5).

Figure 5


© N. Phillips

*The common pochard (*Aythya ferina*) is an introduced species that has integrated so completely in the local fauna that many people think it is native.*

In terms of flora, it is generally acknowledged that plants introduced intentionally or unintentionally by humans after the year 1500, the start of introductions from the Americas, are considered alien (Lacroix *et al.*, 2007; Pyšek *et al.*, 2009). It is more difficult to apply that particular date to Asian, Eurasian and Mediterranean species for which the date of introduction in France is often unknown (Toussaint *et al.*, 2007). In these cases, some species are considered native if an analysis of regional and national bibliographic data indicates that they were widely found and seen as growing spontaneously in a given area at the end of the 1800s (Lacroix *et al.*, 2007). On the other hand, rare species not commonly found at the end of the 1800s may be considered alien (Lacroix *et al.*, 2007).

■ Impacts

The inclusion of the concept of impacts in determining whether a species is alien is still a topic of debate. Not all the stakeholders in this field share the same perception of invasive species and the modifications that they cause in host ecosystems, nor concerning the effective or presumed disturbances (Lévêque *et al.*, 2012). For certain authors, the concept of impacts is indispensable in determining whether a species is invasive (Davis and Thompson, 2001). However, it is often necessary to precisely define the ecological impacts of a species in order to make this criterion less subjective (Daehler, 2001). This uncertainty explains why a species is occasionally categorised as an invasive alien species if it rapidly and extensively colonises a new ecosystem, before any impacts have been identified.

Similarly, for managers, impacts and an assessment of their severity can justify management work on a species. Definitions including the two criteria, i.e. the alien status and the ecological and/or socio-economic impacts identifying the species as invasive, constitute a more operational approach for management. Discussions with stakeholders in the horticultural sector have shown that a common definition integrating management and clarification of the objectives for the lists of species to be drawn up jointly are seen as the indispensable prerequisites for effective, preventive management (Mandon-Dalger *et al.* 2013).

However, waiting for a species to cause significant negative impacts before taking action runs counter to the precautionary principle whereby work should be undertaken as soon as the species has been detected and an assessment of the risks involved has been run (Menozzi, 2010), two major elements in the various strategies implemented (see for example, Matrat *et al.*, 2012).

If the precautionary principle is interpreted to mean that immediate intervention following detection is required, excellent predictive capabilities concerning the future behaviour of the recently detected species would be necessary. The starting point in the analysis would be the impacts caused by the species already observed in other nearby, biogeographic areas in order to assess the risks involved in its introduction to the new area, and an analysis of the biological traits of species for which background data is absent (see Box 2, page 27).

At any rate, it is necessary to include the concept of impacts and damages in the definition of invasive alien species, at least tentatively as species having the “potential” to cause damage. The type of damage would depend on the ecological characteristics of the species and on those of the living communities in the colonised habitat, as well as on how humans use the environment in question (see Figure 6). In this case, as soon as a species is deemed likely to cause clearly defined damages, management work could be undertaken taking into account the issues specific to the site in question.

Figure 6

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*The clearest impacts concern how environments are used. In the photo, a thick bed of parrot-feather watermilfoil (*Myriophyllum aquaticum*) blocks the passage of anglers (Léon pond, Landes department, 1993).*

Introduction of species

Reasons and vectors

The introduction of a species, whether intentional or not, can take place via many paths (transportation itineraries) and many vectors (transportation means) (see Table 2 and Figure 7). A majority of introductions are caused by human activities.

Tableau 2 *Examples of introduction paths and vectors, both intentional and unintentional. According to Soubeyran, 2008.*

Intentional introductions		Unintentional introductions
Direct introductions	Evasions following planting or captivity	
Agriculture	Evasions from botanic gardens	Sea and air cargo
Forestry	Private gardens	Ballast water
Horticulture	Garden stores / Pet shops	Fouling of hulls
Animal farming	Zoos	Transport and construction machinery
Restocking	Animal farms	Transported earth and landfill
Releases of mammals	Bee keeping	Road cutting and filling
Hunting	Aquaculture	Agricultural products
Biological control	Aquariums	Seeds
Soil improvement	New types of pets	Construction materials
Agricultural expansion	Research centres	Wood
	Restocking	Packing materials
		Postal packages
		Waste
		Canals (navigation)

Figure 7

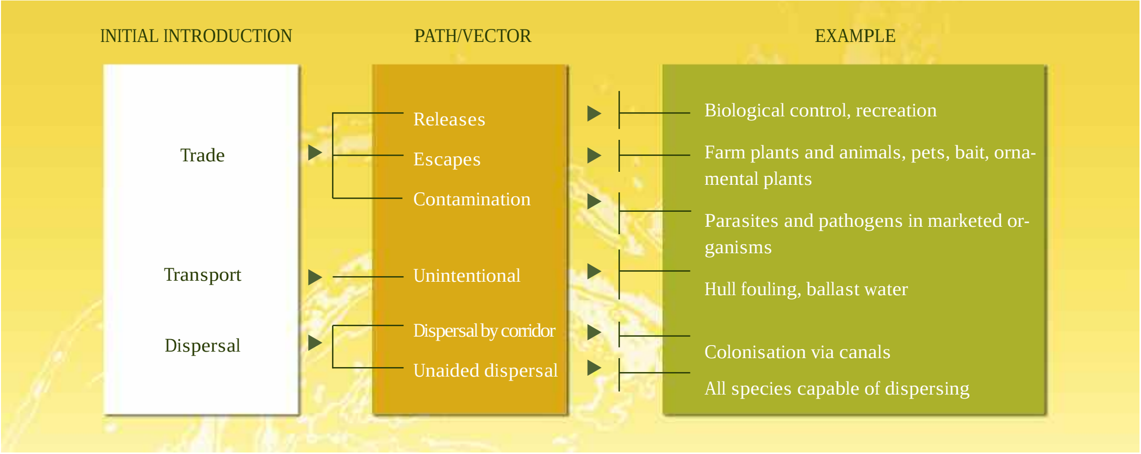

Diagram showing the various introduction paths and vectors. According to Hulme et al.*, 2007, in Poulet, 2010.*

■ Intentional introductions

Certain species were introduced for the biological control of another species, e.g. the eastern mosquitofish (*Gambusia holbrooki*), a small fish introduced to limit mosquito populations. An analysis of its feeding habits has shown, however, that the species does not feed specifically on mosquito larvae, but also on other prey (aquatic insects and crustaceans) (Pascal *et al.*, 2006).

Plants have been introduced for ecological restoration, e.g. protection of soil and dunes, efforts to limit the erosion of river banks, etc. (Boudouresque, 2005). That is the case, for example, of the Hottentot fig (*Carpobrotus edulis*, see Figure 8) and the groundsel tree (*Baccharis halimifolia*). These two species are now considered extremely invasive along a major part of the coastline in continental France.

Figure 8

© E. Mazaubert

The Hottentot fig.

Animal farming is the cause of the intentional or unintentional introduction of many species. For example, many mammals were introduced in Europe in the early 1900s for the fur industry, including coypus (*Myocastor coypus*, see Figure 9), muskrats (*Ondatra zibethicus*) and American mink (*Neovison vison*) (Léger 1999; Léger and Ruette, 2005). The same is true for the Red swamp crayfish (*Procambarus clarkii*) that was introduced for commercial production (Vigneux, 1993; Laurent, 1983).

Figure 9

a © Maurice, 1931
b © Le pêcheur français, 1984

Advertisements for a) a farm raising coypus in semi-liberty in the Eure department in 1931 and b) a farm raising signal crayfish in 1984.

Recreational hunting and fishing are also a source of direct introductions in the natural environment, examples being the largemouth bass (*Micropterus salmoides*), a carnivorous fish introduced for fishing, and Sika deer (*Cervus nippon*), introduced as game (Saint-Andrieux, 2006). It should be noted that restocking of fish for recreational fishing may result in unintentional introductions if the fish come from fish farms in ponds. That is the probable cause of the arrival in France of the topmouth gudgeon (*Pseudorasbora parva*) and the Albanian roach (*Pachychilon pictum*) (Pascal *et al.* 2006; Keith and Allardi, 1997).

The species imported for ornamental purposes and sold in garden stores, pet shops and plant nurseries have also been found in the natural environment. Water primrose (*Ludwigia* spp.) and parrot-feather watermilfoil (*Myriophyllum aquaticum*) were spread far and wide in ornamental pools (Dutartre, 1995). Numerous birds, e.g. Canada geese (*Branta canadensis*) and black swans (*Cygnus atratus*) (Fouque 2011a and 2011b), and certain fish, e.g. goldfish (*Carassius auratus*), have also been introduced for ornamental purposes in parks and gardens. Red-eared slider turtles (*Trachemys scripta elegans*, see Figure 10) were imported as pets (Dupré *et al.*, 2006).

Figure 10

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*Red-eared slider turtles (*Trachemys scripta elegans*) can be easily identified by the red spots on the side of the head. They have rapidly colonised many aquatic environments, e.g. the Vistre River in the Gard department.*

Indirect introductions are a further possibility. This is the case where animals held captive (farms, aquariums, zoos, pet owners) escape or are released to the natural environment by people unaware of the consequences. Examples are the sacred ibis (*Threskiornis aethiopicus*) (Clergeau *et al.*, 2005) and the red-necked Wallaby (*Macropus rufogriseus*) (Tillon and Lorvelec, 2004). Similarly, American mink (*Neovison vison*) and northern raccoons (*Procyon lotor*, see Figure 11) escaped from farms and have since firmly established themselves over large parts of continental France (Léger and Ruette, 2005). New types of pets, such as red-eared slider turtles (*Trachemys scripta elegans*) and Siberian chipmunks (*Tamias sibiricus*), have often been released to the natural environment by owners who no longer wished to keep them (Dupré *et al.*, 2004; Chapuis, 2005).

Figure 11

© C. Lemarchand

Raccoons escaped from farms prior to establishing feral populations in France.

■ Unintentional introductions

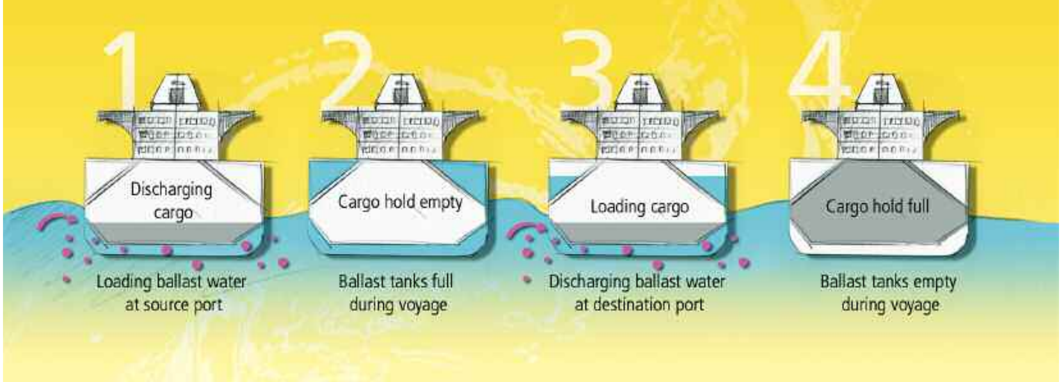
Certain species are transported unintentionally via water, on the hulls of boats. The phenomenon where organisms attach to hulls is called biofouling. Zebra mussels (*Dreissena polymorpha*) originated in the Black Sea and were introduced to Western and Northern Europe via canals and subsequently to North America by trans-atlantic shipping (see Figure 12). Intercontinental transport combined with biofouling is thought to be responsible for the introduction of over 60% of the invasive alien species (IAS) in marine environments (Molnar *et al.*, 2008).

Figure 12

*Zebra mussels (*Dreissena polymorpha*) attached to the navigational instruments of a ship.*

Ballast water, used to stabilise ships when travelling with no load, is subsequently pumped out in a port where cargo is loaded. As a result, enormous quantities of water containing local fauna and flora are transported from one ocean to another by ships serving as "giant aquariums" (see Figure 13). Ballast water thus constitutes one of the most effective vectors for the introduction of marine species as well as for freshwater species when ships travel to or from the Great Lakes in North America. Worldwide, Carlton and Geller (1993) estimated that between 8 and 10 billion tons of ballast water are transported annually and that at least 3 000 to 4 000 species travel around the world in this manner every day. An example is the Chinese mitten crab (*Eriocheir sinensis*) introduced to the United States, via California, in the ballast water of ships arriving from the Far East (Cohen and Carlton, 1997).

Figure 13



Cross-section of a ship showing ballast tanks and ballast-water cycle. Adapted from the Global Environmental Fund, United Nations Development Program, International Maritime Organisation, Global Ballast Water Management Program, 2007.

Unintentional imports can also occur during the transportation of goods (marine or air cargo) when species are inadvertently enclosed in containers. That is the case for the Asian hornet (*Vespa velutina*) that entered France through the Aquitaine region around the year 2000 via goods shipped from Asia (Villemant *et al.*, 2006) and for the narrow-leaved ragwort (*Senecio inaequidens*) whose seeds were lodged in imported sheep wool (Muller, 2004).

A further source of unintentional introductions is IAS-contaminated materials and machinery that travel around the country for development work (road construction, sanitation networks, river maintenance, transportation and reuse of landfill), to say nothing of the remains of invasive plants (Muller, 2004). Knotweed (*Reynoutria* spp.) has been widely dispersed by excavation machinery and landfill containing fragments of stalks and/or rhizomes. The wheels of cutting machines and the machines themselves (buckets, blades, dump trucks) cause unintentional introductions by transporting plants from one site to another unless they are properly cleaned after each job. Several examples of fragments of water-primrose stalks being transported by machinery working in aquatic environments have been noted. That is thought to be the case for the introduction of large-flower water primrose in the Brière regional nature park (Haury and Damien, 2012).

Movements by certain types of people (anglers, boaters) from one aquatic environment to another can also result in the transport of species, generally over fairly short distances, in the form of plant fragments stuck to boats or trailers, animals attached to boat hulls, etc. (Anderson *et al.*, 2014) (see Figure 14).

Figure 14

© CAISIE – IFI.

Disinfection of recreational boats to avoid transporting invasive species to Ireland.

Finally, a further possibility consists of the transportation of plant propagules by animals, notably birds. It would seem certain that waterfowl[3] are responsible for the colonisation of isolated lakes by *Lemna minuta*. The colonisation of isolated lakes by water primrose is probably due to the same cause.

In France, of introduced freshwater plant species, 38% were introduced for ornamental reasons and 29% are used in aquariums (Muller, 2004). In continental France, 44% of the 43 species of introduced freshwater fish have naturalised and among them, almost half were introduced for recreational fishing (Keith and Allardi, 1997). In Europe, the two main reasons for the introduction of fish are aquaculture and recreational fishing (Gozlan, 2008).

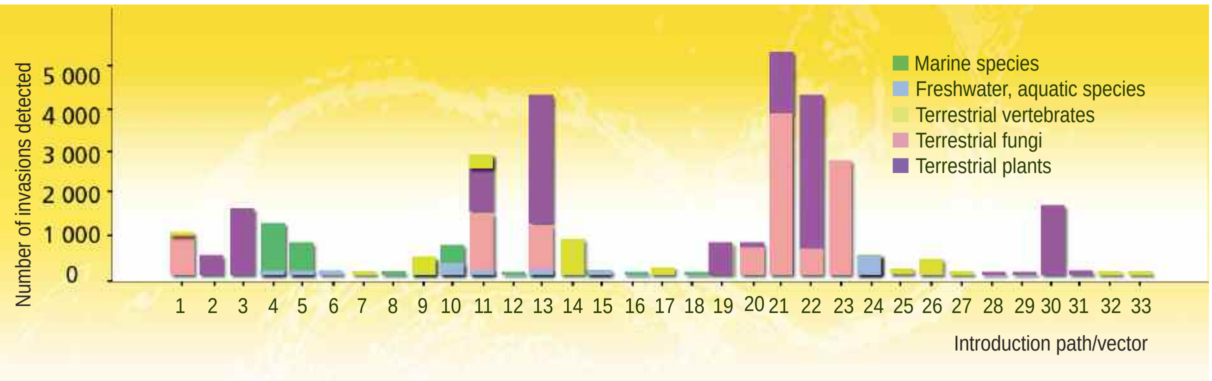
A study carried out on aquatic environments in Italy (Gherardi *et al.*, 2008) revealed that introductions of freshwater animal species from other continents were essentially the result of sport fishing and extensive fish farming (30%), intensive aquaculture (27%) and ballast water (25%). Ornamental uses in aquariums and basins represented a further 9% of introductions. The transported organisms can then colonise a new geographic area that in some cases is very far from their original range (see Table 3 and Figure 15 on the following page).

3. Waterfowl in this case consist of wildfowl, i.e. wild birds travelling significant distances.

Table 3 *List of the introduction paths/vectors for the IAS discussed in the second volume of this book.*

Species	Introduction path/vector
FLORA	
Curly waterweed - *Lagarosiphon major, (Ridl.) Moss*, 1928	Aquariums
Large-flowered waterweed - *Egeria densa*, Planch., 1849	Aquariums
Water pennywort - *Hydrocotyle ranunculoides*, L.f., 1782	Ornamental horticulture
Parrot-feather watermilfoil - *Myriophyllum aquaticum*, Verdcourt, 1973	Ornamental horticulture
Water primrose - *Ludwigia* spp.	Ornamental horticulture
New Zealand pigmyweed - *Crassulla helmsii*, (Kirk) Cockayne, 1907	Ornamental horticulture
Groundsel tree - *Baccharis halimifolia*, Linnaeus, 1753	Ornamental horticulture
Giant hogweed - *Heracleum mantegazzianum*, Sommier and Levier, 1895	Ornamental horticulture
Box elder - *Acer negundo*, Linnaeus, 1753	Ornamental horticulture
Knotweed - *Reynoutria* spp.	Ornamental horticulture, agriculture (fodder)
Goldenrod - *Solidago* spp.	Ornamental horticulture
Garden balsam - *Impatiens* spp.	Ornamental horticulture
Water finger grass - *Paspalum distichum*, Linnaeus, 1759	Agriculture (fodder)
FAUNE	
Signal crayfish - *Pacifastacus leniusculus*, Dana, 1852	Aquaculture
Red swamp crayfish - *Procambrus clarkii*, Girard, 1852	Aquaculture
Pumpkinseed - *Lepomis gibbosus*, Linnaeus, 1758	Fishing and aquariums
Red-eared slider turtle - *Trachémys scripta elegans*, Wied, 1839	Pets
African clawed frog - *Xenopus laevis*, Daudin, 1803	Raised for scientific research
American bullfrog - *Lithobates catesbeianus*, Shaw, 1802	Farming, ornamentation
Canada goose - *Branta canadensis*, Linnaeus, 1758	Ornamentation
Egyptian goose - *Alopochen aegyptiacus*, Linnaeus, 1766	Ornamentation
Ruddy duck - *Oxyura jamaicensis*, Gmelin, 1789	Zoos
Sacred ibis - *Threskiornis aethiopicus*, Latham, 1790	Zoos
American mink - *Neovison vison*, Schreber, 1777	Raised for the fur industry
Coypu - *Myocastor Coypu*, Molina, 1782	Raised for the fur industry
Muskrat - *Ondathra zibethicus*, Linnaeus, 1766	Raised for the fur industry

Figure 15 *Main introduction paths/vectors of alien species in Europe. Source: DAISIE, 2009.*



1. Biological control
2. Contaminated materials
3. Escaping animals
4. Boats
5. Canals
6. Recreational activities
7. Escaping pets
8. *Biofouling*
9. Others
10. Aquaculture
11. Unknown
12. Ballast water
13. Ornamentation
14. Wildlife improvement
15. Fish farming
16. Dispersal
17. Natural dispersal
18. Floating structures
19. Agriculture
20. Forestry
21. Horticulture
22. Contamination by seeds
23. Product storage
24. Transport
25. Hunting
26. Animals escaping from breeding centres
27. Fur industry
28. Contamination by minerals
29. Intentional introduction
30. Unintentional introduction
31. Hybridisation
32. Animals escaping from farms
33. Animals escaping from zoos

Spontaneous and subspontaneous invasions

■ Spontaneous invasions

Certain species can establish themselves in a new geographic area without any help from human activities. Such species are not, strictly speaking, invasive alien species (see the definitions page 10). Their invasion may be qualified as spontaneous or natural. It may occur when a physical or environmental barrier between two areas disappears, thus enabling the movement of the species to the new area via either biotic (animal) or abiotic (water current, wind, etc.) means of transportation (Ashton and Mitchell, 1989).

Spontaneous invasions are rare and little is known about them. The physical distance between the original range of the species and the new area is probably the most difficult barrier to overcome, particularly for freshwater, aquatic plants. The chances of these species succeeding in travelling to new areas are slight given that they cannot survive out of water over long periods and they react poorly to long stays in seawater (Haller *et al.*, 1974).

The greater dispersal capabilities of certain animal species put them in a better position to overcome these barriers. That is the case for the Eurasian collared dove (*Streptopelia decaocto*) that originally came from Asia minor and the Near/Middle East. It is thought to have spontaneously reached Constantinople and established large populations as early as the 1500s. Today, it has spread widely throughout continental France (Pascal *et al.*, 2006). Another example is the violet dropwing (*Trithemis annulata*) that is believed to have naturally migrated from Northern Africa to Southern Europe since the end of the 1900s. It is now settling progressively in France (Deliry, 2010), perhaps due to climate change.

■ Subspontaneous invasions

The opening of new passageways facilitates the movement of species from one geographic area to another. The term "subspontaneous invasion" is used when human activities bring into contact previously separate environments, thus indirectly making possible the arrival of a species in a new area. The construction of navigation canals linking previously isolated river basins made it possible for many aquatic species to expand their distribution range, either by using human means of transportation or their own means. For example, the construction of the Suez canal (see Figure 16) led to the introduction of 200 to 300 species from the Red Sea to the Mediterranean in what are called Lessepsian migrations (Ramade, 1993). Similarly, Wels catfish (Silurus glanis) and pikeperch (Sander lucioperca) benefited from the canal network in continental France, in addition to direct vectors such as aquaculture and recreational fishing. The Danube-Main-Rhine canal, opened in 1992, facilitated passage to Western Europe (Ponto-Caspian migration) for Ponto-Caspian fauna, e.g. for various goby species Neogobius melanostomus, Ponticola kessleri, Proterorhinus semilunaris, etc.) (Manné *et al.*, 2013) and aquatic invertebrates (Devin *et al.*, 2005) that are now firmly established in the Rhine basin.

Figure 16

© NASA MISR images

Satellite view of the Suez canal and the surrounding area.

Subspontaneous dispersal may also be caused by environmental changes, e.g. deforestation, or climate change. Increases in temperature, variations in hydrological regimes or rises in sea levels will have major consequences for water quality and the functioning of the environments in question and could lead to modifications in the dynamics of native and non-native species (Dutartre and Suffran, 2011). It should be noted that the recently adopted European regulation does not include among the invasive species "species changing their natural distribution range without human intervention, in response to changing ecological conditions and climate change".

Colonisation dynamics and chronology

■ An array of natural barriers

Not all the species imported by humans become invasive. According to Richardson *et al.*, (2000), an alien species must overcome different geographic and/or environmental barriers (see Figure 17) before it becomes invasive. For each barrier overcome, the terms employed for the status of the species change and an invasion becomes more probable.

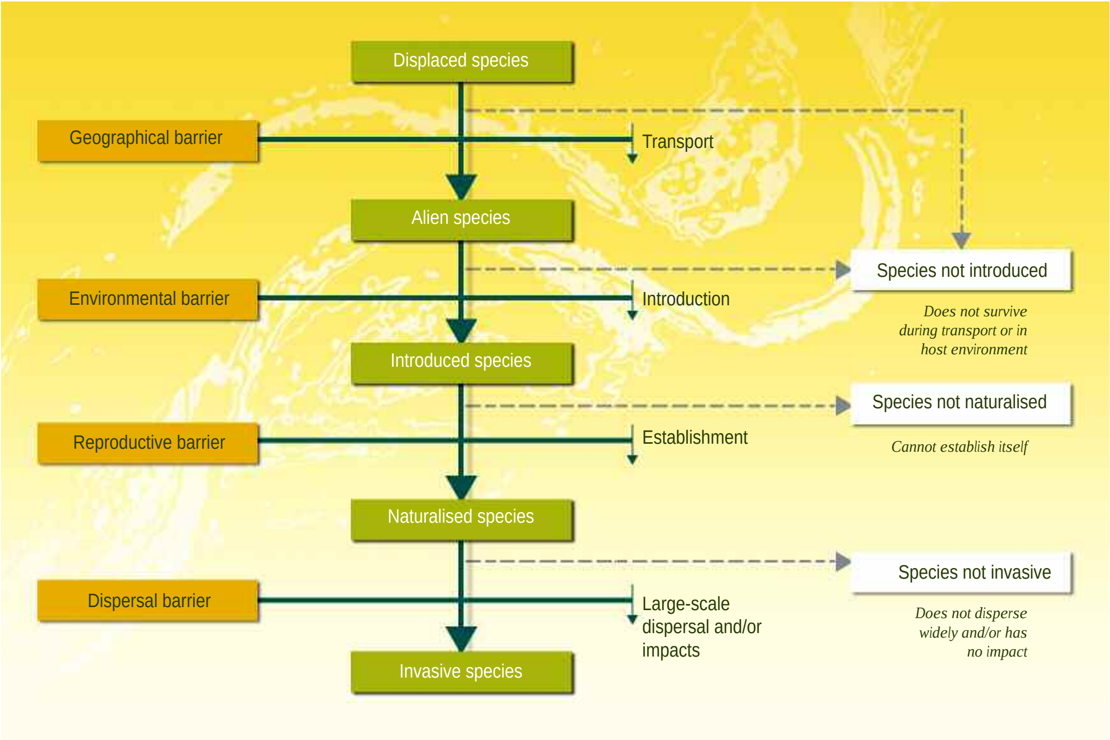
The first geographic barrier is generally overcome thanks to human intervention, i.e. via a means of transportation and intentional or unintentional introductions. This is the introduction phase.

The environmental barriers oblige the species to acclimate to the environmental conditions of the host site, i.e. the abiotic (climate, resources, habitats) and the biotic (predators, pathogens, trophic resources) conditions. This is the adaptation phase.

The third type of barrier deals with reproduction. The species must be capable of reproducing if it is to develop a viable population over the long term. This is the naturalisation phase.

Finally, the last barrier limits species dispersal. If overcome, the species can expand in the new area by colonising new habitats. This is the expansion phase.

Figure 17



The barriers that must be overcome before an alien species becomes invasive. This theoretical diagram showing the species dynamics leading to biological invasions should be used with caution because survival and dispersal may occur throughout this sequence. According to Richardson et al.*, 2000. Diagram adapted by Mazaubert, 2013.*

Success rate of biological invasions

Many species are not capable of successively overcoming the various barriers. Only a very small percentage of the species that are effectively introduced after overcoming a geographic barrier go on to become invasive and to have a negative impact on the environment and on human activities.

In 1996, Williamson proposed the "Three tens rule". This rule starts with the number of imported species in a given area and postulates a reduction by a factor of ten first in the number of introduced species, then in the number of naturalised species and finally in the number of invasive alien species inhabiting the area.

For example, if 1 000 species are imported by humans, 100 would be introduced in the area, 10 would succeed in reproducing and a single species would become invasive (see Figure 18). These values are probabilistic and vary depending on numerous factors, i.e. the type of species, the type of site and host community, and the introduction conditions.

Figure 18

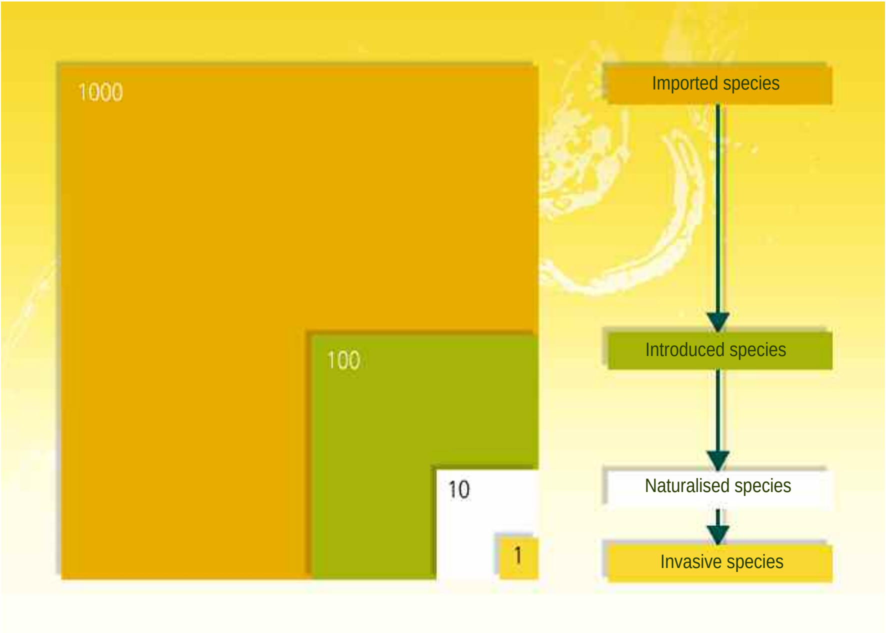


Diagram showing the "Three tens rule" developed by Williamson. According to Mazaubert, 2008.

This empirical rule turns out to be fairly accurate for plant species, however success rates for vertebrates are much higher and range between 15 and 50% (Jeschke and Strayer, 2005). For aquatic species introduced to Europe, a naturalisation rate of 63% has been estimated (García - Berthou *et al.*, 2005).

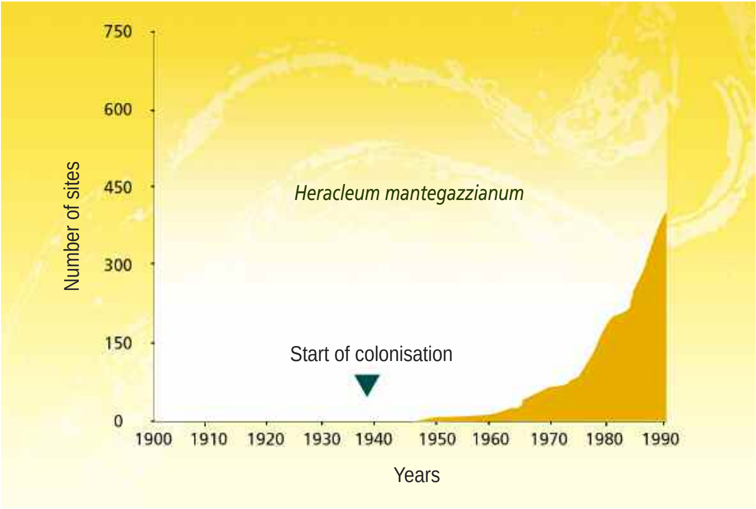
Une phase de latence

The transition over the environmental and reproductive barriers differs significantly among species. It may last several decades and even reach 150 years in some cases (Kowarik, 1995). An alien species can remain in a latent phase over very long periods in the host ecosystem without becoming invasive.

The invasion, when it occurs, may be triggered by ecological modifications in the environment (in some cases caused by human activities, in others not), by biological modification in the species (adaptation to the host environment) or when the species exceeds a population threshold enabling it to grow more rapidly, thus becoming invasive (Soubeyran, 2008).

For example, in their study on the invasion dynamics of giant hogweed (*Heracleum mantegazzianum*) in the Czech Republic, Pyšek and Prach identified a latent phase, following the introduction of the species in the 1800s up to the beginning of the 1940s, during which the population numbers remained very limited (see Figure 19). Subsequently, the number of sites increased sharply. According to the authors, this was due to modifications in the habitats of the species (Pyšek and Prach, 1993 in Muller, 2004).

Figure 19

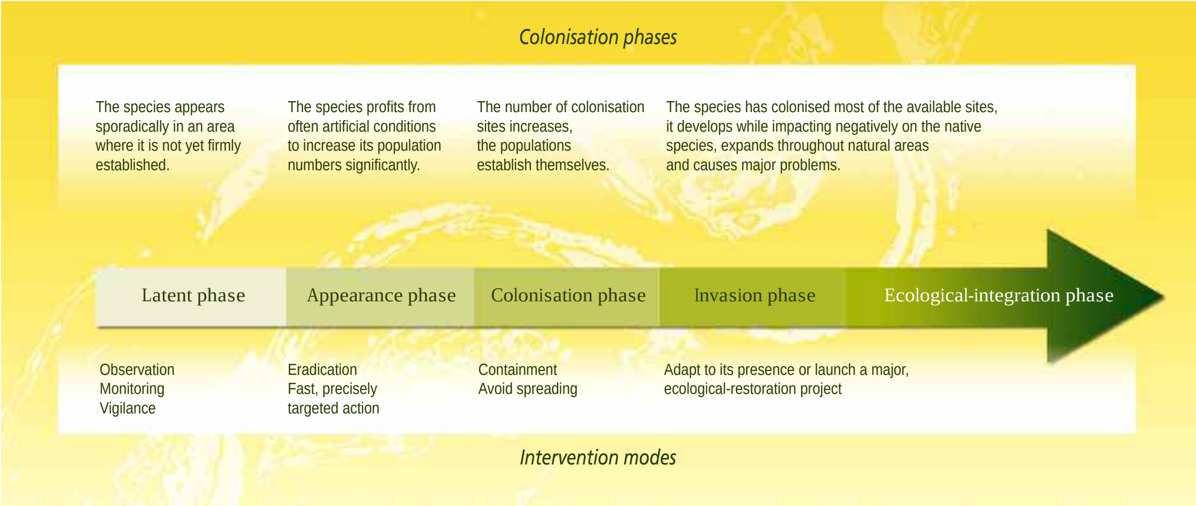


*Graph showing the invasion of giant hogweed (*Heracleum mantegazzianum*) in the Czech Republic over the 1900s. According to Pyšek and Prach, 1993.*

Colonisation phases

The invasion process results in successive colonisation phases in a given area, corresponding to the transitions over the barriers mentioned above. They range from the arrival of the alien species to the point where management difficulties caused by species proliferation are observed. Depending on the species, the potentially effective management techniques can vary according to the current phase and may become increasingly expensive in step with the successive stages in the colonisation process.

Figure 20



The different colonisation phases for an alien species and the corresponding management techniques. According to Mazaubert, 2008.

Before a species arrives in an area, prevention is without any doubt the best solution. An assessment of the risks and a reduction or even the elimination of species movements through improvements in regulations governing the sale of species worldwide, among other methods, would certainly limit the impacts of biological invasions.

Once an alien species has arrived in an area, the most effective and least costly management measures are clearly those taken during the initial phases of the colonisation process (i.e. rapid intervention). During the latent phase, it is difficult to determine whether the species will become invasive, however risk analysis can be carried out on the basis of the available information concerning its colonisation capabilities in other areas, thus making it possible to set up a preventive management strategy comprising, for example, measures to limit species dispersal by humans in the natural environment (raising awareness, restrictions on sales, etc.).

The appearance phase would seem to be the most decisive because eradication remains a feasible objective. The objective is to remove the species and its propagules from the host site in order to avoid any later dispersal. All available knowledge on the species biology and ecology can be of help in selecting the intervention techniques for each particular case.

During the colonisation phase (geographic expansion), any chance of eradication is rapidly lost. Two techniques may be used. The first consists of containing the species within the already occupied area. For the second, managers must monitor the zones around the infested area and set up warning systems in order to halt any progression in the colonisation through measures adapted to the area and the species in question.

During the invasion and ecological-integration phase, the species has firmly established itself, occasionally over vast areas, and its management becomes more difficult and generally expensive (see Box 2). Regular management work is nonetheless indispensable, the objective being to maintain the species within certain limits where the disturbances and/or damage are not overly serious or are deemed tolerable.

Box 2

The time factor in biological invasions

Biological invasions can take place over decades or occur relatively rapidly and often require, for certain species over unforeseeable time periods, expensive management work intended to reduce the perceived negative impacts or the assessed damage. What is the outlook for these situations? Will these species remain invasive for the foreseeable future and cause further disturbances?

It is obviously difficult to provide an answer to such a general question, given the great diversity of situations and the dynamics involved with the various species of fauna and flora. Each situation (a combination of the local area, the invasive species and the human factors) is relatively unique and the management approach must be closely adapted to the local situation if it is to succeed. Management work on certain invasive alien species has been undertaken as soon as the human resources were available for an organised intervention, even before taking into account the status of the species. Concerning plant species, the manual techniques used in agriculture were progressively replaced by mechanised methods that were then transferred to aquatic environments. This is particularly the case for mowing techniques created in the 1920s for lakes colonised by submergent plants, using cutter bars adapted from agricultural equipment and installed on boats (Dutartre and Tremea, 1990). Management of wildlife that damages crops is also well established and the techniques used to kill or trap are still in use today.

Even though a number of studies on the concept of biological invasions took place fairly early, following the work of De Candolle, Darwin and Thellung, actual scientific research on the topic is relatively recent and the book by Elton (1958), titled The *Ecology of Invasions by Animals and Plants*, is generally acknowledged as the first general review of the subject. Since then, a great deal of research has been carried out, but given the recentness of the work, very few projects have studied biological invasions over several decades.

Will the invasive species disappear or, on the contrary, will they integrate the living communities of their host area and play a functional role similar to the native species in these communities? If some of the invasive species are more adaptable to climate change, what would be the consequences on the functioning of ecosystems and on the related services? Could some of the invasive species become domesticated and farmed if the services offered are seen as a means to replace the receding native species?

One example concerning an aquatic plant has been well documented, namely Canadian waterweed (*Elodea canadensis*, Michaux, 1803). This submergent species originated in North America and was noted for the first time in Europe in 1840, near Dublin, then in 1842 in the U.K. and in Belgium and France starting in 1860 (Sculthorpe, 1967). The plant progressively spread throughout Europe, including Scandinavia, and after causing problems in numerous lakes in Western Europe up until the early 1900s, it would now seem to have stabilised and, to our knowledge, no longer causes difficulties, except in the northern countries (Hellsten, Oulu Univ., personal pub.) and on rare occasions (Haury *et al.*, 2010). Today, it is one of the hydrophytes widely prevalent in stagnant aquatic environments or in those with slow to moderate currents in Europe. The plant is still considered an IAS, but its geographic expansion would seem to have stopped. After having been invasive and seen as such for over 50 years, is the plant now an integral part of European hydrophyte communities?

Even when modified by human intervention, the population dynamics of living organisms can take decades to fully develop, an example being the latent phase of certain alien species before they effectively begin to invade. The integration (if it occurs) of invasive species in host communities can undoubtedly take decades as well, which can render an analysis of their evolution highly complex. Water primrose, which has been present in continental France for over 150 years and invasive for approximately 40 years, is regularly consumed by native invertebrates, for example *Ludwigia grandiflora* is consumed by the beetle *Altica lytrhi* (Petelczyc *et al.*, 2006) (see Figure 21). These opportunistic, plant-eating insects may be capable of exerting increasing pressure on the water primrose to the point of reducing its presence in biotopes to levels commensurate with those of native aquatic plants, but over what time frame?

In addition, the co-evolution processes continually at work within communities will also affect at least those invasive species that persist over the long term in their host communities. But how quickly will those processes proceed, what will be the consequences for future ecosystems and what will be the future needs in terms of management?

Figure 21

© J.K. Lindsey

Altica lytrhi is a small beetle that eats large-flower water primrose.

Factors contributing to the success of invasions

The success of an invasion depends on a combination of characteristics specific to the introduced species and to the more or less favourable environmental components in the colonised ecosystem, and on chance (Soubeyran, 2008). Environmental modifications, whether natural or anthropogenic, can also facilitate invasions. The countless number of combinations among these factors makes it very difficult, perhaps impossible, to predict an invasion, even if certain determinants have been identified.

■ Propagule pressures

The success of an invasion may depend on the incoming volumes and species introductions, i.e. the number of individuals introduced and the number of introductions, which have been defined as the "propagule pressure" (Williamson, 1996). The term "propagule" (or diaspore) covers any part of a plant or animal that can be dispersed and give birth to a new individual, for example stalk fragments of large-flowered waterweed (see Figure 22). It has been shown that propagule pressure is generally a factor explaining the success of species in naturalising and the degree of biological invasions (Williamson, 1996; Lockwood, 2005; Colautti, 2006; Dehnen-Schmutz, 2007; Pyšek *et al.*, 2009; Simberloff, 2009). This is because the greater the number of individuals and introductions in a given area, the higher the probability that the species will succeed in establishing itself.

Figure 22

© A. Dutartre, Irstea

Plant fragments deposited on a beach of Parentis-Biscarosse Lake (Landes department). The stalks of certain submergent plants, e.g. curly waterweed or large-flowered waterweed, can survive in water over long periods and are easily transportable. Each fragment is a potential cutting.

■ Characteristics of the host environment

The host environment also plays an important role in an invasion. According to Williamson (1996), all communities may be invaded, but some are more likely candidates due to their fragility. It would seem that ecological disturbances in habitats are a factor contributing to biological invasions. The ecosystems in anthropogenised and artificialised environments have reduced levels of resistance and resilience[4] to withstand invasions (Williamson, 1996; Mack *et al.*, 2000), thus paving the way for opportunistic, alien species. The same is thought to be true for ecosystems where ecological niches are vacant or those comprising a small number of species (Williamson, 1996; Mack *et al.*, 2000).

4. Resilience is the capacity of an ecosystem, confronted with major pressures, to self organise and trend back to its earlier evolutionary trajectory.

■ Biological profile of invasive alien species

A definition of the fundamental characteristics of an invasive species could theoretically make it possible to prevent future invasions and to enhance management strategies and regulations. Unfortunately, though certain invasive species would seem to have shared traits, there are numerous exceptions and the process is made complex due to the many interactions that exist between the characteristics of the species in question, those of the host ecosystem and the conditions under which the introduction takes place (Barbault *et al.*, 2010; Mack *et al*. 2000). For these reasons, it is virtually impossible to establish a "typical biological profile" of an invasive species, if only because there is never one invasion, but many.

Some authors have nonetheless identified certain biological traits that can contribute to the successful establishment of an IAS, such as high reproductive and resource-capture capabilities due to rapid and strong growth, high dispersal capability, good adaptation to disturbances (Pyšek *et al.*, 1995) and behaviour or population dynamics that fit well with human activities (Pascal *et al.*, 2006). These characteristics form the basis of methods to assess the risks of introduction (see Box 3).

For example, Hayes and Barry (2008) reviewed 49 studies testing 115 biological characteristics within seven groups of species. The characteristics that best explain the successful establishment of species have to do with the biogeographic similarity of the original and the new environments, and propagule pressures. Of less importance are the physiology and the morphology of species. Concerning plants, the study showed that the leaf surface area, the sexual reproduction system (dioecy, monoecy, hermaphrodism) and the size of the original distribution range play a central role in the successful establishment of species. For the seven species groups studied, the propagule pressure, also known as the introduction effort, plays a major role in the successful establishment of species and is often encouraged by humans via repeated, intentional introductions.

To date, attempts to predict which species, among a set of potential introductions, are likely to become invasive have met with highly limited success (e.g. Mack *et al.*, 2000). This is because the models used do not take into account the complexity of the analysed system. The biological and ecological profile of invasive species is still very difficult to establish and a prediction of the areas likely to be invaded is even more complex given that little is known about the colonisation capabilities of each species, the characteristics of ecosystems and the interactions between introduced species and each ecosystem.

In spite of the difficulties in attempting predictions, preventive measures remain necessary in the overall management procedures for invasive alien species, which means managers must be able to anticipate on the basis of an assessment of invasion risks.

■ Risk analysis and assessment

Prevention of biological invasions requires regulations making it possible to control the transfers of species on every possible geographic level. This means that an assessment of the invasion risks and of the impacts that a species may cause in a new area is required and must address both the species likely to be imported and those arriving inadvertently.

This risk assessment, taking into account the available knowledge on the biology and ecology of the species in question and resulting in a proposal to include the species in a particular list, i.e. confer upon it a status, should help in formulating the applicable management policy.

This aspect of the preventive measures has been the topic of research and analysis in many countries confronted with diverse types of biological invasions. Numerous procedures are currently available and present a set of characteristics and objectives offering a relatively wide choice, depending on specific context in which the preventive measures are implemented (see Box 3).

Some of the available risk-assessment methods

Weed Risk Assessment (WRA) (Pheloung *et al.*, 1999)

The purpose of this system, developed in Australia, is to accept or refuse species whose importation has been requested, on the basis of 49 questions concerning the biology, biogeography, colonisation history and ecology of the species. A score is given for each criterion and the final score determines whether the importation request is approved, rejected or requires more in-depth study.

Weber and Gut model (2004)

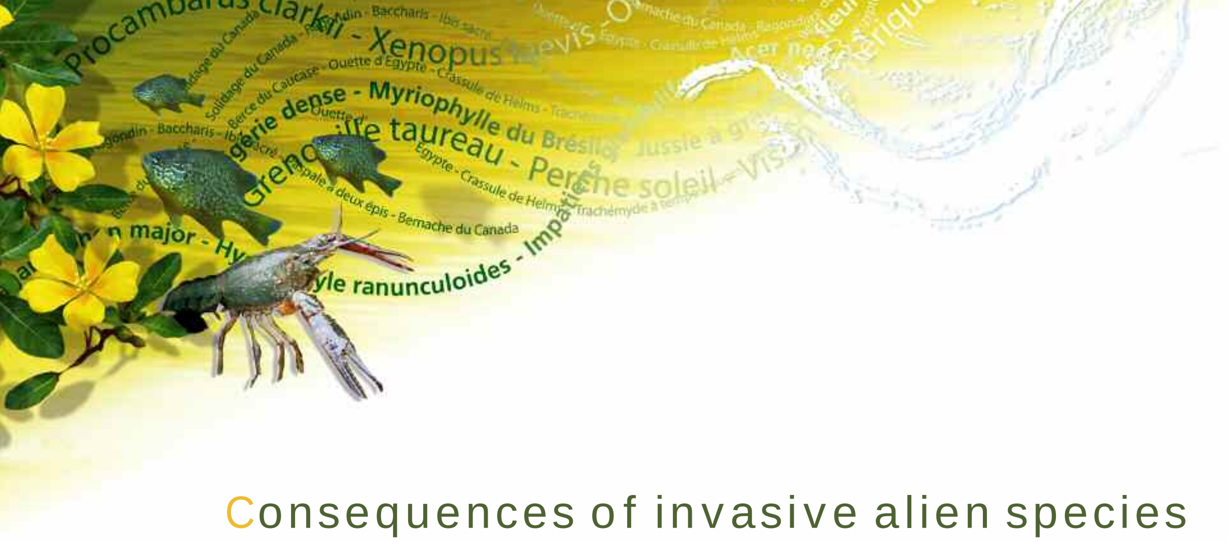
This protocol was developed to assess the risk of proliferation of all types of plants introduced in Europe. The answers to twelve questions on the species (distribution, taxonomy, growth rate, habitats, dispersion, population densities, climate similarity between the original distribution range and the introduction area, viability of seeds and their dispersal, etc.) result in a score ranking the species in different risk categories (low to high).

Pest risk analysis (Fried et Brunel, 2009, Mandon-Dalger *et al.*, 2012).

This is the method used by the European and Mediterranean Plant-Protection Organisation (EPPO). It determines the probability of a new species arriving in a given territory, naturalising there and producing impacts. Where necessary, it can also propose the most suitable control methods. This method can be used for all types of organisms, including plants, insects, bacteria and viruses. Its implementation is relatively long and costly, i.e. it is not easily applicable to all of the potentially invasive species already present in France or Europe. That explains the present need to develop simpler prioritisation tools in view of listing the invasive and potentially invasive species and determining those requiring an analysis of the plant-protection risks involved.

According to Mandon-Dalger *et al.*, 2012, Mazaubert and Dutartre, 2010.

With the above in mind, the French Ecology and Agriculture ministries requested that the State services rank the risks represented by the alien plant species in France and submit a list of the most dangerous species with the background information (Mandon-Dalger *et al.*, 2012). Various methods were then tested taking into account the different levels (regional and national) of management for invasive plants. The pest risk analysis and the Weber-Gut model were deemed the most suitable, however improvements and adaptations concerning the response typologies and the proposed thresholds were requested. An analysis to produce a ranking of habitats on the regional level is also indispensable in order to better determine the impacts that invasive alien species could cause by colonising those habitats (Mandon-Dalger *et al.*, 2012), it being understood that the results are simply a general indication that must be adapted to each particular situation.



Consequences of invasive alien species

The intentional introduction of new species is occasionally justified by the services that they can provide to humans (nutritional or ornamental value, agriculture, hunting, etc.).

However, when a species becomes invasive, the type and level of service provided no longer compensate the disadvantages caused by the proliferation. Not all alien species have consequences deemed serious in the host ecosystem, such as notable changes in status or functional conditions. But some of them produce major impacts, either direct or indirect, on different levels. In Europe, the Delivering Alien Invasive Species Inventories for Europe (DAISIE) programme has estimated that 11% of IASs have negative ecological impacts and 13% have negative economic impacts. The assessment of the annual costs incurred by damage and management work on IASs in Europe as a whole, carried out by Kettunen and his colleagues in 2008, exceeded 12 billion euros (Kettunen *et al.*, 2008).

IAS impacts can be grouped into five categories (Ciruna *et al.*, 2004):

- impacts on biodiversity;
- impacts on the ecological functioning of ecosystems;
- impacts on human health;
- impacts on human safety;
- socio-economic impacts.

In addition, it is important to note that the immediate impact must be put into perspective with the future impacts, or deferred impacts, given the need for mid to long-term management.

Harm to biodiversity

Worldwide, IASs are currently seen as one of the major threats to biodiversity and, according to IUCN, they are the second cause of documented species' extinctions and the third threat to species in danger of extinction (IUCN, 2014).

Over 54% of documented species' extinctions have been linked to IAS impacts and one extinction in five (20%) is directly caused by IASs (Clavero and García-Berthou, 2005). Similarly, Vié *et al.* (2008) estimated that 33% of threatened birds and 11% of threatened amphibians are impacted by IASs. In Europe, out of 395 threatened species, over 110 are directly threatened by IASs (Ciruna *et al.*, 2004). However, proof of extinctions directly linked to IASs are rare and have been documented primarily on islands. In many cases, species' extinctions are the result of a combination of pressures including IASs, but also habitat destruction, overuse, pollution, etc.

IASs can harm biodiversity in a number of ways, including genetics, species and ecosystems, but also communities by impacting their structure and composition (Randall *et al.*, 2009). These impacts are particularly destructive for ecosystems such as freshwater aquatic environments where IASs can cause cascading cumulative effects on the entire food chain.

■ Hybridisation

One form of impacts on genetic diversity is hybridisation where there is a transfer of genes between the introduced species and the native species. This phenomenon is particularly serious when the native species is rare and threatened.

Sterile hybrids can result in a decline in the populations of native species if they represent a majority of the descendants. For example, cross breeding of native Atlantic salmon (*Salmo salar*) and brown trout (*Salmo trutta*) introduced to the Americas has produced sterile hybrids that reduce the population growth rates of Atlantic salmon (Garcia de Leaniz and Verspoor, 1989). Even on the infraspecific level, it is important to note that restocking using farmed brown trout has a negative impact on the genetic integrity of local populations (Berrebi *et al.*, 2000).

If the hybrids are fertile, they can breed among themselves and with the natives. That is the case, for example, of the ruddy duck (*Oxyura jamaicensis*) that breeds with the white-headed duck (*Oxyura leucocephala*), a protected species threatened with extinction and present in Spain (Caizergues and Fouque, 2008). In France, giant hogweed (*Heracleum mantegazzianum*) can hybridise with a subspecies of common hogweed (*Heracleum sphondylium* subsp. pyrenaicum) to produce a hybrid (*Heracleum x carbonnieri Reduron*) that proliferates along rivers in the Eastern Pyrenees. These genetic disturbances threaten the integrity of native species and can propagate genes that are poorly suited to the local ecological conditions, resulting in a gradual decline in the native population (Hulme, 2007). Another potential genetic impact takes place when hybrids have new characteristics enabling them to occupy ecosystems where their parents were absent and in which they can better develop. That is the case, for example, of *Reynoutria* X *bohemica* (see Figure 23), a generally sterile hybrid produced by cross breeding of Japanese knotweed (*Reynoutria japonica*) and giant knotweed (*Reynoutria sachalinensis*). Finally, hybridisation of individuals from the same species, but from different places can explain the high level of genetic diversity found in some invasive populations (sometimes higher than that of the native populations) and their success in invading an area (Kolbe *et al.*, 2004).

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Figure 23

© J.-P. Reygrobellet

*Bohemian knotweed (*Reynoutria X bohemica*).*

■ Predation and competition

Modifications in species' diversity may be qualitative (replacement or exclusion of a native species) and/or quantitative (reduction in population numbers) (Hulme, 2007). Examples of causes of changes in species' richness are interspecific competition for food and habitats or direct predation. Competition may reduce and in some cases totally eliminate native species over a more or less large part of their distribution range. In other cases, however, it can stimulate diversity and even encourage native species. An analysis of system evolution must address not only temporal, but also organisational aspects.

Invasive alien predators with opportunistic feeding habits (wide feeding spectrum) can have a serious impact on native populations. In the U.K. for example, the American mink (*Neovison vison*) is responsible for the decline in vole populations (*Arvicola terrestris*) (Bonesi *et al.*, 2006). Muskrats (*Ondatra zibethicus*) eat freshwater mussels and have often caused local extinctions (Jokela and Mutikainen, 1995).

Competition for resources between IASs and native species is often difficult to document or to quantify, notably for animals, for which the data are often based on discrete observations (Hulme, 2007). For plants on the other hand, competition for light, e.g. between box elder (*Acer negundo*) and white willow along rivers (Bottollier-Curtet *et al.*, 2012), and nutrients has been better documented (*European Environment Agency*, 2012). Similar to certain dominant native species, many invasive alien plant species end up forming a monospecific cover, thus leading to a major reduction in the richness of local species (Muller, 2004; Fried *et al.*, 2013).

■ Transmission of pathogens and parasites

Biological invasions may also have negative health consequences due to the direct introduction of pathogens, contaminated carriers or the emergence of new pathologies. American bullfrogs (*Lithobates catesbeianus*, see Figure 24a) and the African clawed frog (*Xenopus laevis*) are the healthy carriers of a parasite fungus, *Batrachochytrium dendrobatidis*, acknowledged as a major cause in the extinction of native amphibians (Berger *et al.*, 1999). That is also the case for the three native crayfish species in France, stone crayfish (*Austropotamobius torrentium*), noble crayfish (*Astacus astacus*) and white-clawed crayfish (*Austropotamobius pallipes*), that are sensitive to "crayfish plague" (aphanomycosis), a deadly pathology caused by a water mold (*Aphanomyces astaci*) carried by American crayfish, namely the Eastern crayfish (*Orconectes limosus*), signal crayfish (*Pacifastacus leniusculus*) and red swamp crayfish (*Procambarus clarkii*), that were introduced in the 1900s and are now widely present throughout France (see Figure 24b) (Diéguez-Uribeo and Soderhall, 1993).

Figure 24

a © E. Mazaubert
b © N. Poulet, Onema

An American bullfrog (a) and the red swamp crayfish (b), healthy IASs that carry pathogens.

When these species dominate, their overall impact can lead to a thinning of native biological communities and to a more or less significant transformation of ecosystems, which can in turn lead to more uniform environments and living communities.

Impacts on the ecological functioning of aquatic ecosystems

■ Modifications in food chains

One may reasonably assume that any introduction of an alien species is likely to modify the food chain in the colonised environment. Though that is not always the case (see the example of top-predator fish introduced into lakes, Boulêtreau, 2012), there are some particularly striking examples where it is the case, e.g. for invasive bivalve molluscs such as the zebra mussel (*Dreissena polymorpha*) and Asian clams (*Corbicula* spp.). These organisms filter water (one to two litres per day for an adult mussel) in order to breathe and to feed on very small phytoplankton and zooplankton. All suspended matter in the water that is smaller in diameter than the inhalant siphon is drawn into the animal. This filtering activity creates a link between the water column and the river bed, i.e. between the seston (particles in the water column) and the benthos. When zebra mussels and clams proliferate, the living communities are subject to benthification, i.e. the filtration activity transfers the biomass (essentially phytoplanktonic) from the seston to the bed via the digestive waste. The sharp drop in phytoplanktonic and zooplanktonic biomass results in clearing of the water, grass beds grow and the other compartments (fish, invertebrates) chain react to the modifications. It may be tempting to see this situation as an improvement in water quality, however the consequences of bivalve invasions are complex (see the section on pH and dissolved oxygen below) (Beisel, 2014). For example, the composition of algal communities changes, in particular the type of dominant species. In some cases, green algae and diatoms gain the upper hand, in others cyanobacterial blooms, e.g. *Microcystis aeruginosa*. Another example is the red swamp crayfish. Its invasion in the Brière marshes resulted in a profound modification of the food chain by becoming the main link in the transmission of energy to fish (Paillisson *et al.*, 2012), a role probably played previously by various species of benthic invertebrates that have become very rare.

■ Temperature and gas exchange

In stagnant environments, the density of invasive alien grass beds can create temperature gradients having a negative impact on aquatic fauna and flora. This plant cover limits gas exchange with the atmosphere (Lejas, 2002) and is not specific to alien species. However, native species that develop in this manner generally cover small surface areas or special biotopes.

■ pH and dissolved oxygen

The proliferation of submergent plants, whether alien or not, can produce significant variations in the pH and dissolved-oxygen levels over the day that are detrimental to animals. Oxygen saturation levels can reach 200% at the end of the day, followed by extremely low saturation levels at the end of the night, and pH levels can change by a full two units (Dutartre *et al.*, 2009). The intensity of these nyctohemeral variations depends on the quantity of plant biomass and on the water renewal rate. The variations are particularly severe in stagnant environments. Among invasive alien species, the submergent Hydrocharitaceae, i.e. tape grasses (*Elodea* spp., *Egeria densa, Lagarosiphon major*) are capable of producing such variations.

Bivalve molluscs filter water in order to feed and to draw oxygen. The decomposition of organic matter falling to the bed also consumes oxygen. During the summer, the period of low-flow levels and high temperatures, the effect of bivalve molluscs on oxygen levels can lead to a lack of oxygen detrimental to other compartments, notably fish (Beisel, 2014).

When oxygen levels in water fall below 2 mg/litre, no fish species can survive. That can occur when water primrose (*Ludwigia* spp.) or parrot-feather watermilfoil (*Myriophyllum aquaticum*) proliferate in stagnant environments. Their dense beds cover the water and block oxygen exchanges.

■ Light

The growth of grass beds, whether alien or native, that are highly productive at the water surface can lead to a drop in light levels and consequently to a reduction in the potential development of other plants. This phenomenon may represent a risk of uniformity when the shade impacts one or more species, thus limiting the overall biological richness of the habitat. This can occur following the development of dense beds of submergent plants that rise to the surface or of floating plants. For example, among the submergent alien species, a bed of large-flowered waterweed (Egeria densa) blocks the penetration of light at one metre depth to 1% of the incident light (Nakanishi *et al.*, 1989). The same is true for duckweed (Lemna spp.). Among the alien species, least duckweed (Lemna minuta, see Figure 25) and red duckweed (Lemna turionifera) can reduce the incident light in water by 80% and cause the elimination of submergent plants (Peltre *et al.*, 2002). Invasive fauna, such as the common carp (Cyrpinus carpio), can also cause aquatic plants to disappear through grazing, but also through their agitation which results in high levels of suspended matter that limit light penetration into water (Weber and Brown, 2011).

Figure 25

© E. Mazaubert

*Duckweed (*Lemna spp.*).*

■ Undermining of river banks and infrastructure

When digging their burrows, coypus (*Myocastor coypus*), Eastern crayfish (*Orconectes limosus*) and red swamp crayfish (*Procambarus clarkii*), can destabilise river banks and provoke their collapse. An example from the plant kingdom is Japanese knotweed (*Reynoutria japonica*), which can facilitate winter erosion of banks along some rivers because it eliminates the native vegetation, but provides no cover for the banks (Ciruna *et al.*, 2004). In addition, its roots can penetrate concrete, a risk for structures installed in and along rivers. These impacts are not limited to IASs, but their colonisation capabilities means they can produce those impacts over large areas.

■ Uniform landscapes

When certain species, such as knotweed (*Reynoutria* spp.) or garden balsam (*Impatiens* spp.), spread rapidly over large areas along rivers, the result can be uniform landscapes and environments. The same is true for water primrose (*Ludwigia* spp.) that has colonised dozens of hectares of wet meadows, thus modifying the perception of marshes such as those in the Brière region (Haury and Damien, 2012). Once again, these impacts are not limited to IASs, but their speed of colonisation can significantly modify a landscape in just a few years.

■ Modifications in flows and sedimentation

When an aquatic plant proliferates, the growth in plant biomass can slow the flow of water in rivers. This slowing of the current and the density of the plants can temporarily trap sediment in the plant beds. The vast quantities of biomass and the sediment can reduce the bankfull cross section in rivers and lead to an elevation in water levels in the affected areas, resulting in some cases in spring flooding without any increase in the river discharge. This phenomenon can also cause flooding during the first high-water events in the fall (Peltre *et al.*, 2002). The very high levels of biomass produced by certain invasive plants such as waterweeds can significantly contribute to these phenomena in rivers even if some native species are also capable of provoking local flooding, e.g. river water-crowfoot (*Ranunculus fluitans*).

Impacts on human health

Similar to various native mammals, certain alien mammals can transmit diseases, for example coypus (*Myocastor coypus*) and muskrats (*Ondatra zibethicus*) can transmit via water numerous diseases to humans, including leptospirosis and echinococcosis, which can also be transmitted to livestock (Waitkins *et al.*, 1985). The Siberian chipmunk (*Tamias sibiricus*, see Figure 26), a new, authorised pet, can carry the bacteria causing Lyme disease (Chapuis *et al.*, 2010). The pollen produced by a number of plant species can also create more or less serious risks for human health, including allergies. That is the case for native species such as birch trees and grasses, but some IASs are also well known in this field, e.g. giant hogweed (*Heracleum mantegazzianum*), where a simple contact can cause serious dermatitis (Lagey et al., 1995) and, above all, common ragweed, whose pollen can cause allergies in many people. Allergies to common ragweed were treated for approximately 230 000 people in 2011 in the Rhône-Alpes region alone, costing between 14.2 and 20 million euros (Observatoire régional de la santé Rhône-Alpes, 2012).

Figure 26

© J.L. Chapuis

The Siberian chipmunk can carry the bacteria that cause Lyme disease.

Impacts on human safety

A number of vertebrates, both native (wild boar, deer) and alien, can cause accidents on the road or in the air. Alien species that have caused problems in this field are, among others, in the Netherlands the Egyptian goose (*Alopochen aegyptiacus*) and in the U.K. the Canada goose (*Branta canadensis*), whose large flocks hinder the take-off of planes from airports (Gyimesi and Lensink, 2010; Watola and Allan, 1999).

The rapid growth of certain aquatic plants in large rivers, both native such as river water-crowfoot and alien, e.g. waterweed, can result in safety problems for nuclear power plants, in particular on the Loire and Rhône Rivers, where masses of plants floating down the river block the pumping intakes for cooling water. Some molluscs, such as the Zebra mussel (Dreissena polymorpha, see Figure 27), can colonise the intakes in numbers, causing the same problems (Khalanski, 1997).

Figure 27

© USGS

Dreissena polymorpha.

Economic impacts

The impacts of invasive alien species do not concern biological functions alone, they can affect a number of economic sectors. This may have several consequences.

■ Loss of production for certain industries (commercial sea fishing and aquaculture)

For example, the *Mnemiopsis leidyi* (see Figure 28), a North American carnivorous ctenophore inadvertently introduced to the Black Sea via ballast water, caused the collapse of commercial anchovy fishing, with losses estimated at over one billion dollars (Ivanov *et al*., 2000). Agricultural losses due to the eating of crops along aquatic environments by rodents such as coypus and muskrats have also been frequently mentioned (Panzacchi *et al*., 2007).

Figure 28

© S.G. Johnson

Mnemiopsis leidyi, *a North American carnivorous ctenophore introduced into the Black Sea and recently observed in the Thau Lake (Hérault department, France).*

■ Reduced availability and accessibility of water for industrial companies due to blocked pipes, air vents, water inlets/outlets

In addition to the safety risks, the accumulation of zebra mussels (*Dreissena polymorpha*) can have a functional impact on certain nuclear power plants in France, such as Cattenom on the Moselle River, Golfech on the Garonne River or Bugey on the Rhône. The installations must be cleaned when they are pulled out of the water or divers can even be required for cleaning in some cases (Khalanski, 1997).

■ A physical hindrance for fishing and recreational boating

The formation of dense beds of invasive macrophytes such as curly waterweed (*Lagarosiphon major*), large-flowered waterweed (*Egeria densa*), water primrose (*Ludwigia* spp.) and parrot-feather watermilfoil (*Myriophyllum aquaticum*, see Figure 29) can limit navigability on lakes and rivers (Nepveu and Saint-Maxent, 2002) and justify repeated macrophyte harvesting (Dutartre *et al.*,1989; Haury and Bouron, 2012). In some cases, the presence of large numbers of birds on sites used by humans can provoke significant disturbances. For example, a large population of Canada goose (*Branta canadensis*) and eutrophication of bathing water caused by their waste made it necessary to close a recreational centre in the Paris region (Fouque *et al.*, 2011c).

Figure 29

© F. Mercier, CEN BN

Manual removal of parrot-feather watermilfoil.

■ Direct damage to infrastructure

Coypus (*Myocastor coypus*) cause major damage. Their burrows destabilise river banks and dikes, resulting in repair costs of several million euros in some cases (Panzacchi *et al.*, 2007).

These impacts have major economic consequences, but remain difficult assess, even if they are better perceived, evaluated and taken into account than the ecological impacts, given their monetary value.

An assessment of IAS impacts on ecosystem services (see Table 4 on the next page), which would constitute a useful addition to the analysis of the damages effectively caused by biological invasions, requires significant further work (Vilà *et al.*, 2010).

Table 4 *Impacts of invasive alien species on ecological services in Europe. According to Vilà* et al.*, 2010.*

Supply services	Regulatory services	Support services	Cultural services
■ Loss or gain of food, material, fibres ■ Threats to native species ■ Alteration of genetic resources	■ Alteration of biological control functions ■ Modification of pollination services ■ Pathogen transmission ■ Protection against natural hazards ■ Modification of erosion functions ■ Water purification and regulation ■ Bioaccumulation	■ Modification of soil and sediment composition ■ Alteration of nutrient cycles ■ Changes in communities ■ Modifications in primary production	■ Effects on ecotourism ■ Changes in landscape perception ■ Aesthetic impacts ■ Changes in local habits

In continental France, little is known on the consequences of invasions in the environment, due to a lack of sufficient experimentation and suitable research (Haury *et al.*, 2010). Gaps in knowledge concerning historical data on species distributions and ecosystem functioning must be filled in if progress is to be made in this field. The absence of untouched control sites for comparative analysis and the difficulties encountered in setting up long-term monitoring systems constitute two more major handicaps in pursuing assessments.

Sociological aspects

Here an obvious characteristic makes itself felt again, i.e. we are confronted with highly diverse biological invasions and not simply with a single process to which an overall analysis can be applied. Depending on the causes of their introduction and the more or less perceptible negative impacts, IASs, as defined in terms of the management needs of the concerned ecosystems, can be seen by the public in totally different, even opposing ways.

Ranging from dramatic, doomsday predictions to the behaviour of certain urban dwellers toward coypu populations in cities, as noted by Olivier Sigaut (2012) in his text *City coypus vs. country coypus*, there are many perceptions concerning alien species and biological invasions.

The vision of a “stable and harmonious world” (Maris, 2010), which was still dominant at the start of the 1800s, progressively gave way following the work of Darwin and many other researchers, and eventually became more realistic and less influenced by religious certainties. An example is a book published in 1867 by George P. Marsh, a naturalist and diplomat, who noted that *“man is everywhere a disturbing agent. Wherever he plants his foot, the harmonies of nature are turned to discords. The proportions and accommodations which insured the stability of existing arrangements are overthrown. Indigenous vegetable and animal species are extirpated, and supplanted by others of foreign origin. Spontaneous production is forbidden or restricted, and the face of the earth is either laid bare or covered with a new and reluctant growth of vegetable forms, and with alien tribes of animal life.”*

Well before the work by Elton (1958) and obviously prior to the emergence of the term “biological invasion”, studies addressed these issues of species transfers, the negative impacts in some cases and management requirements. The initial reactions and management efforts concerned the alien species having direct impacts on agricultural production and were thus focussed on areas and their surroundings with significant human activities.

In this context, the work was planned and implemented as a battle to eliminate the damage to agricultural production and the regulations that were progressively established also contributed to this protective approach.

Changes then occurred that completely modified this approach to the management of invasive species:

- a vast increase in the numbers of introductions, due in part to increasing demand for ornamental plants and pets (particularly "new pets");
- dispersal of these species to non-agricultural environments, i.e. urban and rural areas;
- increases in environmental disturbances, including in the aquatic environments, facilitating certain dispersals;
- better understanding and acknowledgement of the ecological functioning of ecosystems and a widening of management objectives to include all environments;
- etc.

IAS management efforts progressively spread to more "common" environments, originally seen as having no particular use value, contrary to agricultural land. They took on importance in step with the disturbances caused by these species in the functioning of environments and with the development of new activities, often corresponding to a "need for nature" that it was possible to satisfy. More recently, it became necessary to expand the work to protecting biodiversity, for which the biological invasions constitute a disturbance.

Part of IAS management remains focussed on the studies and approaches that originally dealt with crop protection, clearly in view of eliminating "weeds" and "harmful" animals, terms which also apply to native species. That is even today a common theme in efforts to inform the general public on IASs. However, the expansion of management to different environments and ecosystems, for different needs, should inspire us to renew our analysis of current work, not necessarily in view of modifying the objectives, but perhaps in order to better assess the issues, expectations and, in some cases, the practical work conditions.

The relation to nature of the general public and the stakeholders in IAS management, as well as the aesthetic properties and visibility of species (Dalla Bernardina, 2010) largely determine perceptions. Very popular ornamental plants, e.g. the water hyacinth, see Figure 30) and fashionable pets are initially seen in a positive light. Then, when the plants escape from their basins and become disturbances in "natural" landscapes or when animals proliferate, opinions change from interest to rejection and requests for intervention. The increasingly frequent information on IASs in the media and the management work undertaken have contributed to convincing of the need for interventions, but it is interesting to note that the objective of eradicating species is more rarely mentioned. It would seem that the information disseminated by researchers, experts and the managers themselves has in fact been understood by the mainstream media.

Figure 30

*The beautiful flowers of the water hyacinth (*Eicchornia crassipes*) have contributed considerably to its dispersal over the entire planet.*

A further difficulty in this field arises from the fact that perceptions can differ extremely between plants and animals, particularly as concerns mammals and birds. These two groups of animals are generally seen, at least initially, in a much more favourable light than the other IASs. A part of the public is attached to the aesthetics of birds and the behaviour of mammals similar to that of farm animals or pets, which may explain certain negative comments on, for example, the programme to eradicate the sacred ibis and the shooting of Canada goose on sites visited by the public.

Though the alien origin of IASs is generally mentioned in the media, it is less often explicitly seen as the main reason for the damages caused by these species. On the other hand, that origin has been used by certain researchers to criticise management programmes, accusing them of nativism (a political opinion found in countries with many immigrants, such as the U.S., and opposed to any new immigration), xenophobia and even racism, in reference to the fears aroused by globalisation, thus creating a degree of confusion concerning management objectives ("eliminate the foreigners"). On this topic, Simberloff (2003) reviewed many of these opinions and demonstrated that this criticism of work to control biological invasions often neglected the ecological and economic impacts of IASs. He was of the opinion that *"These impacts ... constitute a cogent, ethical basis for management of introduced species"*.

This ethical basis cannot, however, confer indisputable and permanent legitimacy on all interventions. This is because IAS management objectives and conditions are directly confronted with a number of limits, socio-economic (the perceptions and financial decisions of societies), scientific (current knowledge) and technical (intervention possibilities), in a world and environments subject to rapid and uncertain dynamics. What do we know of the future and the potential roles played by certain invasive, currently regulated species in ensuring the functions of aquatic environments in a context of climate change (Dutartre *et al.*, 2012)? This ethical basis is but one of the elements requiring regular reappraisal in terms of management objectives and how they should be implemented.

But perceptions concerning IASs and the resulting relations do not consist solely of these management issues. In an increasingly urban world, the relations between city people and nature are evolving rapidly and the "need for nature" can occasionally take on strange forms. The example of coypus in urban areas (Sigaut, 2012), where they are welcomed and fed by people, whereas their populations are regularly trapped in rural areas, illustrates the diversity of the existing perceptions (see Figure 31).

It also explains why, in a periurban recreational centre in the Paris region, trapping and shooting of the many coypus causing various damages had to be planned at times when families bringing bread were not present on the site, in order not to shock the children and their parents (B. Breton, personal pub.).

Figure 31

© N. Poulet, Onema

Coypus are a true attraction in urban areas.

This inherent complexity in the relations between humans and biological invasions should inspire us to continuously maintain an analytical attitude toward management policies, with regular reappraisals of the issues, objectives, intervention conditions, as well as how communication is carried out with the other stakeholders, including the general public. Awareness of all aspects of management must be maintained if we are to improve it.

Further research

In spite of the significant progress made over the last few years, a great deal of research is still required on numerous aspects of invasive alien species. To enhance IAS management, research must be pursued on various issues, targeting different objectives, including species biology and ecology, invaded environments, monitoring and surveillance methods, intervention techniques, economic assessment of damage and intervention programmes, etc. Research programmes clearly addressing IAS management have yet to be developed in view of encouraging partnerships between researchers and managers. It should be noted, for example, that the INVABIO programme set up by the Ecology ministry from 2002 to 2006 funded approximately 30 research projects of which only one-third addressed management issues.

Need for taxonomic progress

People are not always fully aware of or understand taxonomy, which makes it more difficult to set up monitoring programmes and quarantines. Better information on the numbers and identity of introduced species will require further taxonomic research. Similarly, because some IASs are immediately identifiable but other are not, efforts to identify the taxonomic criteria of use for routine work are required in view of developing a permanent monitoring network across the country. In addition to standard identification based on species morphology, work on genetics, including research on environmental DNA (Miaud *et al.*, 2012), should produce major improvements in this field.

Pursue research on species biology and ecology

It is clear that invasion mechanisms must be better understood in order to better anticipate them. In particular, IAS effects on ecological processes such as the structure of food webs, energy flows and IAS dispersal conditions also require a great deal of work.

Improvements in surveillance methods and systems, in early detection of invasions and monitoring systems are required. Solutions must be developed to rapidly draw up species inventories that are reliable and cost effective. They are indispensable components in establishing early-detection and monitoring networks that make possible rapid interventions. Innovative technologies for inventories, such as the molecular methods capable of detecting DNA in aquatic environments (method used to detect American bullfrogs and currently being developed for the African clawed frog, Dejean *et al.* (2012)), must be perfected and the corresponding marker banks must be expanded.

The development of technical solutions for management requires excellent knowledge of species biology and ecology, notably for trapping, the use of biocides and for biological control. Population dynamics, parasite interactions and species ecophysiology are some of the fields that research must address.

Other research issues that merit work include:

- what are the short and long-term impacts of hybridisation and genetic-introgression phenomena following the establishment of IASs?
- how can IAS impacts be distinguished from the consequences of other forcings, such as habitat loss, pollution in aquatic environments and modifications in hydrological connectivity?
- what are the key factors in ecosystem resistance and resilience when confronted with biological invasions?
- what processes can facilitate the integration of certain invasive species in host communities?
- how can invaded ecosystems be stabilised and over what time frame?
- what forecasts can be made concerning the future relations between biological invasions and climate change?

Study and quantify the ecological, health and economic impacts

The ecological and socio-economic impacts caused by most IASs are generally not well documented locally. Policy makers and managers nonetheless need information on the costs of the damage incurred by IASs and cost-benefit analyses for their management, in view of setting priorities for action. The economic and financial information, i.e. the costs of interventions, constitute the only available data and are not sufficient for prioritisation. Existing studies generally concern the species having major economic impacts and there are few studies on IAS impacts on ecological services. Studies are often launched fairly late, when introductions have already occurred and data on the initial status are no longer available, which makes it difficult to determine the ecological and economic impacts of a species.

Invasive alien species and the human and social sciences

Socio-cultural impacts are rarely addressed in studies on how invasions are perceived by local communities, whose opinions in some cases can differ from those of researchers and managers (Menozzi and Pellegrini, 2012).

Research on the links between socio-economic and environmental sectors, including the feedback loops between them, must be developed to assist in creating better decision-aid tools. Communication strategies designed to prevent invasions must also be devised to raise the awareness of stakeholders and the general public.

Generally speaking, the emergence of these problems on the international level raises the question of how human societies relate to the non-human species making up “nature”. This question involves numerous aspects, philosophical, ideological, etc., that should induce a major cultural shift, i.e. the change from being consumers of nature to managers and caretakers.

Research and management

Applied research, in close partnerships with the managers of natural areas, should make it possible to improve control and restoration methods, and to assess the technical and economic feasibility of a project (Dutartre, 2010). Among the research topics that should be developed to provide managers and policy makers with the critical tools required to set up effective management strategies, we should mention (Soubeyran, 2008):

- improvements in surveillance methods, in early-detection and monitoring systems;
- ranking of the ecological and socio-economic impacts by different stakeholders, thus putting the managers of natural areas and policy makers in a position to set priorities for action;
- development of control and eradication techniques for invasive species;
- increased production and marketing of native species for the ecological restoration of aquatic environments, that could also serve for the landscaping and ornamentation of sites;
- enhanced knowledge to improve the operational management of species in terms of inventories, distribution, geographic dynamics, evolutionary factors, impact factors, etc.;

- support for and contribution to the formulation of regulations, to public awareness and information, on the basis of confirmed scientific data.

It should be noted that IASs are a cross-cutting topic due to the different biological mechanisms governing their appearance in an area, their installation and their spatial and temporal dynamics. These issues must be taken into account in conjunction with other global issues such as environmental degradation and climate change. Financial support for research programmes would thus appear indispensable for all effective management strategies based on solid scientific data and addressing invasive alien species.

This chapter was drafted by:
Emilie Mazaubert (Irstea),
Emmanuelle Sarat (IUCN French committee).

With the collaboration of:
Jean-Marc Cugnasse (ONCFS),
Alain Dutartre (independent expert, formerly at Irstea),
Pierre Ehret (Agriculture ministry),
Nadia Le Botlan (Ecology ministry),
Roland Matrat (Pays-de-la-Loire regional environmental directorate),
Nicolas Poulet (Onema),
Yohann Soubeyran (IUCN French committee).

The list of texts proposed in this chapter is not intended to be absolutely complete. It constitutes a panorama of the main conventions, agreements, laws and regulations concerning invasive alien species in aquatic environments applicable internationally, in Europe and in continental France.

The legal and regulatory situations presented in this chapter pertain to the texts as they existed at the time of writing (October 2014).

Legal framework and regulations on invasive alien species

2

International level

On the international level, the preliminary work for conventions indicates growing awareness of the issues involving invasive alien species. They provide the ratifying countries with important guidelines on how to prevent introductions and to manage invasive alien species.

Convention on biological diversity (CBD)

In May 1989, the United Nations Environment Programme (UNEP) set up a special work group of technical and legal experts to create an international legal document concerning the conservation and sustainable use of biological diversity. In February 1991, the special work group became the Intergovernmental negotiation committee. The committee terminated its work on 22 May 1992 at the Nairobi conference with the adoption of the Convention on biological diversity.

Initial signing of the CBD took place on 5 June 1992 at the United Nations Conference on Environment & Development (the “Earth summit” in Rio). The convention entered into force on 29 December 1993 and was ratified by France on 1 July 1994.

The CBD proposed significant progress in regulations governing the conservation of biological diversity, the sustainable use of its components and a fair and equitable sharing of the advantages derived from the use of genetic resources (http://www.cbd.int/convention/default.shtml).

The CBD, in its article 8.h, stipulates that "Each Contracting Party shall, as far as possible and as appropriate… ***Prevent the introduction of, control or eradicate those alien species which threaten ecosystems, habitats or species".***

The Conference of the Parties (CoP), the executive arm of the CBD, directs its implementation through decisions taken during its periodic meetings. A number of these decisions concern invasive alien species:

- decision IV/1 by CoP 4 (1998) devoted a paragraph to invasive alien species representing a threat for ecosystems, habitats and species, and noted that the CoP “Decides that alien species is a cross-cutting issue for implementation of many of the themes of the Convention”;
- decision V/8 by CoP 5 (2000) concerning invasive alien species representing a threat for ecosystems, habitats and species, the CoP “Decides that alien species is a cross-cutting issue for implementation of many of the themes of the Convention” and set in Annexe I “Interim guiding principles for the prevention, introduction and mitigation of impacts of alien species” and in Annexe II, the “Outline for case studies on alien species”;

- decision VI/23 by CoP 6 (2002) included the adoption of guiding principles for the prevention, introduction and mitigation of impacts of alien species threatening ecosystems, habitats and species;
- decision VII/13 by CoP 7 (2004), the CoP "Notes that specific gaps in the international regulatory frameworks at global, regional and national levels persist [...]" and "Requests the Subsidiary Body on Scientific, Technical and Technological Advice [SBSTTA[5]] to establish an ad hoc technical expert group to address gaps and inconsistencies in the international regulatory frameworks at global and regional levels [...]";
- decision VIII/27 by CoP 8 (2006) defined the measures by which the Parties, other governments, relevant organisations and the Executive Secretary should address identified introduction paths of invasive alien species;
- decision IX/4 by CoP 9 (2008) proposed an in-depth examination of current work on alien species threatening ecosystems, habitats and species;
- decision X/38 by CoP 10 (Nagoya, 2010) enabled the CoP to establish and determine the mandate of an "ad hoc technical expert group on addressing the risks associated with the introduction of alien species as pets, aquarium and terrarium species, and as live bait and live food".

(http://www.cbd.int/decisions/)

During CoP 10 in Nagoya in 2010, the Parties also adopted the **Strategic plan for biodiversity 2011-2020,** which set approximately 20 objectives (Aichi targets) to be met by 2020. In strategic goal B to "Reduce the direct pressures on biodiversity and promote sustainable use", target 9 states "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".
(http://www.cbd.int/doc/decisions/cop-10/cop-10-dec-02-en.pdf)

Box 4

Guiding principles set in Annexe I of decision V/8 by CoP 5 (2000)

1. Precautionary approach
2. Three-stage hierarchical approach
3. Ecosystem approach
4. State responsibility
5. Research and monitoring
6. Education and public awareness
7. Border control and quarantine measures
8. Exchange of information
9. Cooperation, including capacity-building
10. Intentional introduction
11. Unintentional introductions
12. Mitigation of impacts
13. Eradication
14. Containment
15. Control

5. The SBSTTA is open to the participation of all Parties. A multidisciplinary group, it comprises governmental representatives in charge of the specific fields in question.

Convention on international trade in endangered species of wild fauna and flora (CITES)

The Convention on international trade in endangered species of wild fauna and flora (CITES or Washington convention) was signed in Washington on 3 March 1973 and entered into force on 1 July 1975. In France, the convention was approved on 11 May 1978 and entered into force on 9 August 1978.

In that trade in wild fauna and flora ranges far beyond national borders, its regulation requires international cooperation to preserve certain species. Designed in a spirit of cooperation, CITES now protects, under different conditions, over 30 000 wild species. The Convention also ensures that international trade in wild animal and plant specimens does not threaten the survival of the species in question.
(http://www.cites.org/eng)

The countries having ratified CITES are members of the Conference of the Parties (CoP). The CoP meets regularly (every 2 to 3 years), primarily to monitor CITES application and to adopt new resolutions.

Among these resolutions, the resolution Conf. 13.10 (Rev. CoP14) concerns **trade in invasive alien species** for which the CoP recommends that the Parties:

- "a) consider the problems of invasive species when developing national legislation and regulations that deal with the trade in live animals or plants;"
- "b) consult with the Management Authority of a proposed country of import, when possible and when applicable, when considering exports of potentially invasive species, to determine whether there are domestic measures regulating such imports; and"
- c) consider the opportunities for synergy between CITES and the Convention on Biological Diversity (CBD) and explore appropriate cooperation and collaboration between the two Conventions on the issue of introductions of alien species that are potentially invasive."

This resolution was amended during CoP 14, held in the Hague (Netherlands) from 3 to 15 June 2007.
(www.cites.org/eng/res/13/13-10.shtml,
www.cites.org/eng/res/13/13-10R14.php)

In Europe, CITES resolutions are implemented by EU regulations that are regularly updated (see page 55).

Convention on the conservation of migratory species of wild animals (CMS)

This convention was signed in Bonn (Germany) on 23 June 1979 and entered into force in France on 1 July 1990. Its purpose is to ensure the conservation of all terrestrial, aquatic and avian migratory species throughout their distribution range.
(http://www.cms.int/en/)

Two articles in the convention mention the introduction of alien species:

- article III 4.c): *"Parties that are Range States of a migratory species listed in Appendix I [endangered migratory species] shall endeavour [...] to the extent feasible and appropriate, to prevent, reduce or control factors that are endangering or are likely to further endanger the species, including* ***strictly controlling the introduction of, or controlling or eliminating, already introduced exotic species";***
- article V 5.e): *"Where appropriate and feasible, each agreement [Appendix II: migratory species covered by*

international agreements for their conservation and management] should provide for but not be limited to [...] conservation and, where required and feasible, restoration of the habitats of importance in maintaining a favourable conservation status, and protection of such habitats from disturbances, including, ***strict control of the introduction of, or control of already introduced, exotic species detrimental to the migratory species".***

In France, decree 90-962 (23 October 1990) published the convention.

(http://www.legifrance.gouv.fr/affichTexte.do?cidTexte=JORFTEXT000000168211&categorieLien=cid)

Agreement on the conservation of African-Eurasian migratory waterbirds (AEWA)

AEWA is an independent international treaty drafted under the auspices of the U.N. environment programme and the Bonn convention (CMS). It was approved on 16 June 1995 in the Hague (Netherlands). The convention was signed by France in 1996 and entered into force on 1 November 1999.

■ Article III of the Agreement on the Conservation of African-Eurasian Migratory Waterbirds includes the following section:

"2. To this end, the Parties shall [...] (g) prohibit the deliberate introduction of non-native waterbird species into the environment and take all appropriate measures to prevent the unintentional release of such species if this introduction or release would prejudice the conservation status of wild flora and fauna; when non-native waterbird species have already been introduced, the Parties shall take all appropriate measures to prevent these species from becoming a potential threat to indigenous species;"

In this framework, various documents have been proposed during AEWA meetings of the Parties, suggesting guiding principles to prevent the introduction of non-native species of waterbirds (Owen et al., 2003). During the fifth Meeting of the Parties (MoP) in La Rochelle on 14 May 2013, the AEWA action plan proposed new measures to rehabilitate or restore areas impacted by invasive alien species (article 3.3) and to encourage the Parties to counter the threats weighing on wetlands, notably in view of preventing IAS introductions (article 4.3.12).

(http://www.unep-aewa.org/en/documents/agreement-text)

Convention for the protection of the marine environment and the coastal region of the Mediterranean

The Convention for the protection of the marine environment and the coastal region of the Mediterranean was signed in Barcelona on 16 February 1976 and subsequently modified on 10 June 1995. Its purpose is to protect the marine environment and the coastal region of the Mediterranean.

One of the protocols drafted in the framework of this convention concerns the specially protected areas and biological diversity in the Mediterranean. Two articles of the protocol deal with non-native species.

■ Article 6, on protective measures, requires "the regulation of the introduction of any species not indigenous to the specially protected area in question, or of genetically modified species, as well as the introduction or reintroduction of species which are or have been present in the specially protected area".

■ Article 13 deals more specifically with the introduction of non-native or genetically modified species and stipulates that:

- "1. The Parties shall take all appropriate measures to ***regulate the intentional or accidental introduction*** *of non-indigenous or genetically modified species to the wild and* ***prohibit those that may have harmful impacts*** *on the ecosystems, habitats or species in the area to which this Protocol applies."*

- *"2. The Parties shall* ***endeavour to implement all possible measures to eradicate species that have already been introduced*** *when, after scientific assessment, it appears that such species cause or are likely to cause damage to ecosystems, habitats or species in the area to which this Protocol applies."*

In France, decree 2002-1454 (09 December 2002) published the convention.
(http://www.legifrance.gouv.fr/affichTexte.do?cidTexte=JORFTEXT000000416310&dateTexte=&categorieLien=id)

Convention on wetlands of international importance especially as waterfowl habitat (Ramsar convention)

The purpose of this convention, signed on 2 February 1971 in the Iranian city of Ramsar, is to provide for the conservation and intelligent use of wetlands and their resources. The convention entered into force in France on 1 December 1986.
(http://www.ramsar.org)

Two resolutions were adopted on invasive species and wetlands during the sessions of the Conference of the Parties having signed the convention:

■ resolution VII.14, adopted during the 7th session (1999), titled "People and Wetlands: The Vital Link";
■ resolution VIII.18, adopted during the 8th session (2002), titled "Wetlands: water, life and culture".

These two resolutions present precise requests to the contracting Parties, i.e., the first calls upon them "to wherever possible address the environmental, economic and social impact of invasive species on wetlands within their jurisdictions" and the second urges them "to address the problems posed by invasive species in wetland ecosystems in a decisive and holistic manner, making use, as appropriate, of the tools and guidance developed by various institutions and processes, including any relevant guidelines or guiding principles adopted under other conventions."

The Ramsar strategic plan 2009-2015, adopted by resolution X.1 (2008) and adjusted for the period 2013-2015 by resolution XI.3 (2012), proposes guidelines to the contracting Parties and the many other convention participants on the means to focus their efforts in implementing the Convention on wetlands.

The plan comprises a number of goals for the implementation and management of the Ramsar convention. The first concerns the rational use of all wetlands. To achieve this objective, various strategies have been proposed, including strategy 1.9 on invasive alien species (see Box 5).

Box 5

Ramsar strategic plan

The Ramsar strategic plan 2009-2015 includes an appendix titled *"How implementation of Ramsar Strategic Plan 2009-2015 strategies contributes to the "Aichi Biodiversity Targets"* (CBD COP10 Decision X/2 Strategic Plan for Biodiversity 2011-2020)".

This appendix clarifies the links between target 9 of the Aichi biodiversity targets and Strategy 1.9 in the Ramsar strategic plan.

Target 9 : *"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."*

Strategy 1.9 : *"Invasive alien species. Encourage Contracting Parties to develop a national inventory of invasive alien species that currently and/or potentially impact the ecological character of wetlands, especially Ramsar Sites, and ensure mutual supportiveness between the national inventory and IUCN's Global Register on Invasive Species (GRIS); develop guidance and promote procedures and actions to prevent, control or eradicate such species in wetland systems."*

International plant protection convention (IPPC)

The International plant protection convention (IPPC) is an international agreement on plant protection, initially adopted in 1952, ratified by France on 20 August 1957 and revised in 1997. The convention provides for the protection of cultivated and wild plants by preventing the introduction and dissemination of plant pests. These organisms (species, strain or biotype of plants, animals or pathogens) are called quarantine pests when they represent a significant risk for the economy of the threatened area, but are not yet present there (or, if already present, are not widely disseminated and are the target of official countermeasures).

IPPC provides an international framework for plant protection that foresees the drafting of international standards for phytosanitary measures (ISPM) intended to preserve plant resources. For example, ISPM 11 (2004) deals with *"Pest risk analysis (PRA) for quarantine pests, including analysis of environmental risks and living modified organisms"*.
(https://www.ippc.int/en/ and http://www.fao.org/docrep/010/a0785e/a0785e00.htm)

The European plant protection organisation (EPPO), which corresponds to the regional plant-protection organisation for Europe within the IPPC framework, assists in preventing the introduction and spread of pests that damage plants in the European and Mediterranean region by carrying out pest risk analyses. EPPO also runs pest risk analysis (PRA) to determine the risks involved with certain invasive alien plant species and to make recommendations on how to prevent their introduction and spread via international trade.
(http://www.eppo.int/ABOUT_EPPO/about_eppo.htm
and http://www.eppo.int/INVASIVE_PLANTS/ias_plants.htm)

European level

In Europe, the Bern convention produced recommendations on how to prevent and manage invasive alien species and served as the backdrop for a European IAS strategy as early as 2003 (see Chapter 3). EU regulations restrict their trade, importation and introduction to natural environments. The European regulation on the prevention and management of the introduction and spread of invasive alien species, adopted on 29 September 2014, reinforced those policies. It targets a reduction in IAS impacts, harmonised management of these species throughout the Union and the development of preventive measures. European directives support EU policy concerning IAS management, but let the Member States decide on the measures required to achieve those ends.

Convention on the conservation of European wildlife and natural habitats (Bern convention)

This convention protects the natural heritage of the European continent, with the exception of Russia, and extends to a few African countries (Morocco, Tunisia, Senegal, Burkina Faso). The convention was signed on 19 September 1979 and entered into force on 1 June 1982. The aim is to conserve wildlife and natural habitats, and to promote European cooperation in this field. France ratified the convention in 1990.

Article 11.2.b) of the convention stipulates that "each Contracting Party undertakes [...] to **strictly control the introduction of non native species**".

The Standing committee, comprising representatives of the Contracting Parties, monitors the application of the convention and issues guidelines on its implementation and continued development. It also makes recommendations concerning measures to be taken for the purposes of the convention and on enhancing its effectiveness.

Among those recommendations, approximately 20 refer to alien species, e.g.:

- recommendation 154 (2011) on the European code of conduct on pets and invasive alien species;
- recommendation 149 (2010) on the eradication of the ruddy duck (Oxyura jamaicensis) in the Western Palaearctic;
- recommendation 134 (2008) on the European code of conduct on horticulture and invasive alien plants;
- recommendation 125 (2007) on trade in invasive and potentially invasive alien species in Europe;
- recommendation 99 (2003) on the European strategy for invasive alien species.

The Standing committee has also set up numerous groups of experts specifically devoted to certain types of species. One of these groups deals with invasive alien species.

The group of experts for invasive alien species was established in 1992. It meets every two years and works on harmonising national regulations addressing species introduction. One major tool of the group is the European strategy for invasive alien species that is presented in greater detail in Chapter 3 of this book.
(http://www.coe.int/en/web/bern-convention/invasive-species).

Regulations on the importation and introduction of invasive alien species in the EU

■ European commission regulations relating to CITES

Council Regulation (EC) 338/97 of 9 December 1996 on the protection of species of wild fauna and flora by regulating trade therein is implemented in compliance with the objectives, principles and stipulations of the CITES convention. The regulation provides for restrictions on the introduction of certain species in the EU (article 4, paragraph 6) and on the holding and movement of live specimens of species whose introduction is already subject to restrictions (article 9, paragraph 6). Various invasive alien species observed in France are listed in Annexes B and C of the regulation.
(http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:1997:061:0001:0069:EN:PDF)

Regularly updated implementing regulations (REU) are derived from this regulation. These regulations can:

- modify the classification of species proposed in the annexes of regulation (EC) 338/97;
- suspend or prohibit the introduction of certain species in the EU.

For example, Commission regulation (EU) 101/2012 of 6 February 2012 amending Council Regulation (EC) 338/97 of 9 December 1996. In Annex B, it mentions (in compliance with Article 3, paragraph 2, point d) three squirrel species (Callosciurus erythraeus, Sciurus carolinensis and Sciurus niger) that constitute an ecological threat to the red squirrel (Sciurus vulgaris) and to certain habitats and plant communities.

(http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2012:039:0133:0200:EN:PDF)

Similarly, the Commission implementing regulation (EU) 888/2014 of 14 August 2014, derived from the 1996 regulation, prohibits the introduction in the EU of specimens of certain species of wild fauna and flora.
(http://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=OJ:JOL_2014_243_R_0002&from=EN)

The invasive alien species whose introduction in the EU is currently prohibited are therefore the ruddy duck (*Oxyura jamaicensis*), three squirrel species (*Callosciurus erythraeus* (see Figure 32), *Sciurus carolinensis* and *Sciurus niger*), the painted turtle (*Chrysemis picta*), American bullfrogs (*Lithobates catesbeianus*) and the red-eared slider turtle (*Trachemys scripta elegans*).

Figure 32

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Pallas' squirrel (Callosciurus erythraeus), native to East Asia, has been introduced into France, Italy, the Netherlands and Belgium. Its introduction in the EU has been prohibited since 2012 and a national action plan against the species was launched in France the same year.

■ Council Regulation concerning use of alien and locally absent species in aquaculture

Council Regulation (EC) 708/2007 of 11 June 2007 concerning use of alien and locally absent species in aquaculture is part of the Commission action plan in favour of biological diversity. It complies with the guiding principles set by the CBD convention.

The first article of the regulation establishes that *"This Regulation establishes a **framework governing aquaculture practices in relation to alien and locally absent species** to assess and minimise the possible impact of these and any associated non-target species on aquatic habitats and in this manner contribute to the sustainable development of the sector." Article 2 sets the scope of the regulation and indicates that "This Regulation shall apply to the introduction of alien species and translocation of locally absent species for their use in aquaculture in the Community...".*

(http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2007:168:0001:0017:EN:PDF)

The text makes necessary a permit to introduce non-native species in the EU and assigns to the Member States the responsibility of granting or refusing permits. Applicants must supply sufficient information to enable the Member States to determine the risks of an introduction. When the environmental impacts of an introduction are likely to affect several Member States, the decision is taken by the Commission.

(http://www.assemblee-nationale.fr/europe/dossiers_e/e3129.asp)

Regulations on the prevention and management of introductions of invasive alien species in the EU

■ Regulation of the European parliament and of the Council on the prevention and management of the introduction and spread of invasive alien species

This regulation was published in the EU official journal on 24 October 2014 and entered into force on 1 January 2015. It provides "a framework for action to prevent, minimise and mitigate the adverse impacts of IAS on biodiversity and ecosystem services" and "to limit social and economic damage". These objectives are to be reached through "measures addressing the intentional introduction of IAS into the Union and their intentional release into the environment, the unintentional introduction and release of IAS, the need to set up an early warning and rapid response system, and the need to manage the IAS spread throughout the Union".

(http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=OJ:JOL_2014_317_R_0003&from=EN)

This regulation meets EU international and European commitments undertaken in the framework of the Convention on biological diversity (article 8h and Aichi target 9) and the EU biodiversity strategy for 2020. It also fills a gap in EU legislation by creating a harmonised management system for IASs spanning the entire EU (coordinated action, information exchanges) that is deemed more effective than the current fragmented situation with national policies (Le Botlan and Deschamps, 2014).

The regulation focusses on implementation of a list of invasive alien species of Union concern. The list should include all types of organisms (fauna and flora) with selection based on risk assessments and scientific data. The importation, sale, purchase, use and release to the environment of the concerned species are prohibited in the EU.

On the basis of the list of species of Union concern, the regulation provides for three types of intervention.

■ **Prevention.** A number of prohibitions apply to the species on the Union list (introduction, reproduction, transportation, sale, use, exchange, holding and release to the environment). Action plans for specific introduction paths will be prepared to prevent non-intentional introductions.

■ **Early warning and rapid response.** Member States must institute a surveillance, detection and monitoring system for invasive alien species. Border checks must be set up by the Member States to prevent the intentional introduction of these species. Member States detecting the installation of an IAS must take immediate measures to eradicate the species as soon as possible.

■ **Management of invasive alien species already established.** If one of the listed species has already spread widely, measures intended to reduce the damage to a minimum must be implemented by the Member States.

Following the debates held in the Council and the European parliament (see Figure 33), it was announced that the Member States would be fully involved in drafting the list. In line with the subsidiarity principle, the Member States will be able to establish their own additional list of species seen as alien and invasive in their country and take more rigorous countermeasures against the species on the Union list (Le Botlan and Deschamps, 2014).

Figure 33

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The European parliament in Strasbourg.

Member States submitted opinions on the regulation that was then examined by the Council and the Parliament, the institutions jointly charged with adopting the text. Amendments were proposed and voted by the Environment commission of the Parliament on 30 January 2014. Finally, the regulation was voted during a plenary session of the Parliament on 16 April 2014. Effective implementation should start in 2015.

Certain aspects of the regulation are still debated within the European institutions (Le Botlan and Deschamps, 2014) (see Figure 34). IAS management raises a number of questions, notably concerning:

■ the types of impacts caused by these species and their prioritisation (biodiversity, ecosystem services, health, economy);

■ the alien or native nature of the species placed on the Union list, as well as the areas of observed or potential establishment of these species;

■ uniform application in all 28 Member States of the regulatory measures concerning the species on the Union list.

Figure 34

© N. Poulet

*The red swamp crayfish (*Procambarus clarkii*) is marketed under certain conditions. It is feared that the species may be established sustainably in the natural environment for commercial reasons or that it may escape unintentionally during transportation to processing centres.*

The regulation of the European parliament and of the Council on the prevention and management of the introduction and spread of invasive alien species is accompanied by an implementation plan.

This document lists the implementation objectives of the regulation on IASs and also mentions the issues at hand;

- shift from a fragmented approach to joint action on priority species:
  - focus on priority IASs,
  - assess risks;
- shift from reactive efforts to prevention:
  - more preventive work,
  - reinforce surveillance and monitoring,
  - enhance management of introduction paths;
- increase communication and raise awareness of stakeholders.

For each issue, the implementation plan proposes support measures and deadlines for the Commission and the Member States.

(http://ec.europa.eu/environment/nature/invasivealien/index_en.htm)

European directives addressing the risks of IAS introduction in the EU

European Council directive on the conservation of wild birds

Directive 79/409/EEC, voted by the Council on 2 April 1979, commonly called the "Birds directive", provides for the protection and long-term conservation of bird species (including their eggs, nests and habitats) living naturally in a wild state in the European parts of the Member States (with the exception of Greenland).

Article 11 of the directive stipulates that *"Member States shall see that* ***any introduction of species of bird which do not occur naturally in the wild state in the European territory of the Member States does not prejudice the local flora and fauna.*** *In this connection they shall consult the Commission."*

(http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:1979:103:0001:0018:EN:PDF)

Regulations, directives, decisions and recommendations

In carrying out their missions, the European institutions may adopt, as per article 288 of the Treaty on the functioning of the European Union, regulations, directives, decisions, recommendations and opinions:

- *"A regulation shall have general application. It shall be binding in its entirety and directly applicable in all Member States";*
- *"A directive shall be binding, as to the result to be achieved, upon each Member State to which it is addressed, but shall leave to the national authorities the choice of form and methods";*
- *A decision shall be binding in its entirety. A decision which specifies those to whom it is addressed shall be binding only on them";*
- *"Recommendations and opinions shall have no binding force".*

Each act thus has a number of specific characteristics. A regulation is directly applicable in all Member States, which means it creates rights for individuals without requiring national transposition measures. In theory, consequently, a regulation is a precise act that is in itself sufficient. A directive, on the other hand, imposes mandatory results on Member States, but allows them to decide how to achieve those results. Recommendations and opinions are of limited use in that they are not binding.
(http://europa.eu/eu-law/decision-making/legal-acts/index_en.htm).

European Council directive on the conservation of natural habitats and wild fauna and flora

Directive 92/43/EEC, voted by the Council on 21 May 1992, commonly called the "Habitats directive", aims to maintain biodiversity through the conservation of natural habitats and of wild fauna and flora of community interest.

Article 22.b) of the directive stipulates that *"In implementing the provisions of this Directive, Member States shall ensure that the deliberate introduction into the wild of any species which is not native to their territory is regulated so as not to prejudice natural habitats within their natural range or the wild native fauna and flora and, if they consider it necessary, prohibit such introduction".*
(http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:1992:206:0007:0050:EN:PDF)

European Council directive on protective measures against the introduction into the Community of organisms harmful to plants or plant products and against their spread within the Community

Directive 2000/29/EC, voted by the Council on 8 May 2000, aims to protect the Member States against the introduction of organisms harmful to plants or plant products from other Member States or from other countries.
(http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2000:169:0001:0112:EN:PDF)

By "harmful organism", the directive means any species, strain or biotype of plants, animals or pathogens that can harm plants or plant products. This definition includes insects, acari, bacteria, fungi, viruses and parasite plants. Annexes I and II list the organisms that are prohibited in the EU, either the organisms themselves or when they are present on certain plants or plant products. Annex III lists the plants and plant products that may not be imported from certain non-EU countries.

(http://europa.eu/legislation_summaries/food_safety/plant_health_checks/f85001_en.htm)

Directive 2000/29/EC, in article 16, paragraph 3, enables the necessary measures if new organisms harmful to plants are detected. This option was put to use in November 2012 for a plant-eating aquatic mollusc (Commission implementing decision of 8 November 2012 as regards measures to prevent the introduction into and the spread within the Union of the genus *Pomacea* (Perry).

(http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32012D0697&rid=1)

■ European water framework directive (WFD)

Directive 2000/60/EC of the European parliament and of the Council of 23 October 2000 establishing a framework for community action in the field of water policy, also known as the Water framework directive (WFD), aims to prevent and reduce pollution, promote sustainable use of water, protect the environment, improve the status of aquatic ecosystems and mitigate the effects of flooding and droughts. The objective is good ecological and chemical status of all EU waters by 2015.

(http://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1454786519547&uri=CELEX:32000L0060).

To assess the good ecological status of water bodies, the WFD calls on indices for the quality of various biological communities, e.g. benthic invertebrates (IBGN, IBGA), fish (IPR), macrophytes (IBMR), diatoms (IBD) and oligochaeta (IOBS). Given that IASs can alter the structure and functioning of aquatic environments, a work group held several meetings in 2008 and 2009 to discuss the possibility of including these species in the ecological assessment required by the WFD.

The directive does not require the Member States to take alien species into account in assessing the ecological status of their surface water bodies. This lack of any clear reference means that most assessment tools for ecological status do not explicitly include IASs.

On the other hand, the WFD requires that the assessments of ecological status signal any divergence from high status, which means that, practically speaking, IASs and their impacts on communities should be included in the WFD assessment. That is why the work group put so much work into the topic.

The meetings did not produce an immediately applicable, common approach. In fact, the opinions on the topic of the various Member States represented diverged significantly.

No majorities could be found for any of the main options, i.e. 1) create an IAS-specific index (biopollution index), 2) adopt the position that certain indices currently available in fact already include IASs or 3) create and include IAS-specific metrics in the existing methods.

Above and beyond these formal proposals, a concern of some Member States (including France) was that IAS-integration in the assessment of the ecological status of water bodies might result, if a single IAS was present in the water body, in the systematic disqualification of the water body, even though no assessment of the actual ecological impacts of IASs has yet been carried out.

In the absence of any concrete proposals following the meetings and in as much as agreement on invasive species and the ecological classification of water bodies in Europe was deemed necessary, the topic was added to the 2010-2012 work list of the ECOSTAT work group, but to date no particular progress has been made.

National level

For continental France, the main regulations governing invasive alien species are contained in the Environmental code and the related enacting documents. Phytosanitary and plant-protection regulations are not discussed in detail here.

A summary of the various texts applicable in France is presented in Table 5, page 68.

Regulations on the introduction of invasive alien species

■ Law reinforcing environmental protection (Barnier law)

■ **Article 56** in Law 95-101 (2 February 1995) modified the New Rural code by including article L.211-3: “To avoid harm to natural environments and to wild fauna and flora, it is ***prohibited to introduce*** into the natural environment, voluntarily, through negligence or imprudence:

1° any specimen of an animal species that is non-native to the area and not domesticated;

2° any specimen of a plant species that is non-native to the area and not cultivated;

3° any specimen of the plant and animal species designated by the administrative authorities.”

[...] “When an offence takes place, the administrative authorities may immediately proceed with or order the capture, withdrawal, detention or destruction of the specimens of the introduced species.”

(http://www.legifrance.gouv.fr/affichTexte.do?cidTexte=JORFTEXT000000551804#LEGIARTI000006848476)

■ **Article L.211.3** in the New Rural code was abrogated by Ordinance 2000-914 (18 September 2000).

(http://www.legifrance.gouv.fr/affichTexteArticle.do;jsessionid=E5BE262F23EC00948018C773471B45E4.tpdjo13v_3?cidTexte=JORFTEXT000000401865&idArticle=LEGIARTI000006849354&dateTexte=20000921&categorieLien=id)

The new, applicable text is contained in article L411-3 of the Environmental code, presented in the next section.

■ Environmental code

■ **Article L411-3**, modified by Law 2010-788 (12 July 2010), art. 241, sets the general rules governing the introduction of non-native species into natural environments.

“I. To avoid harm to natural environments, to their uses and to wild fauna and flora, it is prohibited to introduce into the natural environment, intentionally, through negligence or imprudence:

1° Any specimen of an animal species that is non-native to the area and not domesticated, listed in the joint decree published by the Ecology minister and either the Agriculture minister or, for marine species, the Marine fisheries minister;

2° Any specimen of a plant species that is non-native to the area and not cultivated, listed in the joint decree published by the Ecology minister and either the Agriculture minister or, for marine species, the Marine fisheries minister;

3° Any specimen of the plant and animal species designated by the administrative authorities.

II. However, the introduction of said species into the natural environment may be authorised by the administrative authorities for agricultural, fisheries or forestry purposes or in the general interest, following an assessment of the consequences of the introduction.

III. When the presence in the environment of a species listed in section I has been observed, the administrative authorities may immediately proceed with or order the capture, withdrawal, detention or destruction of the specimens of the introduced species. The stipulations of section II in article L. 411-5 apply to this type of intervention.

IV. When a person has been found guilty as pertains to this article, the court may assign to that person the costs incurred for the necessary capture, withdrawal, detention or destruction.

IV (2). When the need to preserve the biological heritage, natural environments and their uses justifies a prohibition of dissemination, it is forbidden to transport, trade, use, market, sell or buy the plant and animal species in the list established by the joint decrees published by the Ecology minister and either the Agriculture minister or, for marine species, the Marine fisheries minister.

V. A decree by the State council shall determine the enacting conditions of this article and notably those governing how the public is informed in advance of the introductions into the natural environment mentioned in section II."
(http://www.legifrance.gouv.fr/affichCodeArticle.do;jsessionid=265C271B1FEE450BEB722E3D4EDE61F6.tpdjo15v_2?idArticle=LEGIARTI000022496815&cidTexte=LEGITEXT000006074220&dateTexte=20130726)

■ **Article L415-3** modified by Ordinance 2012-34 (11 January 2012), art. 10, sets the penalties for violations of L. 411-3:

"Shall be punished by one year of imprisonment and a fine of 15 000 euros: [...]

2° The intentional introduction into the natural environment, transportation, trade, use, marketing, sale or purchase of a specimen of a plant or animal species in violation of article L. 411-3 or of the regulations and individual decisions instituted for its application [...]"

(http://www.legifrance.gouv.fr/affichCodeArticle.do;jsessionid=AAE87F623F21F08329A5BCA71FD86CC5.tpdjo14v_2?idArticle=LEGIARTI000006833760&cidTexte=LEGITEXT000006074220&dateTexte=20090911)

The fine is doubled if the offence takes place in a national park or nature reserve. The same penalties apply to offences committed by economic entities raising, selling, renting or transporting non-domestic animal species. The court may assign to a condemned person the costs incurred for the necessary capture, withdrawal, detention or destruction.

■ **Article R415-1** modified by Decree 2007-15 (04 January 2007), art. 1, published in the Official Journal on 05 January 2007, sets the fines for violations of L. 411-3:

"Shall be punished by a fine for a Class 4 offence: [...]

2° Introduction into the natural environment, through negligence or imprudence, of any specimen of a plant or animal species mentioned in article L. 411-3 [...]."

(http://www.legifrance.gouv.fr/affichCode.do;jsessionid=3CCA81AFC128F75E340FB5F2E43F96BA.tpdjo14v_2?idSectionTA=LEGISCTA000006188811&cidTexte=LEGITEXT000006074220&dateTexte=20090911)

■ **Article R432-5** lists the animal species for which the introduction in aquatic environments is prohibited (see Box 7): *"Below is the list of fish, crustacean and frog species likely to provoke biological imbalances in the water bodies mentioned in this section and whose introduction is therefore prohibited.*

Fish

Black bullhead: *Ameiurus melas ;*

Pumpkinseed: *Lepomis gibbosus.*

Crustaceans

Chinese mitten crab: *Eriocheir sinensis.*

Crayfish species other than:

- *Astacus astacus :* noble crayfish;
- *Astacus torrentium :* stone crayfish;
- *Austropotamobius pallipes* : white-clawed crayfish;
- *Astacus leptodactylus* : narrow-clawed crayfish.

Frogs

Frog (*Rana* sp.) species other than:

- *Rana arvalis* : moor frog;
- *Rana dalmatina* : agile frog;
- *Rana iberica* : Iberian frog;
- *Rana honnorati* : European frog;
- *Rana esculenta* : edible frog;
- *Rana lessonae* : pool frog;
- *Rana perezi* : Perez's frog;
- *Rana ridibunda* : marsh frog;
- *Rana temporaria* : common frog;
- *Rana groupe esculenta* : Corsican green frog."

(http://www.legifrance.gouv.fr/affichCodeArticle.do?idArticle=LEGIARTI000006838439&cidTexte=LEGITEXT000006074220&dateTexte=20120402)

Box 7

Changes in regulations and popular misconceptions

Prior to article R432-5 in the Environmental code listing the species "likely to provoke biological imbalances", regulations up to 1984 prohibited the introduction of fish and crustaceans seen as "particularly harmful" (article L439-1). Article 29 stipulated that "Are acknowledged as particularly harmful, notably in application of article 439-1 of the Rural code, the nase, pumpkinseed, black bullhead, Chinese mitten crab and, in Category 1 waters, the eel". At that time, the engineers of the High council on fisheries and the Fishing federations were of the opinion that the nase and eel, even though native to continental France (the nase is native to the Rhine basin), were a source of harmful predation for the other species. We now know that that was not the case. Though there is not necessarily a relation of cause and effect, we observe that the IUCN sees the eel in critical danger of extinction and a European management plan now exists for the species.

Subsequently, the 1984 Fishing law, via de decree dated 8 November 1985, introduced the notion of species "likely to provoke biological imbalances" and the list of those species is the same even today (even though the text was later inserted in the Rural code in 1989 and then in the Environmental code in 2005). On the other hand, at that time, article L432-11 stipulated that the transport of live animals of the listed species was prohibited without an authorisation issued under the conditions set by a decree of the State council. 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 regulate the situation. 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 (see page 66) and requiring an authorisation for the sale and transport of the red swamp crayfish (this text will probably be modified at some point).

(http://www.legifrance.gouv.fr/affichTexte.do?cidTexte=LEGITEXT000006064747&dateTexte=)

Other articles in the Environmental code may also be useful for regulating invasive alien species:

- articles L411-1, L411-2 and L411-3 on the preservation of biological heritage;
- article L412 on activities subject to authorisation;
- articles L413-2 and L413-3 on economic entities in possession of non-domestic animal species;
- article R411-41 on the applicable procedure for emergency measures.

(Environmental code: http://www.legifrance.gouv.fr/affichCodeArticle.do?idArticle=LEGIARTI000006837756&cidTexte=LEGITEXT000006074220&dateTexte=20130531)

Some articles of the Rural code may also concern IASs as pertains to national surveillance:

- animal-health epidemiology: article L201-1 and the following articles;
- biological surveillance: article L251-1 and following, notably article L251-3-1 which stipulates that "All means must be employed to limit the populations of muskrats and nutria";
- organisations defending against harmful organisms: articles L252-1 and following.

(http://www.legifrance.gouv.fr/affichCodeArticle.do?cidTexte=LEGITEXT000006071367&idArticle=LEGIARTI000006582982&dateTexte=&categorieLien=cid)

Enacting texts for the Environmental code and/or the Rural code

Decree (2 May 2007) prohibiting the sale, use and introduction into the natural environment of *Ludwigia grandiflora* and *Ludwigia* peploides.

(http://www.legifrance.gouv.fr/affichTexte.do?cidTexte=JORFTEXT000000465704&dateTexte=)

Decree (30 July 2010) prohibiting in continental France the introduction into the natural environment of certain vertebrates:

Article 2.I : *"It is prohibited throughout continental France and at all times to introduce into the natural environment, intentionally, through negligence or imprudence, living specimens of the following vertebrate species:*

Mammals

*Red-necked Wallaby (*Macropus rufogriseus *[Desmarest, 1817])*
*Raccoon dog (*Nyctereutes procyonoides *[Gray, 1834])*
*American mink (*Neovison vison *[Schreber, 1777])*
*Northern raccoon (*Procyon lotor *[Linné, 1758])*
*Sika deer (*Cervus nippon *[Temminck, 1838])*
All types of Sciuridae except the two following species:
*Alpine marmot (*Marmota marmota *[Linné, 1758])*
*Red squirrel (*Sciurus vulgaris *[Linné, 1758])*
*North American beaver (*Castor canadensis *[Kuhl, 1820])*
*Muskrat (*Ondatra zibethicus *[Linné, 1766])*
*Coypu (*Myocastor coypus *[Molina, 1782])*
*Brown rat (*Rattus norvegicus *[Berkenhout, 1769])*
*Eastern cottontail rabbit (*Sylvilagus floridanus *[J.A. Allen, 1890]).*

Birds

*Ruddy duck (*Oxyura jamaicensis *[Gmelin, 1789])*
*Sacred ibis (*Threskiornis aethiopicus *[Latham, 1790])*
*Canada goose (*Branta canadensis *[Linné, 1758])*
*Egyptian goose (*Alopochen aegyptiacus *[Linné, 1766])*
*Rose-ringed parakeet (*Psittacula krameri *[Scopoli, 1769])*

Reptiles
All species belonging to the following genera:
Chrysemys spp.
Pseudemys spp.
Trachemys spp.
Graptemys spp.
Clemmys spp.
Amphibiens
*African clawed frog (*Xenopus laevis *[Daudin, 1802])*
*American bullfrog (*Lithobates catesbeianus *[Shaw, 1802])*
*Levant water frog (*Pelophylax bedriagae *[Camerano, 1897])*
*Balkan water frog (*Rana kurtmuelleri *[Gayda, 1940]).* »
(http://www.legifrance.gouv.fr/affichTexte.do?cidTexte=JORFTEXT000022806788&categorieLien=id)

■ **The decree dated 17 December 1985** lists the species of fish, crustaceans and frogs present in the waters covered by article 413 of the Rural code. Article 1 (applicable version since 1 January 1986): "*In application of article 413 (2°) of the Rural code, it is prohibited to introduce without authorisation into the waters covered by this article fish, frogs and crustaceans belonging to species not already present in those waters.*"

The list of species present is provided in the same article.
(http://www.legifrance.gouv.fr/jopdf/common/jo_pdf.jsp?numJO=0&dateJO=19860126&numTexte=01464&pageDebut=01464&pageFin=)

■ **The decree dated 20 March 2013 in application of article R. 432-6 of the Environmental code lists the fish species not present whose introduction for scientific purposes may be authorised by the prefect.**
Article 2 : *"The list of fish species not present, mentioned in article R. 432-6 of the Environmental code, whose introduction for purposes other than scientific may be authorised by the prefect, is the following:*
1° The Acipenseriforme species mentioned in the Annex to the above-mentioned decree (23 February 2007), with the exception of the European sturgeon Acipenser sturio (Linnaeus, 1758);
2° The grass carp Ctenopharyngodon idella (Cuvier and Valenciennes, 1844)."
(http://www.legifrance.gouv.fr/affichTexte.do?cidTexte=JORFTEXT000027243221&categorieLien=id)

■ **The decree dated 22 January 2013 prohibits the introduction in France of the Asian hornet Vespa velutina.**
Article 2 : *"It is prohibited throughout France and at all times to intentionally introduce into the natural environment living specimens of the Asian hornet* Vespa velutina."
(http://www.legifrance.gouv.fr/affichTexte.do?cidTexte=JORFTEXT000027048139)

■ Enacting text for Council directive 2000/29/EC

■ **The decree (24 May 2006) on sanitary requirements for plants, plant products and other objects** lists the organisms harmful to plants for which the introduction and dissemination are prohibited throughout the European community.
(http://www.legifrance.gouv.fr/affichTexte.do?cidTexte=JORFTEXT000000637300&dateTexte=vig)

■ **The decree (3 September 1990) on sanitary inspections of plants and plant products** lists the species for which the importation is prohibited in the overseas territories. The technical annexes for continental France (Annexes A) were abrogated following the regulatory modifications that resulted in the decree dated 24 May 2006, however the annexes for the overseas territories (Annexes B) remain in force.
(http://www.legifrance.gouv.fr/affichTexte.do?cidTexte=LEGITEXT000006076933)

Regulations on the holding, trade and presentation of invasive alien species

CITES enacting texts

The decree dated 30 June 1998 sets the enacting conditions for the Convention on international trade in endangered species of wild fauna and flora, Council regulation (EC) 338/97 and Commission regulation (EC) 939/97.

The species for which trade must be authorised in France are those listed in the CITES implementation regulations ((EU) 578/2013).

Enacting texts for the Environmental code and/or the Rural code

The decree dated 10 August 2004, again pertaining to the CITES convention, sets the general operating rules for persons breeding species of non-domestic animals.
(http://www.legifrance.gouv.fr/affichTexte.do?cidTexte=LEGITEXT000018810562)

A second decree dated 10 August 2004, toujours en lien avec la CITES, fixe les règles générales de fonctionnement des installations d'élevage d'agrément d'animaux d'espèces non domestiques.
(http://legifrance.gouv.fr/affichTexte.do?cidTexte=JORFTEXT000000443942&fastPos=1&fastReqId=2009995165&categorieLien=cid&oldAction=rechTexte)

The decree dated 21 November 1997 defines dangerous species, e.g. the common snapping turtle (*Chelydra serpentina*).
(http://www.legifrance.gouv.fr/affichTexte.do?cidTexte=JORFTEXT000000387290&dateTexte=29990101)

The decree (21 July 1983) on the protection of native crayfish (now being abrogated in view of replacement by a more general decree) makes necessary an authorisation for the transportation and sale of red swamp crayfish: Article 2 : *"Authorisation is required, under the conditions set by Decree 77-1296 (25 November 1977) mentioned above, for the importation, under all customs systems with the exception of transit from border to border without trans-shipment, the transport and the sale of living crayfish (no. 03-03 A III ex b customs tariff) of the Procambarus clarkii (Girard) 1852 species, called the red marsh crayfish or the red swamp crayfish."*
(http://www.auvergne.developpement-durable.gouv.fr/IMG/pdf/Arrete_ecrevisses_21_juillet_1983_cle0281bf.pdf)

Regulations on the management of invasive alien species

Grenelle environmental agreement

Article 23 of Law 2009-967 (3 August 2009) on programming implementation of the Grenelle environmental agreement set the objectives in view of stopping the loss of wild and domestic biodiversity and restoring and maintaining its evolutionary capacity.
One of the objectives is the *"implementation of action plans against invasive alien species, both terrestrial and aquatic, to prevent their installation and expansion, and reduce their harmful impacts"*.
(http://www.legifrance.gouv.fr/affichTexte.do?cidTexte=JORFTEXT000020949548&dateTexte=&categorieLien=id#JORFARTI000020949605)

Enacting texts for the Environmental code and/or the Rural code

The decree dated 26 June 1987 lists the wildlife species for which hunting is authorised. The species living in the corresponding aquatic environments are coypus (*Myocastor coypus*), muskrats (*Ondatra zibethicus*), Northern raccoons (*Procyon lotor*), raccoon dogs (*Nyctereutes procyonoides*) and American mink (*Neovivon vison*). Also included in the list are Sika deer (*Cervus nippon*) and fallow deer (*Dama dama*).
(http://legifrance.gouv.fr/affichTexte.do?cidTexte=JORFTEXT000000296288&dateTexte=vig)

■ **The decree dated 31 July 2000 lists the organisms harmful to plants, plant products and other objects that are subject to mandatory countermeasures.** The lists deal with plant diseases and pests, and include in Annex B (mandatory countermeasures under certain conditions) two rodents living in aquatic environments, coypus (*Myocastor coypus*) and muskrats (*Ondatra zibethicus*).
(http://www.legifrance.gouv.fr/affichTexte.do?cidTexte=JORFTEXT000000584174)

■ **The decree dated 11 August 2006 lists the species, races and varieties of domestic animals** of which some are occasionally considered invasive alien species (e.g. black swan, Egyptian goose) if they return to the natural environment.
(http://www.legifrance.gouv.fr/affichTexte.do?cidTexte=JORFTEXT000000789087)

■ **The decree dated 6 April 2007 concerns the control of coypu and muskrat populations.**
(http://www.legifrance.gouv.fr/affichTexte.do?cidTexte=LEGITEXT000006056474)

■ **The decree dated 23 December 2011 authorises hunting of the Canada goose** (*Branta canadensis*) jusqu'en 2015.
(http://www.legifrance.gouv.fr/affichTexte.do?cidTexte=JORFTEXT000025023620)

■ **The annual decree dated 24 March 2014,** in application of article R. 427-6 of the Environmental code, lists the periods and conditions under which alien species of animals deemed harmful shall be destroyed throughout continental France.
(http://www.legifrance.gouv.fr/affichTexte.do?cidTexte=JORFTEXT000028814668&categorieLien=id)

The species in question are coypus (*Myocastor coypus*), muskrats (*Ondatra zibethicus*), Northern raccoons (*Procyon lotor*), raccoon dogs (*Nyctereutes procyonoides*), American mink (*Neovivon vison*) and Canada goose (*Branta canadensis*).

■ **The decree dated 12 November 1996 authorises the shooting of the ruddy duck (*Oxyura jamaicensis*)** by authorised persons, in conjunction with the recommendations made by the Bern convention.
(http://www.legifrance.gouv.fr/affichTexte.do?cidTexte=LEGITEXT000005622132)

In addition, (non-invasive) alien species may be preventively removed from the natural environment on the basis of texts pertaining to sanitary conditions, e.g. the prohibited importation of prairie dogs (*Cyonomis* spp.) from the U.S. to prevent the introduction of monkeypox (Commission decision dated 20 June 2003). Prefectoral orders or municipal bylaws may be implemented to ensure public safety and health.

Locally, numerous prefectoral orders are issued for IAS management, in application of various laws and enacting texts for the Environmental code and the Rural code. The orders pertain primarily to the destruction (administrative hunts) of invasive alien fauna, e.g. sacred ibis and Canada goose.

The list of decrees and articles presented here is not complete, but provides an idea of the current status of French legislation (see Table 5). There is a clear imbalance in the regulatory texts between animal and plant species. To date, only one decree (2 May 2007) concerns plant species. Many regulatory aspects enter into play when management operations for invasive species are set up, e.g. the regulations concerning the management of green waste (see Box 8).

Table 5 *Main regulatory texts governing the introduction, holding, trade and management of invasive alien species in aquatic environments in continental France.*

Scope	Text	Biological group or species	IAS in aquatic environments (partial list)
Introduction	MD 2010/07/30	Mammals, reptiles, amphibians	Red-necked Wallaby Raccoon dog American mink Northern raccoon North American beaver Muskrat Coypu Brown rat Ruddy duck Sacred ibis Canada goose Egyptian goose All species belonging to the genera Chrysemys, Pseudemys, Trachemys, Graptemys, Clemmys, African clawed frog, American bullfrog, Levant water frog, Balkan frog
	MD 2013/01/22	Asian hornet	*Vespa velutina*
	R. 432-5 Environmental code	Fish, amphibians and crayfish	Black bullhead Pumpkinseed All alien crayfish, Chinese mitten crab, Bullfrog
	MD 2007/05/02	Water primrose	*Ludwigia grandiflora* and *Ludwigia peploides*
	MD 2006/05/26	Invertebrates, micro-organisms and parasitic plants	Listed organisms in annexes of Directive 2000/29/EC (08 May 2000)
	Decision 2012/697/EU	Molluscs	*Pomacea* sp.
	MD 1990/09/03 (Overseas departments)	Invertebrates, micro-organisms and plants harmful to plants	*See the list appended to MD 1990/09/03* *Altemanthera phylloxeroïdes* *Elodea spp.* *Salvinia molesta*
Trade	MD 2007/05/02	Water primrose	*Ludwigia grandiflora* and *Ludwigia peploides*
	MD 1998/06/30 (CITES)	Birds, mammals, reptiles and amphibians	Ruddy duck Painted turtle American bullfrog Red-eared slider turtle
Holding Farming Presentation to the public	MD 1983/07/21	Red swamp crayfish	*Procambarus clarkii*
	MD 2004/08/10	Fauna	*See ONCFS review (Sarat, 2012)*
	MD 1997/11/21	Fauna	Species considered dangerous
	MD 2006/06/11	Birds	Black swan Egyptian goose
Hunting	MD 2011/12/23	Canada goose	*Branta canadensis*
	MD 1987/06/26	Mammals	Coypu Muskrat Northern raccoon Raccoon dog
Pest	MD 2014/03/24	Mammals, birds	American mink Muskrat Northern raccoon Raccoon dog American mink Canada goose
Mandatory countermeasures	MD 2000/07/31	Micro-organisms, plants and animals harmful to plants	Coypu Muskrat See the list appended to DM 2000/07/31
Control	MD 2007/04/06	Rodents	Coypu Muskrat
	MD 1996/11/12	Ruddy duck	*Oxyura jamaicensis*

MD: ministerial decree

Partial list of regulations governing the management of green waste

Plants withdrawn from the environment are considered a form of organic waste and, more precisely, green waste (article R 541-8 in the Environmental code). General regulations for waste management apply to organic waste. Plant waste can therefore be put into a number of existing waste elimination and recovery systems.

Storage

Prior to 1 July 2002, it was possible to send this type of waste to landfills (waste storage centres) (Council directive dated 26 April 1999). Green waste could be sent to Class 2 storage centres (non-dangerous waste). Since 1 July 2002 (article L541-24 Environmental code), only ultimate waste may be placed in landfills, i.e. green waste is excluded.

Composting

Green waste may be sent to composting centres (Nomenclature of regulated installations for environmental protection, ICPE 2780) (for use as organic conditioner, crop supports or fertiliser according to precise standards) or transferred to towns or individuals (volumes greater than 5 cubic metres and above the ICPE threshold are subject to departmental health regulations).

Incineration

Incineration of green waste is possible in certified centres compliant with section 2771 of the ICPE nomenclature. However, this solution is not advised due to the atmospheric pollution and the often high level of humidity in the waste.
In that green waste is considered household waste, burning in the open air is prohibited (except with approval by the prefecture following an advisory opinion by the CODERST) by article 84 in the standard departmental health regulations and the interministerial circular dated 18 November 2011.

Spreading on fields

The circular dated 10 January 2012 on the implementation conditions of biowaste sorting at the source by large producers (article L 5541-21-2 Environmental code) sets as the main objective the return to the soil of organic matter that is compatible with environmental-preservation requirements, without excluding other techniques making use of the waste.
This means the biowaste must be sorted at the source for its organic reuse. Plant waste falls under the category of green waste, which itself is part of biowaste (defined by article R 541-8 in the Environmental code). This means that the circular mentioned above is applicable. The only exceptions in terms of the mandatory sorting are pruning and trimming materials that are used for energy generation.
In addition, the circular requires prior treatment of the waste, e.g. composting or methanisation. It is important to note the composting may be carried out by a local government or an individual, with prior temporary storage for drying.
The spreading or plowing under of “fresh” waste (without prior treatment) is not authorised.
These requirements become applicable above certain thresholds (decree dated 12 July 2011 and R. 543-225), i.e. 80 metric tons per year in 2013.
For local governments, the requirement concerning sorting and prior treatment applies only to the quantities over and above the threshold.

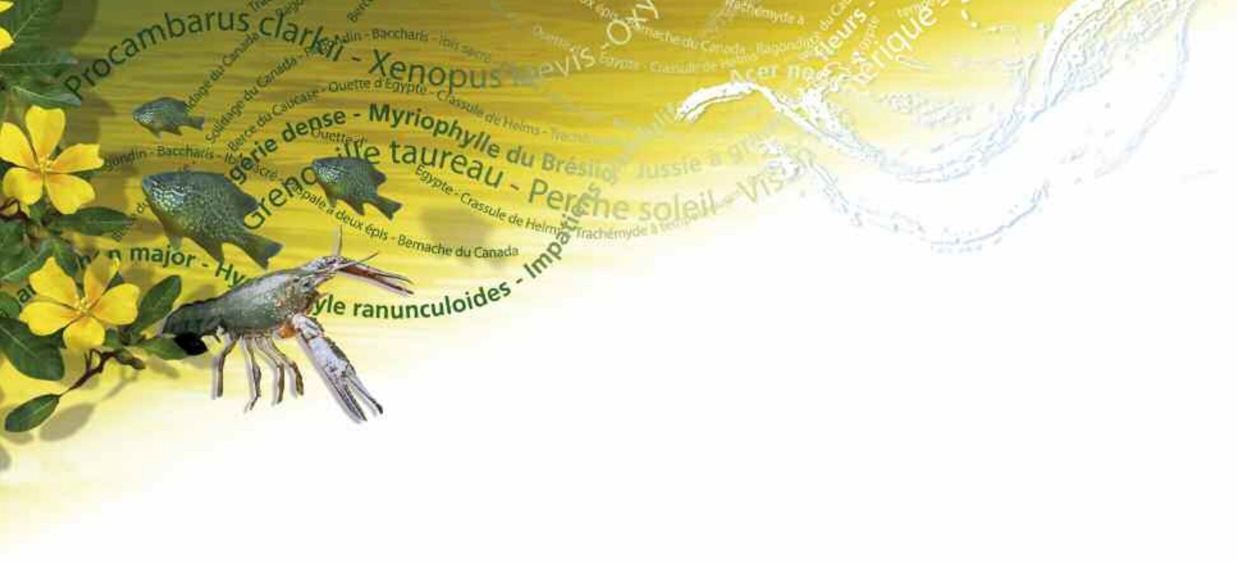
Consequently, compost (primarily of green waste, even if not certified) or digestate (methanisation residue) may be directly spread or plowed under in fields (a spreading plan is mandatory for ICPE waste (authorisation or declaration)).

Methanisation

Use of green waste for methanisation is regulated by ICPE 2781 or subject to the Waste & health network (RSD), depending on the volume.

See articles L 541-1, R 541-8 Environmental code, Voynet circular (28 April 1998) on implementation and changes in departmental plans for the elimination of household and similar waste, circular (28 June 2001) on the management of organic waste, circular (6 June 2006) on installations for the storage of household waste and circular (25 April 2007) on the management plan for household waste), circular (10 January 2012) on the application of biowaste sorting at the source by large producers, interministerial circular (18 November 2011) prohibiting burning in the open air, regulatory and legal framework for agricultural methanisation and composting activities (technical guide, ADEME, 2012).

Roland Matrat, Pays-de-la-Loire regional environmental directorate



Further progress required

Difficulties and needs

Increased trade and international exchanges raise the risk of new species being introduced into continental France. Only a very small proportion of introduced species become invasive, but they can cause considerable impacts in terms of the ecology and/or the economy and/or health. The progression of invasive species ignores all administrative borders and prevention remains the best barrier to new invasions (Lévêque et al., 2012).

The international scope of biological invasions has made it necessary to establish management systems based on legal documents capable of producing results on the international level. Currently, an array of international and regional regulatory texts, more or less binding (see Figure 35), address various aspects ranging from the introduction of alien species to their eradication and control (Shine et al., 2000, 2008). However, to achieve effective results in France, this legislation must be applied throughout the European continent with an equal degree of severity (Lévêque et al., 2012).

In France, similar to many other countries, the rules and regulations concerning alien species are scattered throughout the legislation on nature conservation and biodiversity, on management of water resources, on agriculture and forestry, on fishing and on quarantine measures, a situation that limits their effectiveness in regulating biological invasions (see Box 9) (Shine et al., 2000 and Shine, 2008).

Figure 35

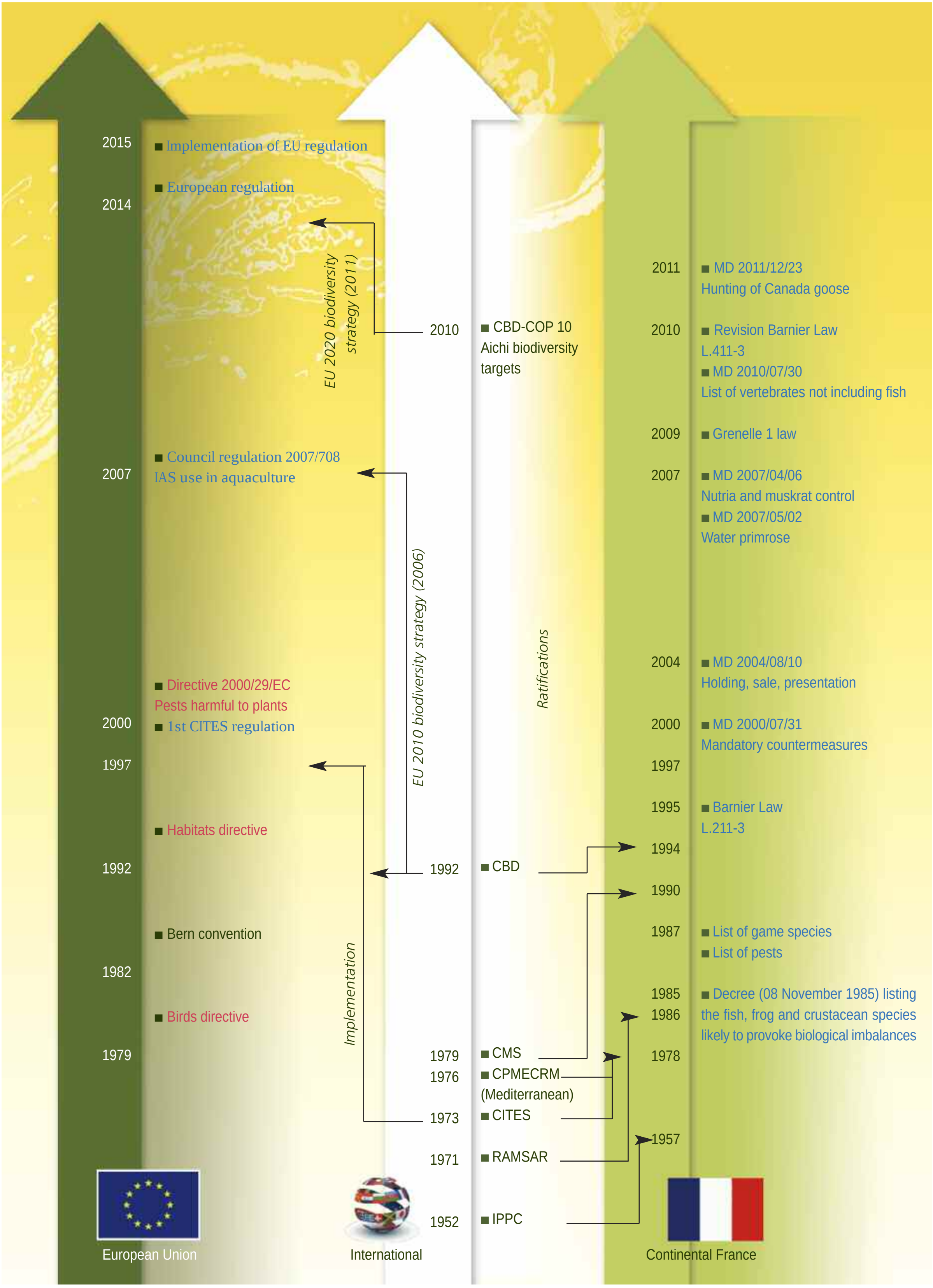


Diagram by Emmanuelle Sarat, IUCN French committee, 11 June 2014

Directives

Regulations, laws and decrees

Conventions

MD: ministerial decree

Legislation and regulations governing invasive alien species. Texts, key dates and links between the institutional levels.

Box 9

Excerpt from the guide on establishing a legal and institutional framework for invasive alien species

"The reasons for this fragmentation [of regulations on biological invasions] are often more historical and administrative in nature than scientific or technical. Generally speaking, the most frequently encountered problems may be grouped in a number of large categories.

■ *Fragmentation of legal and institutional systems*

- Absence of a strategic approach, issues involving alien species are often poorly understood or perceived as minor in the overall framework of territorial planning or the protection of biodiversity.

- Lack of awareness or insufficient coordination among organisations in charge of plant-protection issues, trade, conservation of natural resources and biodiversity, among other aspects, concerning the international standards and the formulation/implementation of national laws and regulations.

- Fragmentation of the applicable systems and inconsistency in legislative approaches, resulting in an array of institutions and great diversity in definitions, criteria, standards and procedures.

- Insufficient coordination between the central and local governments, particularly in some federal and decentralised systems..

■ *Insufficient precision in terms of scope, definitions and terminology*

- Taxonomy: legislation often does not indicate whether the stipulations are applicable beyond the species or subspecies.

- Scope of policy: alien fish and micro-organisms, as well as introductions in certain types of ecosystems are often forgotten.

- Lack of clear objectives, which reflects a lack of awareness or precision in how IASs should be handled, or excessively limited objectives. In some countries, there is no legal basis for prohibiting the introduction of IASs if they are not directly detrimental to agriculture, forestry or fishing.

- No definitions or inconsistency in the definitions of key words.

■ *Difficulties in terms of compliance with regulations, their implementation and legal remedies*

- Dominance of a purely regulatory approach, relatively few incentives and dissuasive measures, financial or otherwise, intended to discourage the introduction of undesirable species, few measures to eradicate or control them.

- Lack of measures concerning paths and vectors of unintentional introductions.

- Cumbersome, long and costly authorisation and risk-analysis procedures.

- Lack of legal documents enabling the creation of continuous-surveillance systems.

- Lack of clearly defined powers and obligations in terms of the eradication, containment and control of invasive species, fall back on crisis-management techniques when invasions occur.

- Insufficient application of legislation (regulations often not observed, lack of means to determine responsibilities) because standard civil and penal procedures are difficult to apply in situations involving alien species."

Similar observations were made on the national level (Shine, 2008).

(http://especes-envahissantes-outremer.fr/pdf/clare_shine_analyse_reglementation_2008.pdf)

This kaleidoscope of texts from different ministries makes it relatively complex to grasp and effectively use the regulations on IASs. Managers of aquatic environments can also encounter difficulties in interpreting the texts, as well as in finding contact persons for assistance in applying the regulations. Effective coordination between the various public organisations in charge of trade, conservation of natural resources, management of pests, etc. would considerably improve the implementation of the regulations.

In addition, a number of gaps exist in the national regulations (see Box 10), in particular concerning aquatic plants for which only one decree is currently applicable, i.e. the decree (2 May 2007) prohibiting the trade and transportation of two invasive species of water primrose (*Ludwigia grandiflora* and *Ludwigia peploides*). The initial list that had circulated among the network of experts included at least 20 species, but only the two primrose species, among the most common in France, were mentioned in the decree (Dutartre et al., 2012).

However, the situation should soon improve with impending regulatory upgrades in the framework of the European regulation and the national strategy for invasive species having an impact on biodiversity, implemented by the Ecology ministry (see Chapter 3) (Dutartre et al., 2012).

One of the main means to improve the implementation of regulations would be to reinforce the human, technical and financial resources allocated to controlling voluntary imports (e.g. the sale of species for ornamentation and aquariums).

Improvements required to meet the needs of managers

The necessary improvements are listed below.

- Avoid duplicate texts in different regulations, particularly concerning animal species (e.g. aquatic rodents, coypus and muskrats, are the topic of regulations concerning plant protection and those concerning hunting, wildlife and pests).
- Improve the interpretation of certain regulatory texts.
- Use common terms in texts (introduced species, non-native species, species likely to provoke biological imbalances, etc.).
- Identify sources for selection of species lists (INPN, DAISIE, regional lists, regulatory lists, etc.).
- Improve interministerial coordination on the national level and take into account all the existing networks of stakeholders.
- Prepare regulations on procedures for early detection and rapid intervention.
- Improve the dissemination of information on recent additions to regulations (e.g. the lists of regulated animal species).
- Facilitate access to and interventions on private property (see Figure 36).
- Set up pragmatic regulations and control methods for captive wildlife whose past escapes have led to numerous populations (northern raccoons, black swans, sacred ibis, ruddy ducks, etc.).
- Enhance the responsibility of people holding captive animals (mandatory chipping of animals, application of the “polluter pays” principle).
- Simplify regulations and make possible consistent prefectoral orders (create the legal basis and similar management conditions in all departments).
- Enhance responsibility, consistency and national solidarity, e.g. the eradication of a species must by carried out in the concerned region and in the neighbouring regions (the case of the sacred ibis).
- Define a widely acknowledged precautionary principle to encourage fast reactions, seen as an essential factor by all stakeholders.

Figure 36

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Difficulties in accessing and taking action on private properties can hinder the management of invasive alien species. That is the case for ponds in Sologne where a management plan for American bullfrogs (Lithobates catesbeianus) has been set up.

Sources of information

Numerous discussions with the managers of aquatic environments have made clear their constant need for practical manuals and guides on regulations governing IASs. The information below is not a manual or guide, but simply a list of reference documents providing information on IAS regulations on different administrative levels.

■ **Légifrance**

Légifrance, the public service for internet access to laws, provides access to French legal documents. The codes, laws, regulations, ministerial decrees and conventions concerning IASs may all be consulted on the site www.legifrance.gouv.fr.

■ **Site of the Biological invasions in aquatic environments work group**

The chapter in this book on applicable regulations may be consulted on the IBMA site and is regularly updated.

(http://www.gt-ibma.eu/base-documentaire/reglementation/)

■ **EauFrance, the water-information portal**

The portal of the Water-information system in France (WIS-FR) presents vast amounts of information on water, aquatic environments and their functions, the threats weighing on them and the applicable laws and regulations. A page is devoted to regulations governing IASs in aquatic environments.

(http://www.zones-humides.eaufrance.fr/reglementation/faune-et-flore-des-milieux-humides).

■ **Guide to designing legal and institutional frameworks for alien invasive species (Shine *et al.*, 2000)**

This guide presents an overview of the legal instruments and the regional and international institutions dealing with IASs, with the relevant texts, decisions, activities and programmes pertaining to those legal instruments.

(http://www.issg.org/pdf/publications/GISP/Guidelines_Toolkits_BestPractice/Shine_etal_2000_EN.pdf)

■ **Sites of the various French ministries**

On the site of the Ecology ministry (not updated):

http://www.developpement-durable.gouv.fr/Un-engagement-international,13025.html

On the site of the Agriculture ministry:

http://agriculture.gouv.fr/actualites-reglementaires.

http://agriculture.gouv.fr/actualites-reglementaires

Regulatory information on the site of the General food directorate (DGAL):

http://galateepro.agriculture.gouv.fr/

■ **Review of regulations on invasive alien vertebrate species in the Loire basin (Sarat (coord.), 2012)**

This review was drafted by the Centre - Île-de-France regional office of the National agency for hunting and wildlife (ONCFS), in the framework of the *Loire grandeur nature* plan. It presents the main elements of applicable regulations concerning invasive alien vertebrate species in the Loire basin. It does not cover all species or all aspects, but will be updated over time, in step with legal developments.

The guide is available on the ONCFS site:

http://www.oncfs.gouv.fr/laconnaissance-et-la-gestion-des-vertebres-amp-nbsp-ru526/La-connaissance-et-gestion-desvertebres-envahissants-ar1376

■ **Management manual for invasive alien plants in aquatic environments and on river banks in the Loire-Bretagne basin (Haury et al., 2010)**

This manual presents the applicable regulations on invasive aquatic and riparian plant species, divided along the legal notions of prevention, introduction into natural environments and management. It also reviews the obligations of managers concerning management work (access to the environment, relations with the water police, work sites for plant removal) and the instruments the site owner must obtain for the management work. The manual is available on the site of the Loire Nature resource centre:

http://www.centrederessources-loirenature.com/mediatheque/especes_inva/manuel/manuel_complet.pdf.

■ **Current situation and recommendations on the legal instruments addressing invasive alien species in the French overseas territories (Shine, 2008)**

This report discusses the current situation and proposes recommendations on the legal instruments addressing invasive alien species in the French overseas territories. It comprises a general section and more specific information on the national legal system and on each local government. It includes:

- a summary of the relevant legal instruments, on the international level and for the local governments, that contain the obligations accepted by France;
- an inventory of existing measures on the national level and in each local government, with an assessment of their effectiveness;
- practical recommendations for the country and each local government on how to improve management of IASs in regulatory texts and the effectiveness of implementation.

(http://especes-envahissantes-outremer.fr/pdf/clare_shine_analyse_reglementation_2008.pdf)

■ **National list of natural heritage**

INPN Inventaire National du Patrimoine Naturel

The National list of natural heritage (INPN) manages and disseminates on the internet information on the national aquatic and terrestrial natural heritage (present and former plant and animal species, natural habitats, protected areas, geological sites) in continental France and the overseas territories. The data are provided by numerous partners and the National museum of natural history is in charge of data management, validation and dissemination. INPN makes available information on the plant and animal species present in France, including introduced species, and presents part of the applicable regulations.

(http://inpn.mnhn.fr)

■ **State services and other agencies**

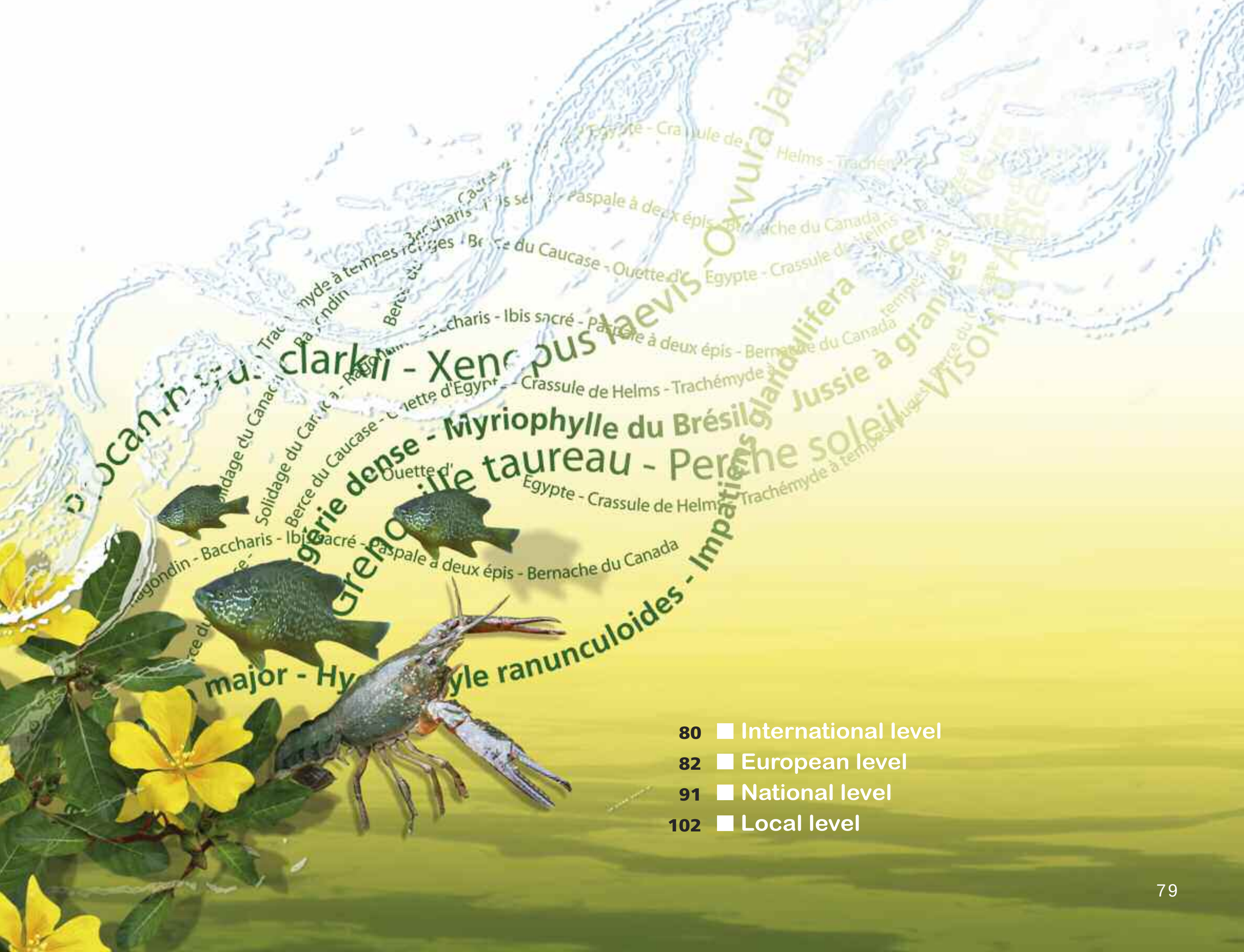
In spite of the diversity of the applicable legal texts and the difficulties in disseminating the information, the various State services, the water police (Onema, ONCFS, DDT(M)) and all the other entities charged with enforcing the law must be familiar with the laws and regulations. They are therefore the first institutions to contact for information on regulations.

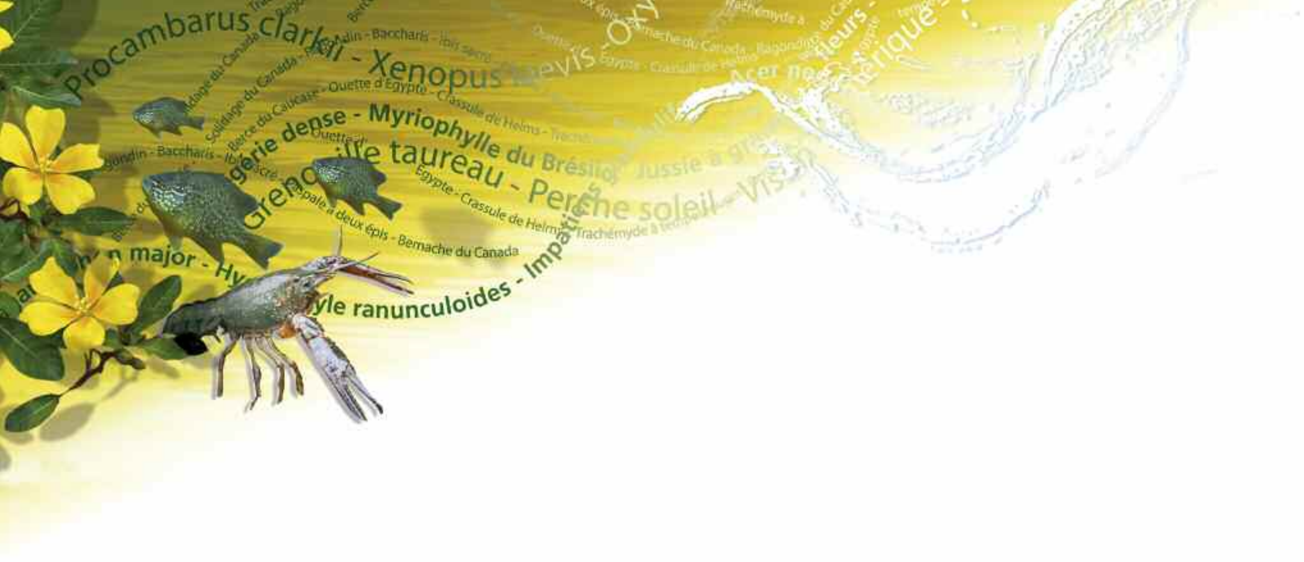
This chapter was drafted by:
Emmanuelle Sarat (IUCN French committee)
and Emilie Mazaubert (Irstea).

With the collaboration of:
Alain Dutartre (independent expert, formerly at Irstea),
Stéphanie Hudin (Federation of conservatories for natural areas),
Nadia Le Botlan (Ecology ministry),
Isabelle Mandon-Dalger (Federation of national botanical conservatories),
Roland Matrat (Pays-de-la-Loire regional environmental directorate),
Nicolas Poulet (Onema),
Jessica Thévenot (MNHN),
Yohann Soubeyran (IUCN French committee).

Panorama of strategies and action plans for invasive alien species

3





International level

Global Invasive Species Programme (GISP)

The Global invasive species programme (GISP) was launched in 1997. GISP is coordinated by the Scientific committee on problems of the environment (SCOPE), in conjunction with the International union for the conservation of nature (IUCN) and the Centre for agricultural bioscience international (CABI). It is one branch of the international programme of biodiversity science (DIVERSITAS).

Its mission is to contribute to biodiversity conservation and to maintain the necessary living resources for humans by limiting (or reducing) the propagation and impacts of invasive alien species.

Its specific objectives are to provide political support to international conventions dealing with IASs, notably article 8 (h) in the Convention on biological diversity (CBD), and to raise public awareness concerning the threats arising from IASs in the world.

Phase I (1997-2005)

During this initial phase, GISP attempted to:

- improve scientific knowledge on IASs to assist in decision making;
- develop the use of early warning, assessments and rapid responses;
- reinforce management capabilities;
- reduce the economic impacts of IASs;
- improve risk-assessment methods;
- strengthen international conventions.

In 2001, GISP published a global strategy for invasive alien species (McNeely et al., 2001) and a guide on enhanced prevention and best management practices for these species (Wittenberg and Cock, 2001). The GISP secretariat was established in 2003 in Cape Town (South Africa) to facilitate and coordinate implementation of the global strategy.

Phase II (2006-2010)

During this second phase, GISP activities dealt with:

- assessing the IAS situation and preventing their propagation worldwide by enhancing scientific knowledge to assist in decision making and improve management;
- studying how IASs affect the main economic sectors in order to reduce their impacts on natural ecosystems and on human food sources;

■ managing and providing a political response by creating an environment conducive to improvements in IAS management.

(http://www.diversitas-international.org/activities/past-projects/global-invasive-species-programme-gisp)

Due to a lack of funding, the GISP secretariat ceased its activities in March 2011.
(http://www.bgci.org/resources/news/0794/).

Global Invasive Species Information Network (GISIN)

The Global invasive species information network was created in 2008 as a platform to exchange information on invasive species worldwide via the internet and other digital means. The network, developed by a group of participants under the direction of the United States Geological Survey (USGS[6]), provides access to data and information of use for detection, rapid response and the regulation of invasive species. An IAS database is available with data on each species and country.
(http://www.gisin.org/DH.php?WC=/WS/GISIN/GISINDirectory/home_new.html&WebSiteID=4)

Invasive Species Specialist Group (ISSG)

ISSG Invasive Species Specialist Group

Created in 1994 and coordinated by the Species survival commission (SSC) of the International union for the conservation of nature (IUCN), ISSG is the IUCN expert group on invasive alien species. It comprises 196 experts in 40 countries plus an informal network of 2 000 other experts and go-to persons. The objectives are to raise awareness concerning IASs and to improve the methods employed to prevent, control and eradicate them.

(http://www.issg.org/about.htm)

ISSG is active in two main fields, namely providing technical and political advice, and facilitating information exchange using on-line tools and by creating networks. Activities include:

■ providing scientific and technical advice to IUCN members for the drafting of management strategies and for their participation in international organisations (CBD, Ramsar, etc.);

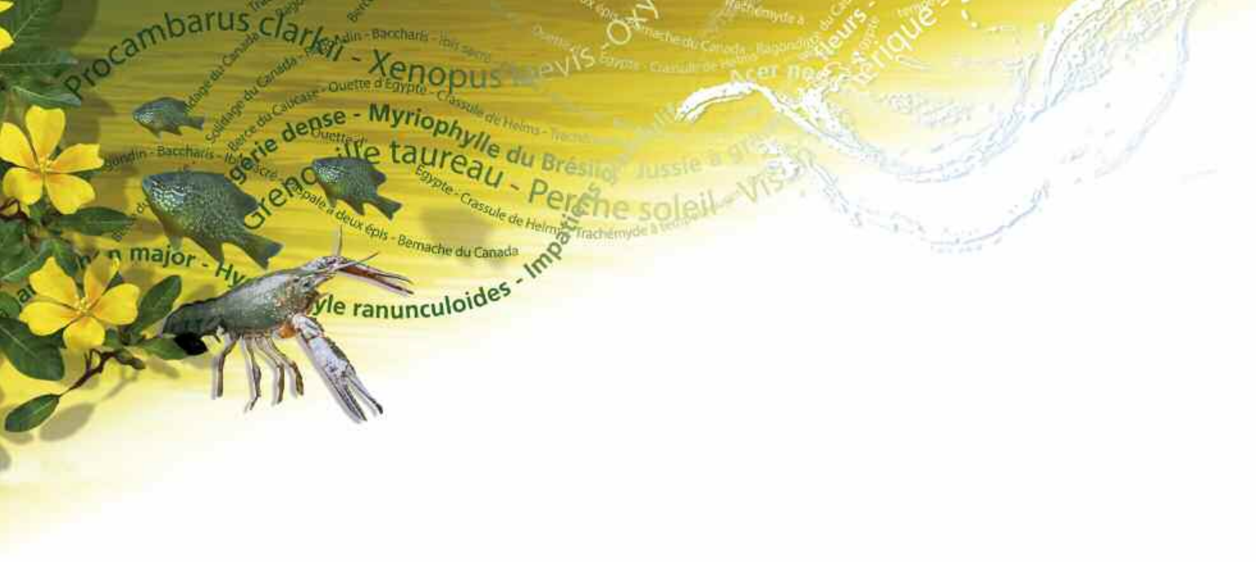
■ publishing a biannual bulletin Aliens (http://www.issg.org/publications.htm);

■ managing the worldwide database GISD on invasive species
(http://www.issg.org/database/welcome/) ;

■ managing the mailing list Aliens-L, that enables users to locate and share information on invasive species and their impacts
(https://list.auckland.ac.nz/sympa/info/aliens-l) ;

■ providing an information service Aliens-referral, to facilitate contacts between the experts and other stakeholders.

6. USGS is a scientific organisation that produces information on the health of ecosystems and the environment, see: http://www.usgs.gov/aboutusgs/



European level

European strategy for invasive alien species (Council of Europe - Bern convention)

Acknowledgement of the problems caused by invasive alien species on the international level, notably in the framework of the Convention on biological diversity (CBD) in 1992, led to the establishment of a European strategy for IASs (see Figure 37). During its 21st meeting in November 2001, the CBD Standing committee requested that a European strategy for invasive alien species be established.

An initial, draft strategy was presented during the 4th meeting of the expert group held in Hora (Azores, Portugal) in October 2002 and during the 5th meeting of the group in Strasbourg in June 2003.

Finally, the 23rd meeting of the Bern convention Standing committee approved the European strategy on invasive alien species and adopted recommendation no. 99 (2003) on the European strategy and recommending that the Contracting parties:

- *"draw up and implement national strategies on invasive alien species taking into account the European Strategy on Invasive Alien Species mentioned above"*;
- *"co-operate, as appropriate, with other Contracting Parties and Observer States in the prevention of introduction of invasive alien species, the mitigation of their impacts on native flora and fauna and natural habitats, and their eradication or containment where feasible and practical, inter alia by exchanging information, collaborating in European projects and paying particular attention to invasive alien species in trade and transboundary areas"*;
- *"keep the Standing Committee informed of the measures taken to implement this recommendation"*.

(https://wcd.coe.int/ViewDoc.jsp?Ref=Rec(2003)099&Language=lanFrench&Ver=original&Site=DG4-Nature&BackColorInternet=a3b811&BackColorIntranet=a3b811&BackColorLogged=EDF4B3)

The European strategy on invasive alien species encourages the implementation of coordinated measures in all European countries in order to prevent or minimise the impacts of these species on biodiversity, the economy and human health.

The strategy is intended primarily for the governments of the Contracting parties to the Bern convention and for other European states. The detailed document provides guidelines for environmental-protection groups and managers of activities linked to IAS prevention and management.

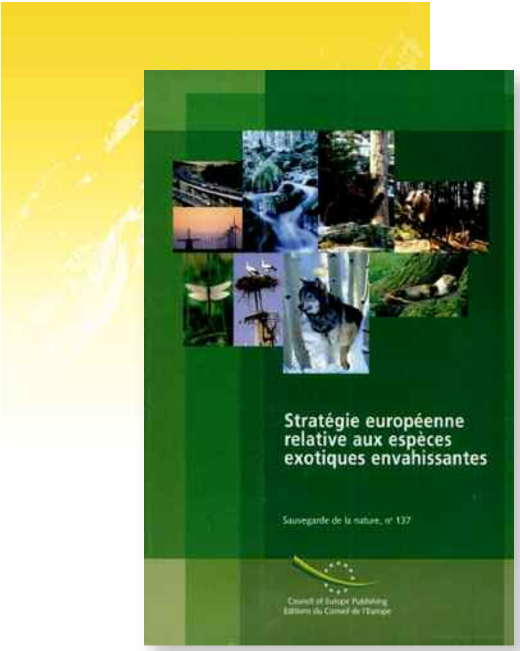
The guidelines propose the following points, among others:

- "*rapidly increase awareness and the available information on the problems caused by invasive alien species and the means to solve those problems*";

- "*reinforce national and regional capabilities and cooperation in confronting the problems caused by invasive alien species*";
- "*prevent the introduction of new invasive alien species in Europe or between regions in Europe, and promote rapid responses to any observed arrivals*";
- "*reduce the impact of the invasive alien species already established*";
- "*provide for the re-establishment of species and restoration of ecosystems and natural habitats that were harmed by biological invasions, where feasible and desirable*";
- "*identify the key measures that must be implemented on the national and regional levels and prioritise them*" (Genovesi and Shine, 2011).

In conjunction with these recommendations, European codes of conduct have been drafted (see Box 11 on the next page).

Figure 37



European strategy for invasive alien species.

European codes of conduct

In the framework of the European strategy on invasive alien species (Genovesi and Shine, 2011), a number of codes of conduct have been drafted for the Member States. These codes are proactive instruments for strategy implementation and are intended for public organisations, economic players, the public and NGOs. The objective is to propose a consistent, responsible and proactive policy for invasive alien species that is applied uniformly across the European Union.

Code of conduct on horticulture and invasive alien plants

In 2008, the Council of Europe and the European plant protection organisation (EPPO) jointly drafted the Code of conduct on horticulture and invasive alien plants (see Figure 38).

The code was adopted by the Standing commission of the Bern convention during its 28th meeting in Strasbourg in November 2008, at the same time as recommendation no. 134 (2008) pertaining to the code and recommending that the Contracting parties:

- "*draw up national codes of conduct on horticulture and invasive alien plants taking into account the European Code of Conduct mentioned above*";
- "*collaborate as appropriate with the horticultural industry and in particular with managers of public spaces (such as municipalities) in implementing and helping disseminate good practices and codes of conducts aimed at preventing release and proliferation of invasive alien plants*";
- "*keep the Standing Committee informed of the measures taken to implement this recommendation*".

(https://wcd.coe.int/ViewDoc.jsp?Ref=Rec(2008)134&Language=lanFrench&Ver=original&Site=DG4-Nature&BackColorInternet=DBDCF2&BackColorIntranet=FDC864&BackColorLogged=FDC864#)

The code, republished in 2011 (Heywood and Brunel, 2011), does not contain any mandatory measures, but proposes various methods to raise awareness among professionals and prevent the introduction of new invasive alien species in Europe:

- "*Be aware of which species are invasive in your area*";
- "*Know exactly what you are growing, ensure that material introduced into cultivation is correctly identified*";
- "*Be aware of regulations concerning invasive alien plants*";
- "*Work in cooperation with other stakeholders, both in the trade and the conservation and plant-protection sectors*";
- "*Agree which plant species are a threat and cease to stock them or make them available*";
- "*Avoid using invasive or potentially alien plants in large scale public plantings*";
- "*Adopt good labelling practices*";
- "*Make substitutes for invasives available*";
- "*Be careful how you get rid of plant waste and dispose of unwanted stock of plants and plant-containing waste*";
- "*Adopt good production practices to avoid unintentional introduction and spread*";
- "*Engage in publicity and outreach activities*";
- "*Take into account the increased risks of alien plant invasions due to global change*".

European code of conduct for botanic gardens on invasive alien species (Heywood, 2013)

In 2013, a European code of conduct for botanic gardens was drafted (see Figure 38). The code explains the specific role played by botanic gardens in biological invasions and proposes guidelines to raise awareness, share information and implement preventive and control measures.
(https://wcd.coe.int/com.instranet.InstraServlet?command=com.instranet.CmdBlobGet&InstranetImage=2300032&SecMode=1&DocId=1943644&Usage=2)

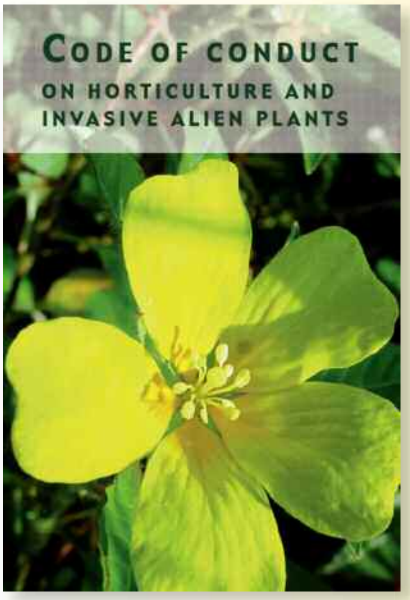
European code of conduct for zoos and aquariums (Scalera *et al.*, 2012)

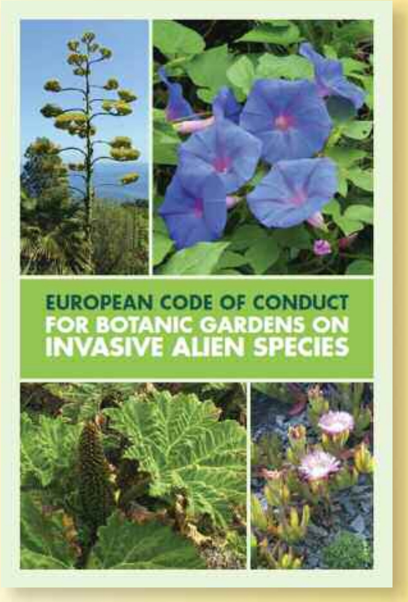
This code of conduct, intended for all zoos and aquariums in the Member States of the Council of Europe, proposes guidelines on voluntary measures that can be set up to mitigate the problems caused by the dissemination of invasive alien species. Five recommendations are provided to:

- set up preventive measures to avoid intentional introductions of IASs and their dissemination in the natural environment;
- integrate IAS risks in management plans for wildlife;
- launch projects to raise awareness of IASs and their impacts;
- adopt good practices in conjunction with an early-detection and warning system for IASs;
- learn about the applicable regulations for zoos/aquariums and IASs.

(https://wcd.coe.int/com.instranet.InstraServlet?command=com.instranet.CmdBlobGet&InstranetImage=2176840&SecMode=1&DocId=1943806&Usage=2)

Figure 38





European codes of conduct for horticulture and botanic gardens.

LIFE and LIFE+ projects

Though a financial instrument specifically intended for IASs does not exist, the European commission has nonetheless contributed to the funding of over 300 projects on the topic since 1992, representing a total budget of over 132 million euros (Scalera, 2010).

LIFE, the EU financial instrument for the environment, is the most frequently used instrument in setting up IAS management programmes. Launched in 1992, the objective of LIFE is to contribute to implementing, updating and developing EU environmental policy and legislation by co-funding innovative or instructive projects generating value for Europe as a whole.

(http://ec.europa.eu/environment/life/about/)

From 1992 to 2006, a total of 187 IAS-related projects were funded by LIFE programmes, representing 44 million euros (Scalera, 2010).

Some 30 projects directly addressed the topic and over 160 included at least one element dealing with IASs. A majority (52%) of projects were run in Spain, the U.K., France and Italy (see Box 12). On average, 12 LIFE projects dealing with IASs were funded each year by the European commission, representing 3 million euros per year.

The LIFE+ programme covered the period 2007 to 2013 with a total budget of 2.143 billion euros.

Regulation (EC) 614/2007 of the Parliament and the Council of 23 May 2007 created the legal basis for the Life+ programme.
(http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2007:149:0001:0016:FR:PDF)

According to the regulation, funded projects must meet the following criteria:

- contribute to the implementation, updating and development of Community environmental policy and legislation;
- be technically and financially coherent and feasible and providing value for money;
- ensure European added value by satisfying at least one of the following criteria:

- be best-practice or demonstration projects, for the implementation of the Conservation of wild birds or the Habitats directives,
- be innovative or demonstration projects, relating to Community environmental objectives,
- be awareness-raising campaigns and special training for agents involved in forest fire prevention,
- be projects for the development and implementation of Community objectives relating to the monitoring of forests and environmental interactions.

Each year, the EU commission issues a call for proposals and decides which projects will benefit from LIFE+ funding. The list of selected projects is regularly published.

Examples of LIFE+ projects concerning biological invasions AlterIAS

AlterIAS (*ALTERnatives to Invasive Alien Species*) is a communication project, aiming to raise awareness in the horticultural sector of the problems caused by invasive alien plants. The overall objective is to reduce intentional introductions of invasive alien plants in gardens, parks, ornamental pools, green spaces and along roads, which are the main starting points for invasions in natural areas. AlterIAS is a national project that served to draft the first code of conduct for invasive plants in Belgium.

(http://ec.europa.eu/environment/life/project/Projects/index.cfm?fuseaction=home.showFile&rep=file&fil=ALTERIAS_Code_conduite_FR.pdf ; http://www.alterias.be/fr/)

CAISIE (*Control of Aquatic Invasive Species and Restoration of Natural Communities in Ireland*) contributes to enhancing comprehension and the control of invasive alien species in Ireland. The overall objective of the project is to halt and reverse biodiversity loss in freshwater ecosystems in Ireland by limiting the impacts of invasive aquatic species through the development of effective management methods, a programme to engage and raise the awareness of stakeholders, and drafting of legislative and political documents. One of the more specific objectives of the project is to eliminate curly waterweed (*Lagarosiphon major*) in Corrib Lake (see the management project in volume 2, page 27).

(http://caisie.ie/)

- **Visón La Rioja** (*Conservación del visón europeo en La Rioja*) is part of a coordinated action plan to save the European mink from extinction in the EU. One of the objectives is to prohibit the installation of the American mink (*Neovison vison*) in the Rioja region. Annual trapping campaigns have been carried out in the neighbouring provinces of Alava and Burgos to prevent the American mink from reaching Rioja rivers where the European mink currently lives.

(http://www.larioja.org/npRioja/default/defaultpage.jsp?idtab=439621&IdDoc=439491)

- **MIRDINEC** (*Management of the invasive Raccoon Dog (Nyctereutes procyonoides) in the north-European countries*) aims to halt and reverse biodiversity loss caused by the raccoon dog (*Nyctereutes procyonoides*), particularly in EU wetlands. An early-warning system has been established to monitor populations of raccoon dogs and innovative elimination and management techniques have been used to control the species.

(http://ec.europa.eu/environment/life/project/Projects/index.cfm?fuseaction=search.dspPage&n_proj_id=3784)

- **Mink control** (*Mink control to protect important birds in SPAs in the Western Isles*) had as its overriding objective the eradication of the American mink (*Neovison vison*) to avoid major disturbances and population losses of internationally important bird species (see Annex 1 in the Birds directive) nesting on the ground.

(http://ec.europa.eu/environment/life/project/Projects/index.cfm?fuseaction=search.dspPage&n_proj_id=1713)

- **Vertebrados invasores** (*Control de vertebrados invasores en islas de Portugal y de España*) is an organisation that works to disseminate the know-how and the feedback acquired in managing invasive alien vertebrate species in the Portuguese and Spanish archipelagos. It also aims to establish a network between agencies to ensure monitoring of and the exchange of technical information on invasive alien species and to inform the concerned sectors on the seriousness of the problem, on the need to set up preventive measures to limit the introduction and establishment of alien species, and on the importance of habitats and native species.

(http://www.gobcan.es/cmayot//medioambiente/medionatural/biodiversidad/conservacion/lineas_actuacion/life14.jsp)

Estuarios del Pais Vasco (*Restauración de hábitats de interés comunitario en estuarios del País Vasco*) attempts to counter the problems caused by the Groundsel tree (*Baccharis halimifolia*), a plant originally from North America, in the main estuaries of the Basque country, by focussing on the most heavily invaded areas. Work deals with habitat conservation by eliminating the Groundsel tree and replanting the affected areas, raising awareness and improving communication with the general public and stakeholders, as well as managing and monitoring the overall project (see the management project in volume 2, page 106).

LAG'Nature a programme to create a network of demonstration sites in lagoons and dunes along the Mediterranean coast in Languedoc-Roussillon, was developed in the framework of the Mediterranean lagoons centre in order to promote innovative operations and demonstrations on pilot sites in Languedoc-Roussillon. Measures to counter invasive plant and animal species are part of the "pilot" projects serving as examples for actual, operational measures. Work is carried out to manage invasive flora and the red-eared slider turtle (*Trachemys scripta elegans*) on the various project sites (see the management project in volume 2, page 175).

(http://www.lifelagnature.fr/)

Many other LIFE projects address invasive alien plant and animal species. Information on past and present projects is available on the internet site of the EU commission.
(http://ec.europa.eu/environment/life/project/Projects/index.cfm)

The European commission will budget 3.2 billion euros for the period 2014-2020 for the new LIFE programme focussing on the environment and climate projects (COM(2011) 874 final).
(http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2013.347.01.0185.01.ENG)

The draft for the new LIFE regulation will draw on the success of the current LIFE+ programme, but will be better structured and more strategic, simple and flexible. Greater importance will be placed on better governance and on the role played by projects in implementing EU policies. New aspects of the future LIFE programme include:

- creation of a new sub-programme for "Climate action";
- clearer definition of priorities, with multi-annual work programmes adopted in conjunction with the Member States;
- new possibilities to implement wider-ranging programmes via "integrated projects" that can call on other EU, national or private funds for environmental and climate objectives.

(http://ec.europa.eu/environment/life/about/beyond2013.htm#proposal)

Projects addressing invasive alien species are clearly eligible in the nature and biodiversity categories. They should target the implementation of measures for invasive alien species via work to experiment and develop approaches to:

- a) prevent the introduction of invasive alien species, notably by addressing the problem of unintentional introduction paths;
- b) establish an early-warning and rapid-response system;
- c) eliminate or reduce invasive alien species established over sufficiently large areas.

These projects must include the three phases (prevention, early warning and rapid response, eradication/ reduction) in a complete approach or, if one phase has already been implemented, at least clearly position

the work in a more general framework combining the three phases. They must be designed to improve the existing technical, administrative and legal frameworks (or create new ones) on the relevant level to ensure that invasive alien species do not gain any more ground in the EU.
(http://eur-lex.europa.eu/legal-content/FR/TXT/PDF/?uri=CELEX:32014D0203&from=FR)

European Alien Species Information Network (EASIN)

The European alien species information network was created by the EC joint research centre and works to improve access to data and information on alien species in Europe. EASIN makes it easier to explore existing on-line databases for policy makers and scientists in their management of these species.

The network works to harmonise the data from an array of sources, thus enabling users to run requests through several databases and organise the results according to their specific needs (e.g. maps, species classification) (Katsanevakis et al., 2012).
(http://easin.jrc.ec.europa.eu/)

Delivering Alien Invasive Species Inventories for Europe (DAISIE)

DAISIE is a research project developed for the EU FP6 programme (6th Framework programme for research and technological development).
The project has set up a large database on introduced species in Europe. Experts in a vast network throughout Europe participate in:

- creating an inventory of the invasive alien species that threaten freshwater, marine and terrestrial environments in Europe;
- structuring the inventory to provide a database for the prevention and control of biological invasions, thanks to better understanding of the environmental, social, economic and other factors involved;
- assessing and summarising the ecological, economic and health risks as well as the impacts of the most common invasive species and/or those causing the greatest impacts;
- using the species-distribution data and feedback from Member States in identifying indicators for early warning.

The database and main programme results may be accessed via the internet site (http://www.europe-aliens.org/).

DAISIE is an important tool in developing a European strategy for the management of invasive species. Reliable and detailed information on species introduced on the European geographic scale represents an essential means of preventing the dissemination of IASs, reducing their impact and applying relevant and effective management strategies. The assembled data deals with vertebrates, invertebrates and plants from both terrestrial and aquatic (freshwater and marine) environments. Over 248 data sets have been assembled and checked by experts, thus constituting the largest database to date on invasive species in the world.

Among the tools created, DAISIE drafted a list of the “100 worst invasive alien species in Europe”, selected for their impacts on biodiversity, the economy and human health. Species data sheets present information on their biology and ecology, their habitats and their distribution range (maps), as well as on introduction paths, invasion trends, impacts and management techniques, including prevention.
(http://www.europe-aliens.org/speciesTheWorst.do).

Framework programmes for research and technological development (FP)

These funding programmes were created by the EU to support and encourage European research.

FP6 served as the general framework for EU activities in the fields of science, research and innovation from 2002 to 2006. The main objective of the sixth FP was to contribute to creating a true European research area (ERA) by improving the integration and coordination of what had been, until then, a relatively fragmented research sector in Europe.
(http://europa.eu/legislation_summaries/research_innovation/general_framework/i23012_fr.htm)

A number of research projects on invasive alien species were developed in this framework, for example:

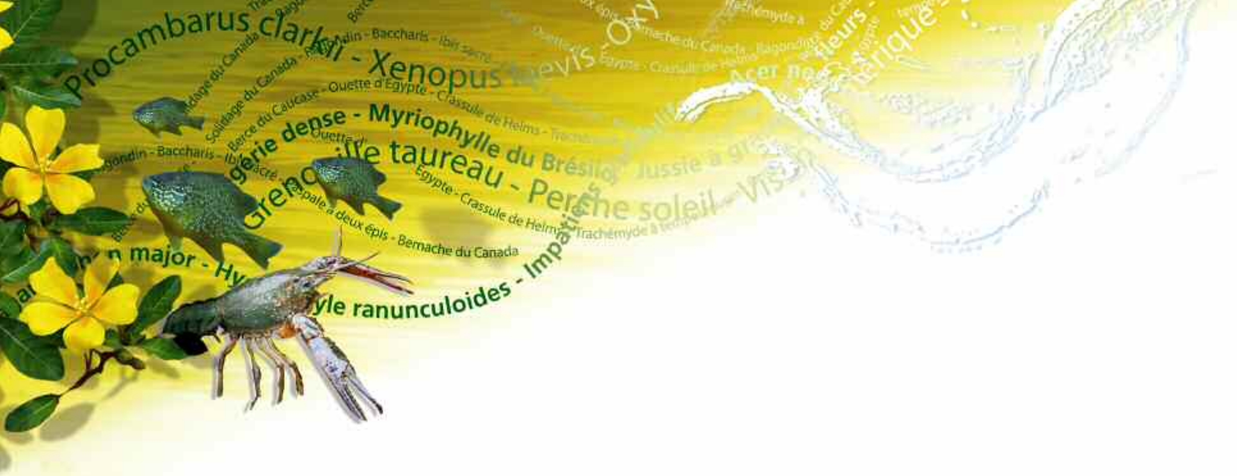
- ALARM (*Assessing LArge scale Risks for biodiversity with tested Methods),* where the objective was to develop and test assessment methods and protocols for large-scale environmental risks in order to reduce their direct and indirect impacts on humans. The potential risks of biological invasions were also taken into account;
(http://www.alarmproject.net/alarm/)
- IMPASSE (*Environmental impacts of invasive alien species in aquaculture),* where the objective was to supply guidelines on ecologically rational practices concerning the introduction and transport of species in aquaculture (quarantine procedures and protocols to assess the potential impacts of invasive alien species).
(http://www2.hull.ac.uk/science/biology/research/hifi/impasse.aspx)

The objectives of **FP7**, spanning the period 2007 to 2013, were to consolidate the European research area and to fulfil the needs of industry and European policies in terms of research and new knowledge. The programme was divided into four categories, namely Cooperation, Ideas, People, Capacities.
(http://europa.eu/legislation_summaries/research_innovation/general_framework/i23022_fr.htm)
(http://cordis.europa.eu/fp7/understand_fr.html)

Further projects on invasive species were carried out in FP7, notably those listed below.

- FRESIS (*Freshwater invasive species in Europe: control, prevention and eradication*), proposed an integrated, multi-disciplinary approach in implementing the three main thrusts (control, prevention and eradication) of the project intended to improve European competitiveness in managing biological invasions.
(http://cordis.europa.eu/projects/index.cfm?fuseaction=app.details&TXT=fresis&FRM=1&STP=10&SIC=&PGA=&CCY=&PCY=&SRC=&LNG=en&REF=94723)
- INSPECTED.NET (*INvasive SPecies Evaluation, ConTrol & EDucation.NETwork*), put together a group of international experts on biological invasions to support and enhance existing programmes such as DAISIE and GISP.
(http://cordis.europa.eu/projects/rcn/101539_en.html)
- PRATIQUE (*Enhancements of pest risk analysis techniques),* where the objective was to improve pest risk analysis (PRA) techniques, which meant gathering the data required to produce valid PRA results for all of Europe, devising multi-disciplinary research programmes to improve PRA techniques and developing an effective and simple decision-making system.
(https://secure.fera.defra.gov.uk/pratique/index.cfm)

The Community research and development information service (CORDIS) provides information on European R&D work and on technology transfers. Ample information is available on the various European projects dealing with invasive alien species.
(http://cordis.europa.eu/home_fr.html).



National level

Strategy and programmes of the Ecology ministry

■ National strategy against invasive alien species

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Ministère de l'Écologie, du Développement durable et de l'Énergie

In 2009, the Water and biodiversity directorate of the Ecology ministry drafted the framework for what was to become the National strategy against invasive alien species having an adverse impact on biodiversity. The central elements of the strategy were based on the commitments undertaken during the Grenelle environmental meetings and the Convention on biological diversity (see Chapter 2).

In implementing the strategy, the directorate called on the National agency for water and aquatic environments (Onema), the National agency for hunting and wildlife (ONCFS), the IUCN French committee and two scientific coordinators, for fauna, the Natural heritage department (SPN) of the National museum of natural history (MNHN), and for flora, the Federation of national botanical conservatories (FCBN).

All the above organisations assist the Ecology ministry in implementing regulations and in various projects concerning invasive alien species.

The strategy included several parts:

- prevention of introductions of invasive alien species into the natural environment;
- creation of a monitoring network;
- design and implementation of national action plans;
- reinforcement of the nature police;
- increased communication, training and research;
- support in establishing regulations.

The publication of Regulation (EU) 1143/2014 of the European parliament and the Council of 22 October 2014 made necessary a complete rethinking of the national strategy. The Water and biodiversity directorate launched a project to revamp the national strategy taking into account the European regulation. The project consists of a steering committee and work groups bringing together stakeholders and experts working in the field of invasive alien species.

■ Biological invasions programme (Invabio)

This programme was established in 1999 by the Ecology ministry. The main objective was to provide the information required for a coherent approach based on improved knowledge (theoretical and practical) on biological invasions and to propose management tools designed to prevent, minimise or eradicate invasive alien species (Barbault and Atramentowicz (coord.), 2010).
(http://www.ecolab.ups-tlse.fr/invabio/accueil.html)

Three topics were set for the research carried out in the Invabio programme:

- the mechanisms underlying invasive phenomena, taking into account the evolution of invasive populations and the characterisation of the invasive phenomenon, to develop the capacity to predict the invasive potential of a population in a given area;
- the socio-anthropological perception of invasive phenomena and an economic assessment of biological invasions with cost-benefit analysis of introductions and cost analysis of the management of invasions;
- the control and management of invasive phenomena, comprising first of all the development of a risk-assessment method, then proposals on techniques, experiments and assessments of one or more control methods that must be adapted to the specific conditions of the invasions and, finally, an assessment of the inherent or secondary risks of the control techniques used for these populations (Mazaubert, 2008).

Between 2000 and 2006, Invabio financed approximately 30 research projects on a vast range of organisms and processes. The main results of these projects were presented during a feedback symposium at Miolets et Maa (Landes department) on 17-19 October 2006. A further objective of the symposium was to propose recommendations for research and management to assist in decision making for public policies.
(http://centrederessourcesloirenature.com/mediatheque/especes_inva/telechargements/evenementiel/publication_invabio.pdf)

Finally, the symposium produced a book reviewing the current situation of IASs in France on the basis of the results of the funded projects.

Strategy of the Agriculture ministry

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MINISTÈRE
DE L'AGRICULTURE
DE L'AGROALIMENTAIRE
ET DE LA FORÊT

The Agriculture ministry is also active in managing IAS issues. The plant-protection services are, among other tasks, in charge of monitoring health and plant-protection issues throughout the country (Dutartre et al., 2010). The National laboratory for plant protection (LNPV) previously reported to the General food directorate of the ministry, but on 1 January 2011, it became the Laboratory for plant health (LSV) and a part of ANSES (Agency for food, environmental and occupational health & safety).
(http://agriculture.gouv.fr/laboratoire-national-de-la)

LSV is now the go-to lab for scientific and technical support for all issues concerning risks to plant health. Its activities within the agency contribute to an overall approach to risk assessment (see Box 13). The Entomological and invasive plants unit in Montpellier deals in particular with regulated insects and acari, and with invasive alien plants. This unit will play a major role in detecting the new species introduced in France and Europe and running the pest risk assessments.
(http://www.anses.fr/fr/content/laboratoire-de-la-sant%C3%A9-des-v%C3%A9g%C3%A9taux#onglet3-tab)

In addition, a professional agricultural group, the National federation against pests (FNLON) coordinates the work of the regional federations (FREDON) and departmental federations (FDGDON), and works closely with the plant-protection services through an agreement with the ministry (Dutartre et al., 2010). These groups working against pests are required to manage the IASs that have been declared as such by the Rural code (e.g. nutria and muskrats).

In the framework of the Ecophyto 2018 plan, an epidemic-surveillance network for plants has been established. The network covers all sectors, in particular non-agricultural areas. A manager was appointed to coordinate projects and to draft a "Guide on observing and monitoring pests in non-agricultural areas".
(http://www.ecophytozna-pro.fr/n/guide-d-observation-et-de-suivi-des-organismes-nuisibles/n:185).

This technical guide discusses observation and monitoring methods for pests, including invasive alien plants having an adverse impact on other plants (Dutartre et al., 2010).

Box 13

Pest risk analysis (PRA)

A double regulatory framework exists for PRA because both the **International plant protection convention** (IPPC) and the **Convention on biological diversity** (CBD) recommend that a collaborative effort be made to address invasive alien species. The latest version of the PRA standard (international standard for phytosanitary measures, ISPM no. 11) includes the risks for the environment, in particular for ecosystems and habitats, and is a regulatory instrument to raise awareness among the public and authorities concerning biological invasions.

For over 60 years, the European plant protection organisation (EPPO), which corresponds to the regional plant-protection organisation for Europe within the IPPC framework, has attempted to prevent the introduction and spread of pests that damage crops in the European and Mediterranean region. However, in step with the regulatory context and starting in the beginning of the last decade, EPPO also launched to work on invasive alien plants capable of severely disturbing or destroying natural plant communities. EPPO, in conjunction with LSV in France, assumed responsibility for PRA to determine the risks involved with certain invasive alien plant species and to make recommendations on how to prevent their introduction and spread via international trade.

Strategy of the Health ministry

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MINISTÈRE DES AFFAIRES SOCIALES ET DE LA SANTÉ

The purpose of the first National plan for health and the environment (PNSE) 2004-2008 was to improve the health of the French people as it relates to environmental quality, in view of sustainable development. One of the eight priority issues according to the PNSE-1 guidelines committee for environmental health was to "prevent respiratory allergies caused by environmental exposure" and one of the corresponding projects dealt with pollen. (http://www.sante.gouv.fr/plan-national-sante-environnement-pnse,3480)

PNSE-2 (http://www.sante.gouv.fr/deuxieme-plan-national-sante-environnement-pnse-2-2009-2013.html) contained the environmental-health commitments undertaken in the Grenelle environmental agreement. The objective was to provide an overview of the main issues, as well as describe and prioritise projects for the 2009-2013 period. However, in a effort to reduce environmental inequalities, PNSE-2 also dealt with the prevention of allergies.

It was in this context that the various ministries, including the Health ministry, launched the project against common ragweed (Ambrosia artemisiifolia), an invasive alien plant from North America. Its widespread establishment in France is a major concern for public health because its pollen can cause severe allergies in humans.

To determine the sectors currently infested, not infested and those in the process of becoming infested by ragweed, the Health ministry assigned to the Federation of national botanical conservatories (FCBN) the task of drawing up a map indicating the presence of the plant.

In addition, in view of reinforcing coordination of the measures against the annual, highly allergenic plant, the Health ministry and the National institute for agricultural research (INRA) established in 2011 the Ragweed observatory. The primary objective of the observatory is to encourage coordination of the measures against ragweed on the national, European and international levels.
(http://www.ambroisie.info/index.php)

National museum of natural history and Federation of national botanical conservatories

During the formulation of the national strategy against invasive alien species, MNHN and FCBN were appointed in 2009 as the coordinators of scientific networks to assist the Water and biodiversity directorate of the Ecology ministry. Management of a network of experts on invasive, introduced plant and animal species is a means to enhance knowledge on a number of taxonomic groups.

- The ministry ordered a report from the two organisations on setting up a network to monitor the natural environment. The report was drafted in 2011 and published in 2014 (Thévenot and Leblay, 2014). The report will be used in preparing the national strategy.
(http://spn.mnhn.fr/servicepatrimoinenaturel/rapports.html)

A framework document containing definitions for biological invasions (Thévenot *et al*. 2013), available via the same link shown above, comprises an array of information drawn from the bibliography and papers submitted by experts.
MNHN and FCBN are also working on devising an IAS prioritisation method:

- concerning fauna, the national list of introduced vertebrates (Thévenot, 2014), the first step, is available on line (see the link above). Step 2 will be a study on their invasive nature;
- concerning flora, an initial proposal listing species requiring regulation, drawn up according to a published method, was submitted to the ministry in 2010. Since then, the federation has worked on improving a semi-automatic risk-analysis technique, integrating field data and bibliographical information from the FCBN network.

The step consisting of proposing measures concerning these species will be handled by an expanded work group in the framework of the activities undertaken by the ministry.

Natural heritage department (SPN) at the MNHN

Currently, MNHN takes part in the national plans against the Pallas' squirrel (*Callosciurus erythraeus*) (see Box 14) and the Asian hornet (*Vespa velutina nigrithorax*), and assists the National agency for hunting and wildlife with the European plan for the ruddy duck (*Oxyura jamaicensis*).

SPN also provides technical and organisational support by making available the tools used to acquire and manage species monitoring and surveillance data in the framework of citizen-science programmes for IASs and for standard inventories (species occurrence observations).

The department draws up departmental maps (Biodiversity atlas for departments and marine sectors (ABDSM) and updates the TAXREF reference dataset on newly detected introduced species and the species status conditions on the national level.

Box 14

National programme against the Pallas' squirrel

The Pallas' squirrel (*Callosciurus erythraeus*), originally from Eastern Asia, entered France via Cap d'Antibes at the end of the 1960s. Initially sold as a pet and released to the environment, the species has become an ecological and economic pest (damage to tree bark, impact on local fauna, damage to fruit, telephone cables, wooden structures in buildings, etc.) requiring control measures.

At first limited to Cap d'Antibes, the species overcame the obstacle represented by buildings in the town of Antibes - Juan-les-Pins toward the end of the 1990s. As of today, the species is also present in the town of Vallauris and has started to colonise neighbouring towns. However, its extension northward is limited by the A8 highway that is currently seen as a very difficult barrier to overcome.

The increase in damage, notably in orchards, has pushed individuals to take action by trapping, shooting and, worse yet, poisoning the animals. These non-selective methods, poorly implemented, may have significant, indirect consequences on wildlife as well as on household animals.

Given this situation and the currently limited range of the species, control measures for this alien squirrel were considered in 2010 by the Ecology ministry. Following an initial phase used to analyse the situation, gather data, obtain the necessary authorisations and organise the intervention, the programme was launched in June 2012 under the responsibility of the National museum of natural history, the Museum of natural history in Nice and the National agency for hunting and wildlife.
(http://ecureuils.mnhn.fr/sites/default/files/documents/plan-national-lutte-ecureuil-ventre-rouge.pdf)

■ Federation of national botanical conservatories

FÉDÉRATION

FCBN represents the network of botanical conservatories working to enhance the knowledge, preservation, management and use of plants (Thévenot and Leblay, 2014). As a joint organisation for all the national botanical conservatories, it encourages the convergence of policies and the tools used within the network. It organises and coordinates the knowledge base of the conservatories available via the network.

It interacts with the public authorities that it assists in preparing and implementing policies concerning the natural heritage, particularly for wild plants and natural habitats. The network of conservatories has a database comprising over 20 million data points on the current and past distribution ranges of plants. This data in map form serves to provide a scientific basis for policies targeting the conservation of nature, to maintain watch over changes in natural environments and to support the implementation of any necessary conservation plans and measures. (http://www.fcbn.fr/)

National agency for hunting and wildlife (ONCFS)

Office National de la Chasse et de la Faune Sauvage

The National agency for hunting and wildlife was founded in 1972 as a public agency under the supervision of both the Ecology and Agriculture ministries.

ONCFS was assigned five main missions listed in article L421-1 of the Environmental code and included among the Grenelle objectives of the French government, namely:

- general surveillance of rural areas and policing activities for the environment and hunting;
- research and studies on wildlife and its habitats;

- technical support and advice for administrations, local governments, territorial managers and planners;
- orient hunting practices toward forms of sustainable development and develop environmentally friendly management techniques for rural areas;
- organise and run examinations for hunting permits.

(http://www.oncfs.gouv.fr/)

In the framework of its strategic objective no. 1 (Contribute to preserving biodiversity), listed in the Statement of objectives for 2012-2014, ONCFS uses its police powers to enforce environmental law and in particular the European Habitat and Birds directives.

Point 3 in the strategic objective no. 1 (Contribute to controlling invasive alien animal species and those interfering with ecosystem balances or human activities) consists of two specific objectives:

- Objective 9, participate in monitoring, studying and managing invasive alien species and protected native animal species interfering with ecosystem balances or human activities;
- Objective 10, assist prefectoral authorities in taking action against wildlife constituting risks for public safety.

Invasive alien species are one of the research topics addressed by ONCFS. IAS management is divided along three lines:

- prevention of introductions in conjunction with informing and raising the awareness of stakeholders;
- surveillance for early detection of new species, monitoring of their development and regular assessments of the situation;
- curative action (up to and including eradication of a species), including national action plans (PNL) or control programmes at the request of the State.

In the field, the agency contributes to numerous IAS management projects for birds and mammals (ruddy duck, sacred ibis, Canada goose and small invasive alien carnivores). These projects are coordinated nationally by the Studies and research directorate, with technical support from experts, in close cooperation with the Police directorate concerning regulatory issues, and are carried out via partnerships when necessary.
(http://www.oncfs.gouv.fr/Recherches-sur-les-especes-exotiques-envahissantes-ru509).

Projects are executed on the regional level and the departmental services ensure that the entire country is covered in terms of police work and for IAS detection, monitoring and management. The results are published, notably in the Faune Sauvage journal.
(http://www.oncfs.gouv.fr/Recherches-sur-les-especes-exotiques-envahissantes-ru509).

ONCFS is also present in the overseas territories where science-advice missions are carried out, in conjunction with local partners, notably the IUCN French committee which has launched a project on IASs in the overseas territories, including territorial diagnoses and control strategies, legal and regulatory support for State services, early-detection studies, monitoring and projects, management and eradication (Cugnasse, Sarat, personal pub., 2013, for the IBMA (biological invasions in aquatic environments) site).
http://www.gt-ibma.eu/oncfs/).

National agency for water and aquatic environments (Onema)

ONEMA
Office national de l'eau
et des milieux aquatiques

The main objective of Onema, a national, essentially administrative agency, is to contribute to overall and sustainable management of water resources and aquatic ecosystems. Its missions are listed in article L.213-2 of the Environmental code and consist of attaining good ecological status, the objective set by the European water framework directive (WFD).

Objective no. 8 in the first Onema Statement of objectives (2009-2012) was to Produce data on aquatic environments in order to characterise their biodiversity, among other aims. To achieve that objective, Onema studied the structure of communities and their changes, targeting in particular migratory species, as well as flag and alien species. Territorial units monitor invasive species (water primrose, duckweed, waterweed, ragweed, Pseudorasbora parva, garden balsam, etc.), notably in the framework of local projects. These units are also in charge of monitoring various crayfish species (native and alien) as per the Natura 2000 regulations. (http://www.onema.fr/Contrat-d-objectifs-2009-2012)

The new Onema Statement of objectives covers the period 2013 to 2018. Objective 12 in the new Statement is to Upgrade data production. To meet that objective, Onema participates in water-status monitoring programmes, in characterising pressures and impacts on aquatic environments and in acquiring knowledge on biodiversity. In addition to the data acquired via the monitoring programmes, other observations of aquatic environments are carried out in the framework of the National biodiversity strategy for invasive and important native species, spawning grounds and ecosystem services. The data produced is fed into the nature and landscapes information system, in compliance with the reference dataset for the national list of natural heritage.
(http://www.onema.fr/L-Onema-vient-de-signer-son-contrat-d-objectifs)

In addition, Onema provides scientific and technical support to the Ecology ministry and the decentralised services. With Irstea (formerly Cemagref), Onema founded the Biological invasions in aquatic environments work group (see page 98). Onema has also funded research projects dealing with biological invasions, for example:

- Genetic structure of alien crayfish populations and pathogenic effects. Invasion mechanisms and impact on native fauna (Symbiose UMR CNRS - Univ. Poitiers 2010-2012);
- Predicting the establishment of alien species in aquatic environments. Progress toward anticipating biological invasions (MNHN, 2010);
- Impact of alien species on food webs in lakes (Ecolab UMR CNRS - Univ. Toulouse III 2010-2011);
- Potential impact of Wels catfish (Silurus glanis L.) on fish. Multi-scalar approach using modelling, isotopic and genetic tools, and in situ observations (Ecolab UMR CNRS - Univ. Toulouse III 2012-2014);
- Preserving biodiversity against invasions of Louisiana crayfish (*Procambarus clarkii*) (INRA and Brière regional nature park 2010-2012, with joint organisation of the first French symposium on invasive alien crayfish in June 2013).

IUCN French committee

The French committee consists of the network of French organisations and experts working for the IUCN. This novel partnership comprises two ministries, 13 public organisations, 41 NGOs and over 250 experts grouped in commissions addressing specific topics and in thematic work groups. Thanks to this highly diverse composition, it serves as a knowledge base and platform for discussion on biodiversity issues.

To meet the challenges of conserving biodiversity in France, the IUCN French committee draws up status reports, issues practical recommendations and manages projects in order to produce better policies, knowledge and measures. Of particular importance is support for conservation stakeholders, including the managers of natural areas, and guidelines for public policies. Concerning invasive alien species, the French committee has two main projects in its Species programme:

- invasive alien species in the overseas territories, a project in conjunction with all the overseas local governments and a wide array of stakeholders (see Box 15);
- since 2014, joint management of the Biological invasions in aquatic environments work group with Onema.

The IUCN French committee and its partners organised the first national IAS symposium, titled “Invasive alien species, reinforced strategies for action”, in September 2014 in Orléans. During the three-day meeting, 200 stakeholders and experts from continental France and the overseas territories traded opinions and discussed project feedback in an effort to address the issues raised by biological invasions, taking into account the new European directive and the future national strategy for IASs.

Finally, the committee also acts as a liaison with the IUCN on the international level and is in close contact with its Invasive species specialist group (ISSG). It participates as well in supplying and updating the world database on invasive alien species (GISD).

Box 15

IUCN French committee project for IASs in the overseas territories

Invasive alien species are one of the main threats to biodiversity in the French overseas territories. Since 2005, the IUCN French committee has run an initial project specifically targeting IASs in the overseas territories in order to assist the local stakeholders.

Thanks to the involvement of numerous partners and precise targets in each of the overseas territories, a network has been established comprising over 100 experts and go-to persons from an array of organisations active in the overseas territories and in continental France.

The main results of this project include:

- publication of a scientific and legal review of the situation in the overseas territories, with numerous recommendations on how to improve the response to the phenomenon;
- drafting of several technical guides and documents to raise awareness, in support of local projects;
- organisation of workshops in the Caribbean, the Pacific and the Indian Ocean to share information and develop solutions;
- creation of an internet site on IASs in the overseas territories (see Figure 39) that serves as a resource centre for all overseas stakeholders;
- dissemination of a quarterly information bulletin.

(http://www.especes-envahissantes-outremer.fr/)

Figure 39

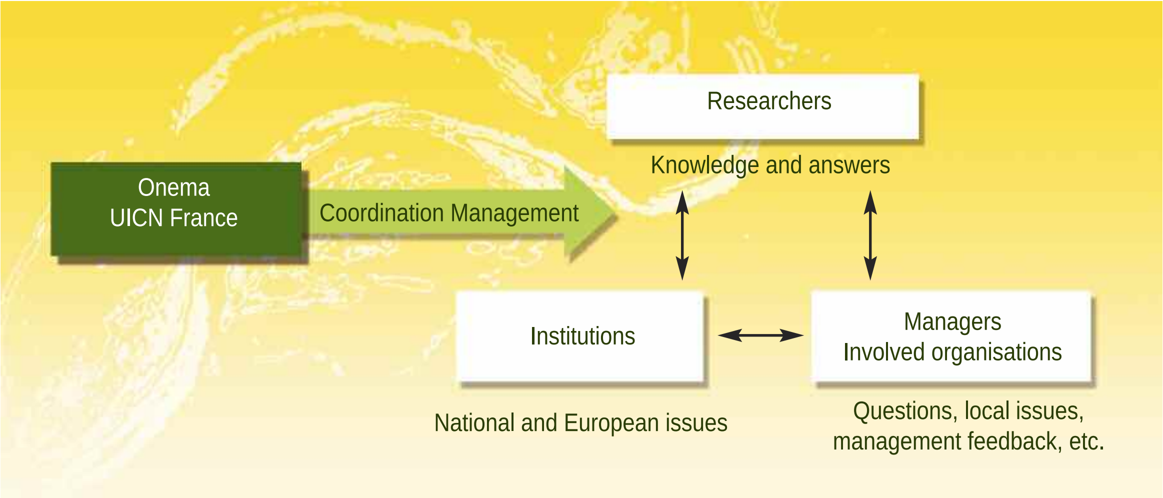
Biological invasions in aquatic environments work group (IBMA)

The group was created in 2009 and serves as an interface for communication and discussion on how to manage IASs in freshwater aquatic environments. The purpose of the group is to enhance coordination among the various stakeholders working on these problems on the national level (see Figure 40).

In order to cover the full range of issues involved in IAS management, the group has co-opted approximately 50 representatives of the various stakeholders, from the “producers of scientific knowledge” to “people active in the field”, i.e.:

- managers of river boards, regional nature parks, conservatories for natural areas, etc.;
- other "involved organisations", e.g. the French national angling federation or Voies navigables de France (French waterways);
- State services and local governments, e.g. the Water and biodiversity directorate of the Ecology ministry, departmental councils, etc.;
- researchers (Irstea, National institute for agronomic research, National scientific-research centre, National museum of natural history, Laboratory for plant health, Agency for food, environmental and occupational health & safety, etc.) working in the life sciences (biology, ecology) and in the human and social sciences (ethnology, sociology, economics) (Dutartre et al., 2012).

Figure 40



Organisation of the Biological invasions in aquatic environments work group (IBMA)

By bringing together these different types of stakeholders, the group serves as an innovative platform where the main objective is to assist managers by digesting and making available the knowledge acquired on IAS management.

The assistance, targeting exclusively those alien plant and animal species seen as invasive in aquatic environments, deals with:

- the development of operational tools to improve knowledge and management of invasive alien species;
- support in implementing management operations for certain species;
- identification of scientific issues and proposals for programmes of applied research;
- the formulation of strategies and public policies for the management of invasive alien species;
- scientific and technical support for the Ecology ministry.

Group activities fall into three categories:

- internal discussions, i.e. current studies, information exchange, meetings, research proposals;
- production and dissemination of knowledge for managers (see Figures 41, 42 and Box 16), including surveys, the knowledge base on species and their management, codes of conduct, management feedback, bulletin and case studies;
- interface and go-between for stakeholders with a listing of managers, monitoring of local committees, organisation of symposia, participation in training sessions.

The group also takes part in the national strategy on invasive species set up by the Ecology ministry. Contacts also exist with a number of organisations supervised by the Agriculture ministry.

Figure 41

Examples of the work by the IBMA work group:
- publication in 2012 of an issue of Sciences Eaux & Territoires dedicated to biological invasions in aquatic environments (http://www.set-revue.fr/les-invasions-biologiques-en-milieux-aquatiques);
- publication in 2015 of two volumes in the Knowledge for action series dealing with invasive alien species.

The group was created through an agreement between Onema and Irstea. It was originally planned to last three years (2008 to 2010), but its activities have been pursued.

Given the importance of the issues involved in biological invasions, its continued existence may be attributed to the quality of the network established, the positive results obtained and the great need for knowledge, communication and coordination in this field on the national level. The recent adoption of the European directive on IASs and the issues involved in its implementation on the national level are a further reason for the group to continue its activities. That explains why, since 2014, group management and coordination is now ensured by a new partnership between Onema and the IUCN French committee.

Box 16

Internet site for Biological invasions in aquatic environments - www.gt-ibma.eu

This site, focussing on biological invasions in aquatic environments, presents the IBMA work group, its activities and provides access to the operational tools:

Figure 42

- management feedback;
- document library;
- regulations;
- existing strategies;
- news;
- bulletin and reports;
- species requiring monitoring;
- events and training;
- case study on management of water primrose in the Brière regional nature park;
- activities and success stories of members.

A large number of initiatives have been taken on the international, European and national levels to develop management tools for invasive alien species. Figure 43 recapitulates the documents and tools available for IASs in aquatic environments, on the international, European and national levels.

Figure 43

Review of the documents and tools available for invasive alien species (IAS) in aquatic environments, on the international, European and national levels.

Local level

Regional environmental directorates (DREAL)

In parallel with the establishment of the national strategy against IASs having an impact on biodiversity, the Ecology ministry, in its 2009-2010 road map for local State services in the fields of water and biodiversity, requested that all DREALs:

- "*raise the awareness of the concerned population groups concerning the hazards involved with invasive alien species*";
- "*list the measures that can be taken by local governments and managers of natural areas against IASs*";
- "*list the scientific and technical organisations already addressing the detection and establishment of biological invasions*";
- "*reinforce their relations with departmental and regional public entities, with local governments in view of coordinating measures to protect natural biodiversity*";
- "*increase inspections on compliance with applicable regulations*".

(http://dise.seine-maritime.agriculture.gouv.fr/IMG/pdf/annexe_feuille_route_2009-2010_cle0da8c3-1.pdf)

Given the specific context of overseas territories due to the fragility of island biodiversities, in 2008 the administrative authorities in each territory received guidelines enabling them to develop a strategy tailored to their territory (Ménigaux and Dutartre, 2012).

Then for the period 2013-2014, the instruction dated 11 February 2013 concerning the road map for local State services in the fields of water, biodiversity and landscapes, stipulated that each *"DREAL encourage its institutional partners to develop monitoring of invasive alien species in view of establishing a monitoring network throughout continental France". It was also requested that the DREALs "finish drafting the national action plans (Pallas' squirrel and Pampa grass) [...] for which they are cognizant and ensure implementation of the plans in their region"*.

(http://circulaire.legifrance.gouv.fr/pdf/2013/02/cir_36545.pdf)

Even prior to the requests of the Ecology ministry, many DREALs were involved in listing, organising studies on and managing IASs in their region. For example, projects have been set up or reinforced throughout the country:

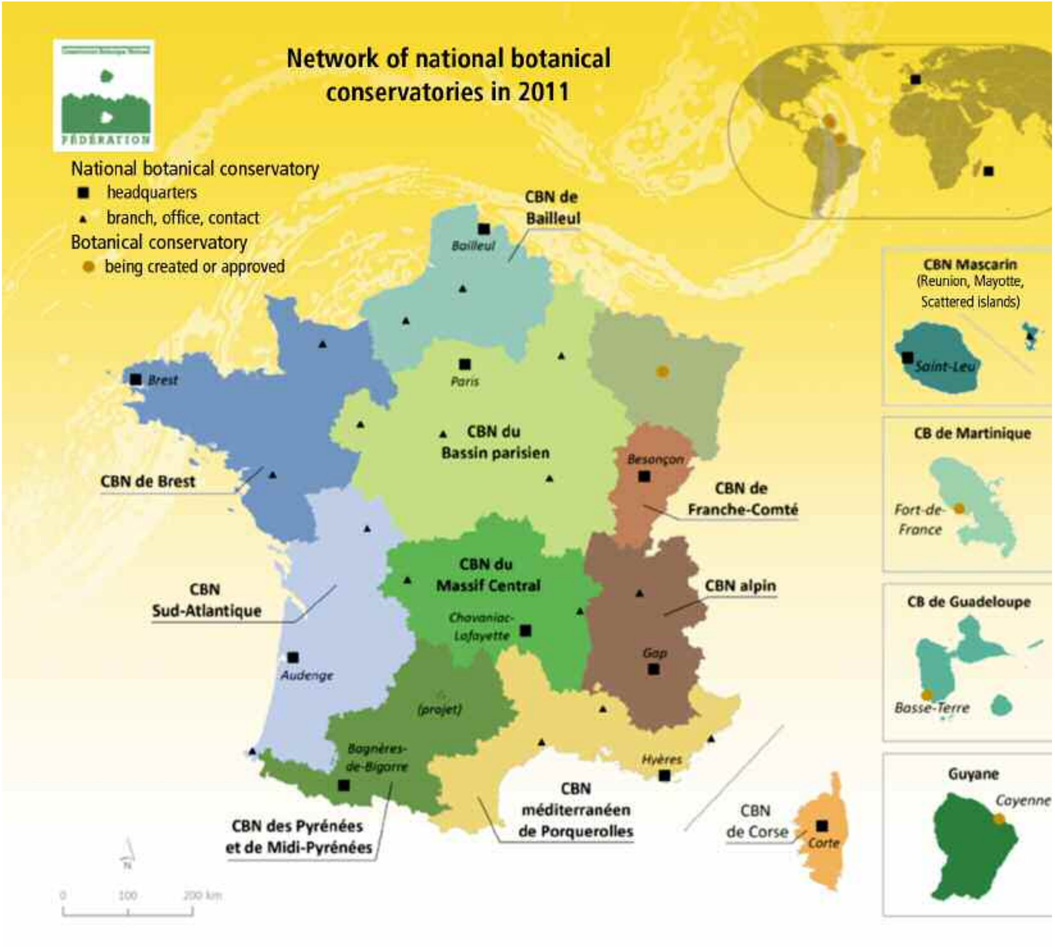
- in the Pays-de-la-Loire region, the DREAL established in 2001 a management committee for invasive alien plants that was expanded to include fauna in 2013;
- in the Midi-Pyrénées region, the DREAL works with the Pyrénées-Midi-Pyrénées botanical conservatory to set up a regional action plan for invasive alien plants;
- in the Centre region, an Invasive plants group has been created, notably at the instigation of the DREAL. Plans are now being made for an Invasive fauna group;

■ in the Basse-Normandie region, a project to organise efforts against invasive species in the region was launched in 2007 with support from the DREAL;
■ in the Auvergne region, the DREAL and the Auvergne conservatory for natural areas are drafting a characterisation report on invasive alien fauna in conjunction with the ONCFS Loire plan and local partners;
■ in the Nord-Pas-de-Calais and Bourgogne regions, studies are under way for regional characterisation reports on invasive alien species.

National botanical conservatories

The network of national botanical conservatories currently groups 11 organisations approved by the Ecology ministry (ten in continental France and one overseas, see Figure 44). They operate in 91 departments and their mission is defined by article D.416-1 in the Environmental code. The missions of the national botanical conservatories (CBN) include gaining knowledge on the status and evolution of wild plants and natural/semi-natural habitats, identifying and conserving plants and rare or threatened habitats, providing scientific and technical support to public authorities (State, local governments) and raising the awareness of the public. They also participate in developing and managing the National list of natural heritage (INPN).

Figure 44



Map of the botanical conservatories in 2011. According to Thévenot and Leblay, 2014.

The national botanical conservatories have extensive experience with biological invasions. They are indispensable scientific partners in terms of acquiring new knowledge and managing invasive plants, and they actively support the State, public agencies, local governments and local work groups.

In carrying out their missions, they (Thévenot and Leblay, 2014):

- collect field data on the biology of invasive plants and draw up maps on species distribution ranges, using scientific methods;
- support and organise regional strategies for invasive alien plants and experiments on their management;
- disseminate information by preparing data sheets to assist in recognising and alerting to invasive alien plants, issuing warnings and drafting species-identification guides;
- propose substitute species that may be used as alternatives to alien species;
- train and raise awareness through regular training courses on invasive alien plants, information targeting the general public and various communication tools.

The above list is far from complete, yet demonstrates that the national botanical conservatories are a highly structured network active in monitoring invasive alien plants and in supporting management work.

Work groups

In the past, requests to control invasive plants have originated from organisations in the field directly confronted with the problems arising in their use of the environment, in some cases following failures to eradicate the species. These requests by managers are transmitted to the entities in a position to provide technical and/or financial assistance, such as the local State services, the Water agencies, etc.

Initially, the response to these requests was handled individually on the local level, but when the number of requests grew, the need became apparent for a more broad-based organisation and form of cooperation capable of collecting information (species biology and ecology, mapping of colonisations, control methods, etc.), organising the information and producing opinions, which led to the creation of ad hoc work groups (see page 217).

A work group comprises a manager (designated in some cases due to his/her organisational capabilities, long-standing activity and/or dynamism) and a number of motivated partners. Its activity takes place within clearly defined territorial limits (department, region, river basin, etc.). Its work consists of organising meetings and projects, disseminating information and, in some cases, collaborating with other groups.

Since 2000, a number of work groups addressing biological invasions have been created. Their organisational and functional characteristics are highly diverse. However, though they did not necessarily have a precisely defined range of activities at the time of their founding, their work has systematically addressed the issues and needs of the stakeholders in the field. These groups have generally demonstrated great dynamism and responsiveness in providing pragmatic answers compensating the impression, at that time, of a lack of national structure and organisation for IAS issues.

The work done by these groups made it possible to improve the coordination of projects concerning various species in many parts of continental France (Dutartre et al., 2010).

The list of territorial groups on the following pages is not complete. The objective here is to present the main committees and to illustrate the diversity of stakeholders and geographic scales. This list is regularly updated on the IBMA internet site (www.gt-ibma.eu).

■ Pays-de-la-Loire committee for the management of invasive alien species

This committee, created by the Pays-de-la-Loire DREAL in 2001, brings together representatives from the scientific community and environmental associations, as well as from State services, public agencies and local governments.

Commissions (Species monitoring and mapping, Communication-training-regulations, Science and management, Terrestrial primrose, Hydrocharitaceae) organise the work, where the objective of the committee is to:

- provide up-to-date information on the status of invasions in the Pays-de-la-Loire region;
- enhance knowledge on proliferation phenomena and develop analysis of control and management techniques (their effectiveness and impacts on the environment);
- develop communication and information;
- encourage training.

The committee organises meetings and symposia that are open to the public, including a regional symposium on Invasive plants in the Pays-de-la-Loire region in 2011.

A commission on invasive fauna was created in 2012.

(http://www.pays-de-la-loire.developpement-durable.gouv.fr/plantes-exotiques-envahissantes-r431.html)

■ Loire-Bretagne work group

This group was created in 2002 by the Water agency, which transferred the daily management in 2007 to the Federation of conservatories for natural areas (FCEN) in the framework of the *Loire grandeur nature* plan. Participants include technical and financial partners, managers and various experts who meet once or twice each year.

The objective of the group is to provide scientific and technical answers to stakeholders in the field and to formulate a management strategy for invasions that can be implemented in the framework of public water and environmental policies.

It coordinates a strategy spanning the Loire basin and contributes to setting up regional work groups targeting:

- the development of strategies tailored to the areas covered by stakeholder groups;
- the dissemination of information between the various levels (local, regional, river basin);
- improvements in knowledge on current colonisation by invasive alien plants in the region, in view of enhancing their management.

To those ends, the work group calls on local coordination and development groups:

- in the Auvergne region, the Auvergne regional group for invasive alien plants (GRAPEE);
- in the Centre region, the Centre regional invasive-plants work group;
- in the Poitou-Charentes region, the Regional observatory on invasive alien plants in aquatic ecosystems (ORENVA);
- in the Pays-de-la-Loire region, the Pays-de-la-Loire committee for the management of invasive alien species;
- in the Loire department, the Departmental committee on invasive plants;
- in the Vienne River basin, the Vienne organisation for the coordination of invasive-plant management.

(http://www.centrederessourcesloirenature.com/home.php?num_niv_1=1&num_niv_2=4&num_niv_3=11&num_niv_4=50)

■ Charente observatory on invasive plants (OPE)

OPE launched its activity in 2003, under the supervision of the Charente departmental council (Water and rivers service), following the appearance of water primrose (*Ludwigia* spp.) in rivers.

Stakeholders in this group meet twice each year, once in the spring to select the zones for study and once in the fall to analyse the results of the work undertaken.

OPE is also active in training, raising awareness and informing on the topic.

Primrose is the main concern for OPE, however a number of observers have regularly alerted to the presence of invasive alien plant species such as parrot-feather watermilfoil, Asian knotweed (*Fallopia* spp.) and Himalayan balsam (*Impatiens glandulifera*).
(http://www.gt-ibma.eu/lobservatoire-des-plantes-envahissantes-de-charente/)

■ Poitou-Charentes regional observatory on invasive alien plants in aquatic ecosystems (ORENVA)

The observatory initiated operations in 2009, under the supervision of the Poitou-Charentes regional council. Two organisations are in charge of management. The Regional observatory on the environment (ORE) is in charge of computer systems and the Forum for Atlantic marshes (FMA) manages the network of stakeholders, provides expert advice on species and organises training for stakeholders in the field.

The objective of the observatory is to assist local managers by organising the stakeholder network and providing a common monitoring tool for invasive phenomena.

A steering committee made up of scientific and technical partners meets once each year to promote greater use of the monitoring tool which involves four levels of observation, ranging from local managers to an interregional coordinating committee.
(http://www.orenva.org/)

■ Network for invasive alien vertebrates in the Loire basin

As part of the *Loire grandeur nature* plan, the ONCFS Centre - Île-de-France interregional office has since 2011 managed a network for invasive alien vertebrates in the Loire basin. The prime objective is to produce and share knowledge on these species. The progressive establishment of a monitoring system is facilitated by training and the involvement of various stakeholders in the basin.

The first phase of the project consisted of drawing up an assessment of current knowledge and measures addressing invasive alien vertebrates, in conjunction with the partner organisations directly involved in managing the species. The result was a collective document presenting the species in the Loire basin, their biology, ecology, the impacts caused and the management projects under way in the Loire basin. Training courses for stakeholders, a review of regulations and a set of reference documents have been prepared to facilitate the exchange of information among the various partners (environmental protection associations, managers of natural areas, administrations and local governments).

The second phase of the project will consist of assisting the partners in setting up regional strategies to manage invasive alien vertebrates and in developing innovative decision-aid tools (Sarat, personal pub., 2013).

■ Basse-Normandie regional committee on invasive species

In 2007, the conservatory for natural areas in Basse-Normandie (CEN-BN) and the DREAL created the Regional committee on invasive species (CREI). The committee, composed of numerous regional stakeholders including the local State services, local governments and the organisations managing natural areas, sets strategic guidelines.

The action programme for 2013-2015 is intended as the operational implementation of the management strategy for invasive species in that it sets the objectives and lists the measures required in Basse-Normandie.

The action programme is structured around three interrelated objectives:

- enhance knowledge on invasive species by participating in setting up the Invasive fauna database, organising data collection, drafting informational documents (species-distribution maps, technical data sheets, project feedback, etc.);
- coordinate regional efforts to control the invasive species designated as the priorities, i.e. provide local project groups with technical support for their worksites, supply the necessary documents (technical information, management recommendations, work contracts, technical specifications, etc.), lead and inform on experiments;
- provide information and raise awareness of invasive species by creating informational documents for the general public (internet site, brochures, etc.) and for managers of natural areas (technical data sheets, etc.), participating in training courses and in public events (stands).

Since its creation, CREI has produced an array of informational documents, e.g., lists of invasive fauna and vascular plants in Basse-Normandie, a brochure and an exhibit for the general public.

(http://www.gt-ibma.eu/strategies-ou-en-sont-les-institutions/strategies-infranationales/cen-basse-normandie/)

Other organisations

A number of other organisations, in some cases integrated in the work groups presented above, are regular participants, often over many years, in the management of invasive alien species or, more generally, in efforts addressing biological invasions.

The list in Table 6 on the next pages presents a wide range of organisations and types of projects, however it is far from complete because many other types of organisations, e.g., river boards, specific units of local governments (departmental and regional councils), conservatories for natural areas, environmental groups managing natural areas, protected areas, etc., are also active in management work for invasive species in aquatic environments.

Regular updating of this list and of the information produced by the organisations would contribute significantly to improving information flows on management issues and to improving the management work itself.

Table 6 *Examples of organisations working on invasive alien species.*

Organisation	Projects
Centre for environmental initiatives (CPIE) in the Creuse department	Reinforce the monitoring network and improve knowledge of invasive alien plants on the local level in conjunction with the work group for the Loire-Bretagne basin: ■ enhance knowledge of the distribution of invasive alien plants in the Creuse department and inform local stakeholders; ■ active efforts against the proliferation of the most troublesome species. (Bodin, personal pub., 2013 for the Biological invasions in aquatic environments site: http://www.gt-ibma.eu/cpie-des-pays-creusois/) (http://www.cpiepayscreusois.com/page.php)
Bressuire urban area	Participation in the monitoring and management of invasive alien species in aquatic and terrestrial environments as part of its Environmental protection and improvement policy: ■ manual removal of water primrose (*Ludwigia* spp.) and monitoring of knotweed (*Fallopia* spp.); ■ action plan against the African clawed frog (Xenopus laevis); ■ campaigns with the Deux-Sèvres FDGDON against nutria (*Myocastor coypus*) and muskrats (*Ondatra zibethicus*). (Koch, Audebaud, personal pub., 2013 for the Biological invasions in aquatic environments site: http://www.gt-ibma.eu/cca/)
Var departmental council, Environment directorate, Rivers and aquatic-environments unit	Survey to locate invasive species in sensitive reaches of the Argens River and some of its tributaries. Event in 2012 to raise awareness and remove water primrose (*Ludwigia* spp.) from a lake, monitoring of the site. (Auda, personal pub., 2013 for the Biological invasions in aquatic environments site: http://www.gt-ibma.eu/cg-var/)
Conservatory for natural areas (CEN) in the Centre region	Work group co-managed by the Centre CEN and the National botanical conservatory for the Paris region (CBNBP) to coordinate efforts to control invasive plants on the regional level. Objectives concern knowledge, management and information on these species. (http://www.gt-ibma.eu/strategies-ou-en-sont-les-institutions/strategies-infranationales/groupe-plantes-invasives-en-region-centre/)(http://www.cen-centre.org/index.php)
Vienne public river-basin territorial agency (EPTB Vienne)	Coordination of a management system for invasive alien plants in the Vienne basin: ■ assist stakeholders in the field in monitoring and controlling the species; ■ provide property owners with information on the most troublesome sectors. (Jean, personal pub., 2013 for the Biological invasions in aquatic environments site: http://www.gt-ibma.eu/eptb-vienne/) (http://www.eptb-vienne.fr/-Plantes-invasives-.html)
Loire-Atlantique departmental federation of pest-control groups (FDGDON 44)	In compliance with regulations: ■ organisation of monitoring on populations of harmful aquatic rodents; ■ control campaigns including both direct interventions and coordination of collective projects. (http://www.fdgdon44.fr/)

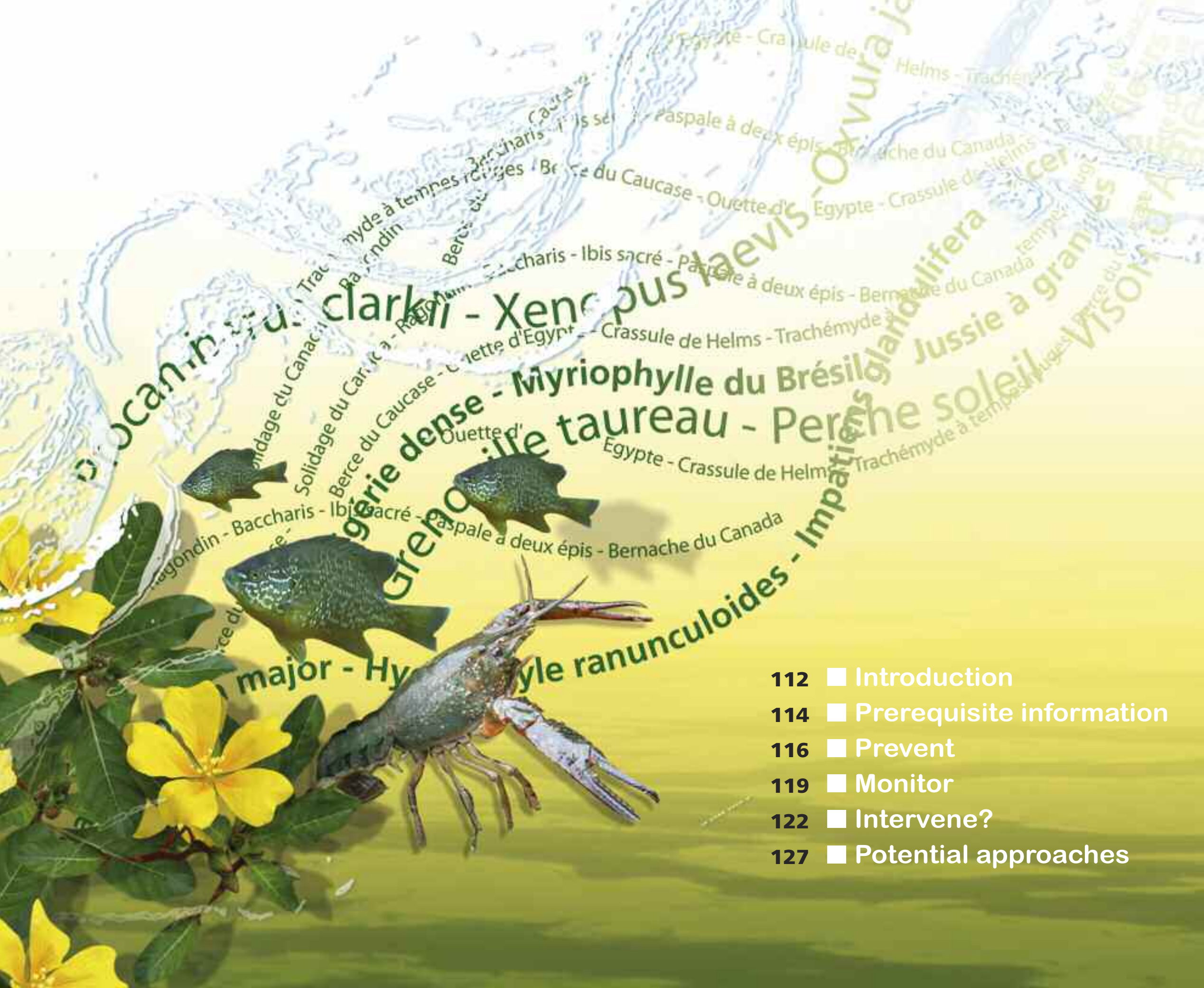
Sèvre-Niortaise basin interdepartmental institution (IIBSN)	■ Technical group working on invasive plant species in the Sèvre-Niortaise basin since 2010. ■ Acquisition and sharing of data and management feedback on these species (maps, interventions and monitoring, methods and tools, tools to disseminate information and raise awareness, etc.). (http://www.sevre-niortaise.fr/accueil/des-thematiques-du-bassin-versant/les-plantes-exotiques-envahissantes/) (http://www.gt-ibma.eu/strategies-ou-en-sont-les-institutions/strategies-infranationales/iibsn/)
Board for balanced management of the Gardons basin (SMAGE) (http://www.les-gardons.com/)	Management of invasive plant species as part of the Natural environment policy since 2009: ■ overall management plan starting in 2011; ■ steering committee and drafting of inventories; ■ management operations for water primrose (*Ludwigia* spp.) and knotweed (*Fallopia* spp.); ■ initial tests on management of ligneous species planned for 2013; ■ efforts to raise awareness of elected officials and the general public. (Reygrobellet, personal pub., 2013 for the Biological invasions in aquatic environments site: http://www.gt-ibma.eu/smage-gardons/)
Beuvron basin management board (SEBB) (http://www.bassin-du-beuvron.com/)	Efforts to control invasive animal and plant species: ■ interventions against water primrose (*Ludwigia* spp.) since 2004, in a partnership with the Departmental committee for the protection of nature and the environment (CDPNE) and the Loir-et-Cher federation for fishing and the protection of aquatic environments: ■ management experiments for Asian knotweed (*Fallopia* spp.); ■ programme to control (2002-2008) and eradicate (2009-2014) American bullfrogs (*Lithobates catesbeianus*). (http://www.gt-ibma.eu/strategies-ou-en-sont-les-institutions/strategies-infranationales/gestion-de-la-grenouille-taureau-en-sologne/)
Géolandes board	Management of invasive alien plants in lakes and ponds of the Landes department: ■ initial restoration work when colonies have already achieved considerable size; ■ repeated maintenance work; ■ creation of a monitoring and maintenance system. (Fournier, Zuazo, 2012)
Departmental, regional and national hunting federations	Participation in: ■ monitoring of invasive alien mammal and bird populations (inter alia in a partnership with ONCFS); ■ preparation of hunting programmes and population-control efforts (Canada goose, Sika deer, etc.).

This chapter was drafted by:
Alain Dutartre (independent expert, formerly at Irstea),
Emmanuelle Sarat (IUCN French committee).

With the collaboration of:
Jean-Patrice Damien (Brière regional nature park),
Nicolas Pipet (Sèvre-Niortaise basin interdepartmental institution),
Nicolas Poulet (Onema),
Jean-Philippe Reygrobellet (Board for balanced management of the Gardons basin),
Yohann Soubeyran (IUCN French committee).

General approach to managing invasive alien species

4



Introduction

Invasive alien species cause major problems for the affected human populations and particularly for the authorities in the invaded areas who must set up and launch the measures intended to solve the problem. Well before the notion of biodiversity emerged in the scientific literature on ecology, proliferations of introduced plant and animal species had caused damage to human uses of the environment. In general, efforts were made to mitigate the impacts of biological invasions in order to enable the continued use of the sites in question.

Advances in scientific knowledge have contributed significantly to better understanding invasions, to better assessing their impacts and to designing corrective measures. Concrete measures undertaken by managers (see Box 17) are generally in response to considerable social pressures. Until recently, due to a lack of access to scientific and technical information, measures were often launched without waiting for instructions or information from outside the immediate area. On the basis of the available knowledge and resources, and the existing regulatory instruments, managers put together local projects, occasionally under crisis conditions. Luckily, the situation has changed considerably since that time.

Box 17

Who are the managers and what does management consist of?

Managers

The term "manager" is derived from the term "management", which is very vague and can be applied to a vast range of subjects and fields. A look in a dictionary indicates that management is the "act of managing", generally the business of another person but also one's own business. The verb "to manage" is synonymous with "to administer" or "to regulate". However, what would seem to be important in these definitions is that management concerns the business of other people. The "other people" are the owners of the land on which interventions take place and, in many cases, the work is conducted by public organisations on private land. That is effectively the case in most situations and being a manager essentially means handling the business of others.

Managers can take on a number of roles, ranging from public or private owners to appointed administrators, spanning all geographic scales and administrative echelons. But their role always consists of administering a given area, according to the many objectives, rights and responsibilities arising from the applicable regulations, as well as the forms of organisation, development and maintenance of natural environments. Concerning invasive alien species, the group of managers effectively confronting the problem, from many different angles, ranges from the State to private property owners and can include just about anyone, to say nothing of the various public agencies and many forms of local government.

In this book, the term “manager” includes all the above, except as indicated otherwise.

Management

Concerning the issue at hand, the term “management” may be summed up in three very simple questions: 1) Is intervention a good idea?, 2) How can the problem be eliminated? or 3) How can we live with the problem? A more formal definition might be “administration of the concrete impacts of biological invasions directly confronting the authorities of the invaded area who must design and effectively implement a policy” (Dutartre, 2010).

What does the notion of management cover? What should it include?

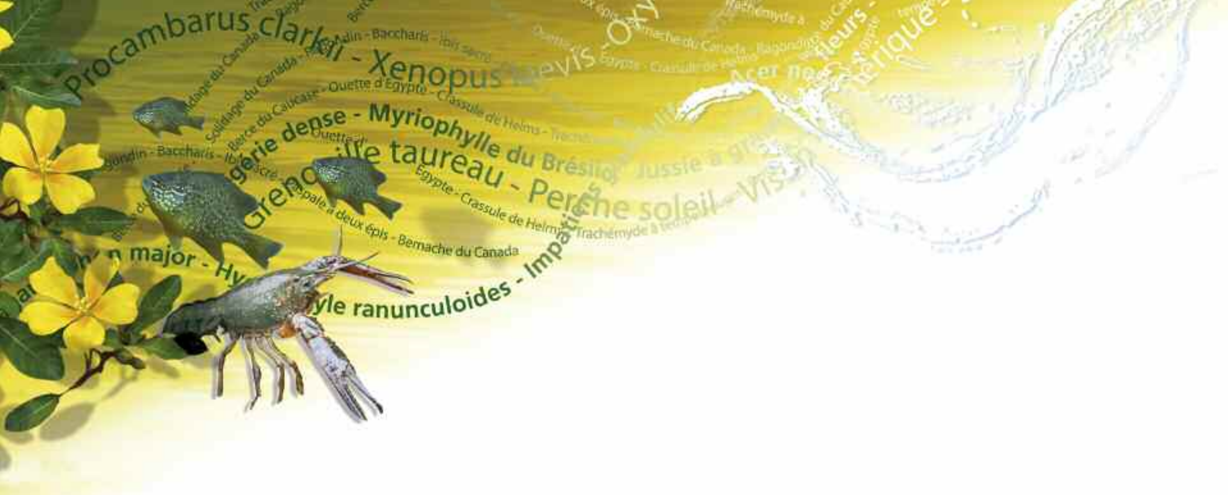
- Management comprises all aspects of the possible interventions against IASs, ranging from a prior assessment of the situation to effective implementation of corrective measures and the subsequent consequences of intervention.
- It necessarily includes strategic and technical decisions, and should include information on the objectives and planned modes of operation, indispensable elements in preparing an intervention.
- It should also include an analysis of the situation as it pertains to the groups of people and their interests/needs in the concerned environments. Management is in fact the “site” where these groups of people can meet, discuss and debate issues.
- It always brings into play groups of participants other than the managers and the directly concerned public and must engage these other groups (researchers, funding entities, etc.) in dialogue concerning a number of aspects (regulations, life sciences, human and social sciences, etc.).

There are many difficulties involved in IAS management. Even if this opinion is increasingly shared by all stakeholders, but does not make matters any easier for those effectively confronted with the problems, this enhanced awareness is a reason to hope that there will be significant improvements in management techniques in the years to come.

The difficulties do not reside exclusively in the technical aspects of the interventions required to reduce or eradicate the plant and animal populations deemed harmful in a given context. On the scale of a single manager, it may be possible to take only the technical aspects into account for a given project because they ensure effective results, however the same approach is not possible when the assessment and the corresponding measures address larger geographic, administrative and time scales.

This is because IAS flows, their expansion dynamics and their impacts result from a wide array of social processes that are often inextricably mixed and part of greater globalisation processes that certainly do not make the situation any simpler. Among the factors contributing to the difficulties are international trade and its regulations, leisure travel and other activities enabling the intentional or unintentional transportation of species, work on aquatic environments, greater and more diverse needs concerning aquatic environments even though many are now degraded, etc.

That is why widely shared knowledge of the basic elements forming the context of IAS management, ranging far beyond the strictly technical and local aspects addressed by a given manager confronted with a given IAS, would appear necessary if IAS management is to improve.



Prerequisite information

Management deals with living organisms, with plants and animals, not inanimate objects. In short, organisms capable of reproduction, of colonising favourable biotopes, of travelling from one biotope to another in different manners, of adapting, etc. In addition, the means of dispersal of animals is generally the animals themselves, but for plants, the propagules can be entire plants or simply stalk fragments, which makes it more difficult to avoid their dispersal.

All management strategies must take this into account and make use of the available knowledge concerning the biology and ecology of these species. However, this knowledge is often incomplete, notably because certain species have undergone biological or ecological adaptations to the host area, for which no information is immediately available. Information from the areas where the species originated is useful and should be taken into account, but the possibility of adaptations should be kept in mind. In addition, it should be noted that many IASs do not cause any particular problems in their original ranges and consequently, any available information may be highly insufficient.

In many cases in the past, it turned out that it was necessary to acquire precise information on a species in the context of the host site (biotope or set of biotopes such as a lake, a river reach, a section in a network of ditches) or the host area in order to prepare better management strategies, improve the technical conditions of interventions and reduce the impact on species not targeted by the management work. The necessary information concerns in particular:

- the biological cycle in order to take action when it is most effective. For example, postnuptial moulting in birds means they cannot fly and may be more easily captured;
- reproductive and dispersal mechanisms in order to select the technical means capable of hindering or reducing dispersal following the intervention. Examples are setting up containment nets for plants with fragile stalks (see Figure 45a) or taking action prior to fruition and seed production in water primrose or various species growing along river banks to avoid contamination in situ and when the plant waste is processed. These measures may also be used to prevent the dispersal of animals (see Figures 45b and c).

Any data available on these species in other parts of the world where they have become invasive are of great value. These data often include useful information on species dynamics, favourable biotopes, known impacts and on the conditions and results of management work already undertaken. Given however that each situation is unique, these data must be approached with some caution.

That being said, it is not necessary to know everything about a species before deciding to take action. Failing an approach based strictly on solid knowledge, an empirical[7] approach may be employed when data are insufficient or support from the scientific community is unavailable, but should be systematically accompanied by simultaneous analysis of the intervention conditions and consequences. Even though managers may not have a great deal of time to devote to this analysis, it is nonetheless important in that it can produce new knowledge on the species managed and can avoid the use of less effective techniques that limit intervention results. The objective of the analysis is to improve the technical conditions of interventions and reduce the uncertainties.

Figure 45

a © Syndicat de rivière Côte-Sud
b, c © M. Collas, Onema

The installation of barriers avoids disseminating the cuttings of plants with fragile stalks, e.g. a) water pennywort in the photo. For animals, physical barriers (trapping barriers and filtering systems) are required to avoid dispersal of the managed species. Examples are b) a barrier around a pond for the Louisiana crayfish and c) a filtering system for a fish farm in a pond.

7. An empirical method is based on past experience and available data, not on theoretical considerations.

Prevent

An attainable solution?

A wide-ranging analysis of the issues involved in biological invasions indicates that prevention is without any doubt the best of all solutions. A reduction or elimination of the unintentional transport of species and an assessment of the risks involved in introducing "useful" species prior to their transport would certainly be of great use in limiting the damage caused by biological invasions.

This approach is clearly a central component in the regulation recently voted by the European parliament (European parliament and Council, 2014, see page 56) in that a significant part deals with analysis of introduction paths, border controls and the creation of an assessment procedure on the risks of introduction.

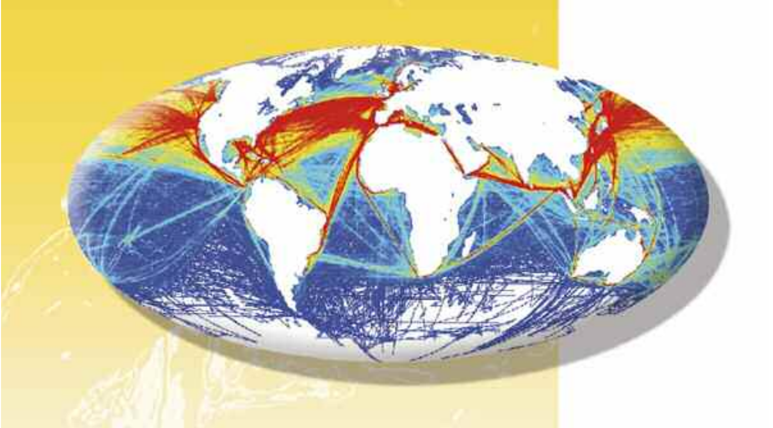
That being said, in the current situation, prevention remains an ideal solution that will be difficult to attain (Dutartre, 2010). Effective prevention of biological invasions would require:

- the means to identify alien species likely to have adverse effects on biodiversity and on human uses of ecosystems;
- identifying and controlling human activities that may be the direct or indirect causes of species introductions.

Though prevention is of course necessary at every possible organisational level ("from the planet to the plot"), it is clear that it will, at best, slow future flows of species, and even then on the condition that it be organised in a coordinated manner across all geographic scales.

International trade is without doubt one of the main causes of species dispersal on the planet (see Figure 46). The analysis carried out by Westphal et al (2008), using a database containing information on species ecology, biogeography, the socio-economics of the countries in question, etc., revealed that the importation of goods is

Figure 46



Map of world maritime activity in 2005.
Source: Voluntary Observing Ship (VOS), World meteorological organisation.

the most important variable. The greater the volume of international trade, the greater the number of invasive alien species. Consequently, international trade and the intentional or unintentional transport of species must be severely regulated. That in itself is a major undertaking.

Organisational proposals

A number of proposals have been made over the past few years to increase preventive efforts. In 2000, Shine *et al.* listed the necessary characteristics of an institutional network designed to manage biological invasions. More recently, Genovesi and Shine (2004) discussed in detail the elements of a future European strategy for invasive alien species. The authors listed a number of sectors where unintentional introductions were likely to occur and proposed examples of "good practices" intended to reduce the risks. Those sectors covered a vast array of activities, ranging from agriculture to ornamental fish, horticulture and falconry.

Prevention on the national level must support the efforts on the international level. The fact that France has a number of territories spread all over the planet, in highly diverse biogeographic areas, adds a further degree of complexity. Implementation of the European regulation on the national level should accelerate the deployment of preventive efforts.

Local managers should implement in full the stipulated preventive measures. As local relays, they have an important role to play in disseminating information on prevention and in raising the awareness of the general public (see Box 18).

Box 18

Managers, participants in prevention

Managers can play an important role in raising awareness among the general public concerning the issues involved in biological invasions. They are familiar with the local area and the stakeholders, have the necessary scientific knowledge and can bring significant resources into play in disseminating information. They can also initiate preventive measures that should be better publicised, as is shown by the examples below.

Meetings with aquarists

The Sèvre-Niortaise basin interdepartmental institution (IIBSN) recently took part in an "aquarist market" in the Deux-Sèvres department. Via a conference, an exhibition, the distribution of informational documents and an anonymous questionnaire to learn how the aquarists operate, IIBSN informed the participants on the consequences of releasing alien species to the natural environment (see Figure 47).

The Onema NE regional office is currently preparing brochures to raise awareness among aquarists and pet shops and inform them on the problems caused by the introduction of alien species into the natural environment.

Information for fishermen and canoeists

One part of the LIFE + CAISIE programme in Ireland to prevent species introductions (www.caisie.ie, see the management report, volume 2, page 27) developed a wide range of tools including biosecurity guidelines for people active in aquatic environments (fishermen, canoeists, divers). Five key steps (inspect, remove, clean, throw away and inform) are presented in detail to encourage people to disinfect their equipment and avoid the unintentional dispersal of IASs in Ireland.

New types of pets

Trade in red-eared slider turtles, a new pet species, was authorised in France until 1997. It has been estimated that over four million turtles were imported between 1985 and 1994. After having outgrown their welcome, notably because they were considered dangerous for children (bites), a large number was released to the natural environment by the owners. To reduce the number of released red-eared slider turtles, the Conservatory for natural areas on Corsica created several informative tools (cartoon, teaching kits, games) to inform a wide public on the problems created by the new types of pets (see the management report, volume 2, page 171). A special internet page informs owners where they can find turtle reception centres and reminds them that it is prohibited to release the animals to the environment.
(http://www.cen-corse.org/conservatoire-espace-naturel/corse.php?menunac=10).

Figure 47

© IIBSN

Information session organised by the Sèvre-Niortaise basin interdepartmental institution (IIBSN).

Monitor

The discovery of a new species on a site may occur fortuitously, however the acceleration in the number of introductions and the increase in the harm and damage done have made it necessary to develop a specific monitoring system. The various types of species likely to be introduced are now fairly well known, as are the most favourable host biotopes for permanent installation, the step prior to dispersal and invasion.

This knowledge can serve in setting priorities for the sites requiring monitoring. For example, stagnant environments are the best for aquatic plants. For helophytes on the other hand, the physical configuration and local disturbances play an important role. For animals that can move more easily and often much faster over greater distances, the presence of food and a biotope/environment offering sites where they can rest in safety can constitute criteria determining where they settle.

However, an effective monitoring system must cover all types of biotopes, including those that might seem less favourable for species. For example, certain submergent plants with fragile stalks that can be easily broken by water currents or waves may nonetheless be found in areas exposed to river currents or to the wind along lake edges that are far from the best for their installation and continued development. An effective system must also be permanent, which does not mean continuous throughout the year, but rather according to a schedule based on the knowledge acquired on the biology and ecology of known introduced species, both in their original range and in the host areas. It must be efficient, given the limited resources (funding, human and technical resources, time, etc.) that can be allocated for IAS management. Finally, it is necessary to encourage synergies among the diverse stakeholders by bringing into play the work groups and monitoring networks that already exist.

Even if the groups of plant and animal species likely to be introduced are now better identified (biological types, groups with particular capabilities, introduction paths conducive to certain species, etc.), it is virtually impossible to know all the species capable of being introduced. That is why particular attention must be paid to all living plants and animals that appear in a monitored biotope. Once the new plant or animal has been observed, an alert must be issued in view of identifying the species. The “newly arrived” species may turn out to be native. This occasionally occurs when submergent plants return to biotopes that have been modified by human activities.

Given that in a particular area, the species capable of establishing a long-term presence have relatively similar ecologies and fairly comparable development rates, it should be possible to identify times during the year when their presence becomes more easily detectable, e.g., flowering of plants, rutting periods of mammals and winter groupings of birds.

The establishment of a monitoring network is confronted with major constraints, notably in terms of limited resources, which can lead to setting intervention priorities for the field operators, and with social obstacles having to do with the implementation of public policies and with the perceptions of the public and managers concerning biological invasions.

In the book that they coordinated, Genovesi and Shine (2004) listed the necessary components of a monitoring system in terms of “information collection, management and sharing”:

- colonisation dynamics, including the arrival of new species;
- trends in the problems and/or adverse impacts caused by the colonisation dynamics, in order to better assess the full range of damage to the environment and to human activities;
- intervention dynamics in view of reducing or eliminating the problems and impacts;
- impacts caused by an intervention in order to determine whether the intervention is harmless, whether the risks are “acceptable” or whether risk management is required when an intervention, seen as indispensable, is itself a source of damages.

Similarly, the European commission working document, that accompanied the proposal for the regulation of the European parliament and Council on “the prevention and management of the introduction and spread of invasive alien species” (section on “Member States actions”, subsection “Strengthening surveillance and control”), contained the following instructions: *“Organise cooperation with the public or specific groups of citizens (nature reserve managers, hunters, anglers, farmers, birdwatchers, etc.) to mobilise expertise and deploy "eyes and ears" on the ground to facilitate detection of IASs”.*

What available forces could be organised for environmental monitoring? A number of different organisations and institutions have operators or employees that work at least part of the time in natural environments. They include Onema, ONCFS, different types of groups such as the Regional federations against pests (FREDON) and the Departmental federations of pest-control groups (FDGDON), associations such as fishing and hunting federations, environmental-protection groups, etc.

The same is true for many local governments that manage rivers and natural environments (river boards, municipal associations, etc.) and have hired technicians in charge of organising the management of their area. Some have already set up work teams for various projects (”green teams”, see the management report, volume 2, page 67). During their work in the field, these technicians and teams could, without too much effort if adequate training is provided, reinforce the available observational capacities and produce data for the monitoring network.

Precise numbers are not yet available, but several hundred people could no doubt be mobilised in continental France and even several thousand if the members of the associations mentioned above were also requested to open their eyes and ears.

These operators and employees of course already have jobs to do and this monitoring activity would come on top of that work. That is why it is important that national negotiations be undertaken under the authority of the State, via the Ecology, Agriculture and Health ministries, in view of progressively creating a large network, thus ensuring that this activity is undertaken in the most efficient manner to limit the time spent by each participant.

This “official” network could also receive support from voluntary observers and citizen groups, thanks in particular to the recent development of citizen-science programmes that make it possible to collect highly diverse types of information (see page 229). This would be a means to fill out the network with decentralised sources of monitoring.

Work has already been put into designing this network (Thévenot and Leblay, 2014) and the local groups that coordinate data collection in their area (for over a decade in some cases) already participate in this monitoring system. However, coordination remains a major concern, for example:

- training network members on how to identify species (see Figure 48);
- progressive widening of the network to include the observation of all plant and animal species. The current specialisation (often plants, more rarely animals) must be overcome by coordinating the members of the pre-existing networks on the local and regional levels;
- validation, transmission techniques and storage of the information produced by the observations;
- dissemination of the information to the entire network;
- the decision-making process for management interventions.

The establishment of such a network will require a cultural shift in that it will oblige the various partners to negotiate and to agree on common objectives, given that each partner has its own specific operating objectives that are not necessarily convergent with those of the other partners. Above and beyond the official requests by the State, funding will certainly have to be provided to assist some partners in effectively taking part in the network.

Figure 48

© E. Mazaubert

One necessary step in establishing monitoring networks is a series of informational and training sessions for the people working in the field.

Schedules for monitoring work must be adapted to each species, for example by shifting observation dates during the spring to ensure that plant development is sufficiently visible and easily detectable (development of beds, flowering, etc.) and, for fauna, during periods when the behaviour of each species makes it more visible. Study has already been put into this aspect, but adaptation to local situations will probably be required, notably to the climatic conditions.

In general, identification of plant, vertebrate and some invertebrate species (e.g. crayfish) does not present any particular difficulties thanks to an array of books, guides and internet sites, however, the same may not be said for a majority of invertebrate species. These species are less easy to observe given their small size and are, to date, less commonly indicated in easily accessible documents, however, many remain very rapid and effective invaders, for example certain molluscs and crustaceans from Eastern Europe arriving via shipping canals (e.g. see Devin et al., 2005).

In general, species identification takes place using the naked eye, stereo microscopes or even compound microscopes for the smallest specimens, however these tools, similar to all others, have physical limits and require special knowledge and/or documentation. Molecular tools are now being developed, e.g. detection of environmental DNA (for example, see Dejean et al., 2012 on American bullfrogs and the management report, vol. 2, page 158), that will progressively fill out the range of currently available tools.

Major needs in terms of training for the personnel participating in this monitoring network will manifest themselves, on network objectives, issues and functioning, on observation and drawing samples in the field, and the transmission of samples and information, etc.

Among the points that require further study are a reduction in lead times between the initial observation, analysis of the situation, definition of a local strategy and effective intervention, taking into account the many regulatory aspects, in particular those dealing with private property.

Monitoring must of course be pursued on sites or in areas where management work on a given species has taken place. It should include assessments tailored to the species in question and be carried out regularly to keep close tabs on the situation.

Finally, to ensure that the “monitoring / early detection / rapid response” system is fully functional, its organisation must span the geographic and administrative levels required to structure the transfer and storage of the information produced by monitoring, as well as the technical, regulatory and financial conditions governing interventions and the fate of the “products” drawn from the intervention sites.

Intervene?

Prevention looks to the future and to the species that will not be allowed to enter a new area. But what of the present, of the alien species having just arrived and the many IAS already well established? A solution might by to intervene rapidly on the former, as soon as they are identified to avoid problems and damage, and to intervene regularly on the latter in order to "regulate" them, i.e. maintain them at a level where the problems are tolerable and the damage remains within limits.

But in all cases, it is necessary to set the intervention conditions following a complete analysis of the situation in view of determining whether an intervention is indeed necessary.

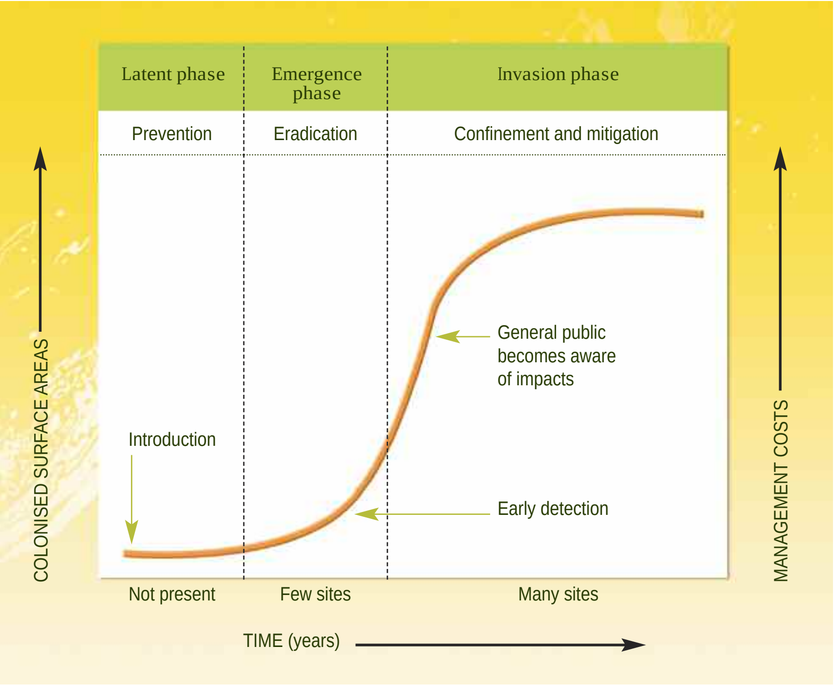
The degree of colonisation, the indispensable criterion in deciding to intervene

One of the criteria determining whether it is necessary to intervene is the degree of IAS colonisation in the given area (continental France, overseas territories).

Three main stages of colonisation have been identified (Dutartre, 2010 and Figure 49).

- **Invasion not yet under way.** This may be the case for an alien species observed occasionally or on a single site, or where the species does not maintain its presence on the sites where it was introduced. However, the capability of the species to invade has been observed in other parts of the world.

Figure 49



Different stages of invasion and management objectives. Adapted from Branquart, 2010, according to Tu, 2009.

■ **Invasion initiated, but limited geographic extension.** The species has been clearly identified as invasive in other areas where it has been introduced, however it is present on only one or on a very small number of sites where it does not expand noticeably.

■ **Invasion has already spread widely.** In this case, the species is present on numerous sites spread over a vast area. It can cause considerable problems, either on certain sites or on all the colonised sites.

The issue of eradication

Eradication of a species, i.e. an intervention resulting in its total (and permanent) disappearance, is possible during the first stage of colonisation, when the alien population is located on very few sites. But once the invasion has begun to spread, efforts to regulate the situation are generally all that remain possible. In this case, it is necessary to "live with it" and to regularly manage the IAS over time. 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.

In their article titled *A pound of prevention, plus a pound of cure, Early detection and eradication of invasive species in the Laurentian Great Lakes*, Vander Zanden *et al*. (2010) drew up a list of questions that should be answered before attempting to eradicate a species.

The list is divided into three main topics.

■ **The cost of the intervention** (in terms of time and money). What is the probability that it will be necessary to repeat the eradication effort? What is the cost of the potential collateral damage for ecosystems and humans? What is the cost of subsequent ecological-restoration work?

■ **How probable is the success of the eradication effort?**

- *Biological factors.* How early in the invasion sequence was the species detected? What is the current status of the invader (density, area colonised, speed of expansion)? Is the eradication likely to be successful, given the species in question and the habitat? What is the probability that a new invasion will occur?

- *Social and institutional factors.* Are the available resources sufficient and do institutions exist that are capable of carrying out an eradication effort (authority, funding, clearly defined organisation, cooperation between institutions)?

Does the public support the initiative and is it willing to participate? Are there legal or institutional obstacles that may counteract or delay the eradication?

■ **The cost of not taking action.** What impacts and what economic and ecological costs may be expected from the invasion? What is the probability that the IAS will cause adverse impacts?

The above list comprises the questions deemed indispensable in preparing an intervention, however its actual execution may encounter many assessment difficulties because a number of elements are very difficult to predict and/or to quantify. The list nonetheless remains a useful starting point in a general approach to the issue.

In their review of eradication efforts for various plant species, Mack and Lonsdale (2000) noted that the available information revealed a small number of clear victories, a few stalemates and many defeats. They drew a number of conclusions for eradication efforts:

■ eradication of invasive alien plants is successful only when they are eliminated immediately following their arrival (which is rarely possible);

■ if eradication is not possible, maximum effort should be put into treating small, isolated areas of introduction;

■ continuous monitoring is required to enhance the chances of early detection and eradication;

■ eradication may led to adverse consequences, e.g. invasion of the site by another invasive species.

A clear definition of the term eradication would also be useful. In common, general usage, it means the complete elimination of the species from the site where it recently settled. This definition was adopted in part by Myers *et al*. (2000) when they wrote "*Eradication is the elimination of all individuals and propagules of an invasive species that have the potential to reproduce",* but they then added a second section that expands the definition and renders it less clear for communication purposes *("or a reduction in species populations to acceptable density levels*").

In order to expand the range of terms, rather than adopting “control” directly from English, it is preferable to use the term “regulation” to designate a reduction in populations (the second part of the definition proposed by Myers et al.) to abundance or density levels that do not cause serious problems in terms of either biodiversity or pest control. The term “eradication” can then be reserved for the total elimination of individuals and propagules (Dutartre, 2010).

Early detection and rapid response

This operational approach is included in most proposals concerning management strategies. It essentially deals with the effort required to identify each newly arrived alien species before it has become permanently established on a site or, failing that, before it can disperse from the initial site to favourable, nearby sites. Early detection enables a rapid response in the effort to manage the newly arrived species, which may include a decision to eradicate.

This approach is based in part on the available knowledge concerning the origins and introduction paths of species (i.e. information on where to focus detection efforts) and on the effective operation of a permanent monitoring network for natural environments, which makes it possible first to detect a species, i.e. precisely identify it with confirmation by an expert, and secondly to make a management decision after consulting a stakeholder network. Each situation must be examined in detail before making a decision which must be based on:

- the available information on the species in question (particularly its invasion capabilities), obtained from the scientific literature or from experts in the network;
- site characteristics (the ecological issues in particular) and its connectivity with other favourable sites for the species.

The decision must be preceded by discussions with the site manager and the site owner (see Box 19). It may also be a good idea to inform the users of the site in order to explain the decision and avoid excessive reactions.

The management decision may opt either for direct intervention on the species (eradication or regulation), with monitoring to determine intervention effectiveness, or, if not much is known on the species, notably its invasion capabilities, for reinforced monitoring of the species, the site and favourable, nearby sites in order to determine the biological and ecological characteristics of the species. It would not be reasonable to adopt a general principle that “each new species must be eradicated” when it is clear that our knowledge base on many species is insufficient. Monitoring based on regular observation campaigns to quantify species dynamics may result at some point in a decision in favour of direct intervention, but in all cases the monitoring reports must be disseminated to the entire network.

The management decision may be taken following rapid discussions among a group comprising the State services, experts and local stakeholders, including a review of the available knowledge concerning the species, the colonisation issues on the host site and the available intervention resources depending on the species and the site. Existing organisations, e.g. certain national or regional work groups (see the IBMA group, page 98), can provide expert knowledge and their highly reactive networks to assist in making the decision.

If direct intervention on the species is deemed necessary, it must be carried out as soon as possible, taking into account any known confinement measures and precautions required for the species or type of species. For example, an intervention on submergent plants with fragile stalks must recognise the risks and adopt precautionary measures such as confinement nets, systematic collection of fragments, etc. The subsequent disposal of the plant or animal biomass drawn from the site should be included in the management strategy. Special monitoring to assess the effectiveness of the intervention should be set up. The monitoring reports, a source of useful feedback, should be disseminated to the entire network.

Cases of early detection and subsequent management

New Zealand pigmyweed (*Crassula helmsii*) :

- Initial observation at the end of 2011 in the Deux-Sèvres department, identification confirmed, significant colonisation of a pond (http://sevre-niortaise.fr/wp-content/uploads/19_347_fichecrassula7_288.pdf).
- The IIBSN intervention protocol was drafted rapidly (mechanical removal and manual maintenance) because the species was well known for its colonisation capabilities and management difficulties (EPPO list http://www.eppo.int/INVASIVE_PLANTS/ias_lists.htm#A1A2Lists and information from the U.K.).
- Data sheet drafted by Nicolas Pipet (IIBSN technician), warning notice drafted and disseminated by CBNSA (November 2011).
- Mechanical removal carried out in April 2012 with regular manual interventions on the site since.
- Intervention reports disseminated by IISBN (see the management report, vol. 2, page 47) and information on the IIBSN site. (http://www.sevre-niortaise.fr/accueil/des-thematiques-du-bassin-versant/les-plantes-exotiquesenvahissantes/).

Cape pondweed (*Aponogeton distachyos*) :

- Initial observation in 2014 in a pond in the Deux-Sèvres department (see Figure 50).
- A CBNSA warning notice existed for the species, indicating that "the species should be monitored to detect any possible invasion dynamics".
- Discussions via email in April and May 2014 among several members of the network (including the naturalists who discovered the species) on the appropriate management strategy.
- An observation report was drafted. (http://www.orenva.org/IMG/pdf/fiche_vanille_d_eau_-_version_iibsnsmbb.pdf).
- Two proposals were discussed, namely 1) eradicate the species on the site (there were worries about subsequent colonisation of the site and nearby sites) and 2) monitor species dynamics on the site and check that it did not yet exist in nearby environments (the species was not known to have high invasive potential and very few plants had been observed). It was decided to run several monitoring campaigns over two years to assess its colonisation capabilities and then reassess the strategy.
- Reinforced monitoring was planned, but the few plants observed were uprooted, apparently in the beginning of the summer, by an unknown person.

Figure 50

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*Cape pondweed (*Aponogeton distachyos*).*

American bullfrog (*Lithobates catesbeianus*):

- Initial observation of a frog found dead in June 2013 in a private lake in the Indre-et-Loire department.
- Information transmitted via internet forums to the French herpetological society.
- Species identified by the French herpetological society on the basis of photos supplied by the private owner.
- Information transmitted to local stakeholders, including ONCFS, Onema, Beuvron river board, Loir-et-Cher Departmental committee for the protection of nature and the environment (CDPNE).
- Site visited in July 2013, but no American bullfrogs observed.
- Samples of environmental DNA drawn the lake and neighbouring lakes. DNA analysis results were negative. Monitoring protocol (listening at night) set up for the year 2014. Monitoring carried out regularly by the Indre-et-Loire ONCFS, in conjunction with local stakeholders (employment agency, local governments).

Regulation

Regulation consists of regular interventions on IASs already established over large areas, in order to restrain them on the managed sites to levels where the disturbances and damage caused remain minor with respect to the uses and ecological functioning of the environments. This type of intervention has already been carried out for over 20 years on some sites in continental France.

The technical aspects of interventions depend in part on the type of species (uprooting of amphibious plants, harvesting of submergent plants, shooting or trapping of animals, etc.), but the practical implementation conditions must be adapted to the site or area and to any specific needs of the managers.

If the species has already been regulated in France or abroad, the feedback from the interventions constitute an excellent starting point for the prior study on how to conduct the future intervention, taking care, however, to check the compatibility of the different situations (characteristics of the site and type of manager, organisational and regulatory aspects). On the other hand, if no information is available on the species or type of species, a more wide ranging analysis of the technical aspects is required, taking into account primarily the known biological and/or ecological characteristics of the species or type of species.

Knowledge and integration of the contextual aspects of the intervention are a key factor in ensuring optimal execution. Knowledge on the biology and ecology of species and on the technical possibilities is now widely available thanks to the increased numbers of studies and better dissemination of information from various sources, however the contextual aspects are 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.

Potential approaches

An approach that begins with the observation of a new species (or the analysis of IAS expansion where the disturbances and damage have begun to be noticed) and ends with effective intervention against the species is one that starts and comes to an end in the field. In the final analysis, management always takes place locally, where the managed species are found.

Some management approaches over the past two or three decades in some parts of continental France were undertaken by managers directly confronted with local difficulties that were often severely criticised by residents and visitors to the sites. Lacking a formal organisational framework, they were obliged in some cases to work under crisis conditions, in the process developing their own local approach based essentially on the available resources and equipment.

Given that the vast diversity of situations (site, IAS, management needs) requiring management obviates any possibility of a one-size-fits-all approach, even for a given species, the local approach mentioned above cannot be directly transferred to other sites, but can nonetheless be very effective on the given geographic and organisational levels.

Over the past several years, particularly in the regional and local groups, considerable thought has been put into IAS management approaches on higher territorial and administrative levels (see Chapter 3), in an attempt to integrate both the effective management done by local managers and more wide-ranging organisational forms. Particular attention was paid to the issues of prevention and the need to coordinate research and management.

The development of the National biodiversity strategy since 2010 and the recent vote by the European parliament of the regulation on IAS management (and its implementation on the national level) have encouraged and will continue to promote these coordination efforts.

These two approaches, the “local” very pragmatic approach and the “general” more theoretical approach, do not oppose each other given that:

- practical aspects are often a topic of study and, conversely, theoretical considerations can provide all stakeholders with general indications on how to approach the practical aspects;
- practical aspects are part of the theoretical process, but remain clearly delineated;
- practical aspects represent the last step in any approach.

Table 7 presents a breakdown of the roles played by the two approaches, indicating their respective positions in each part of the process (either leader or contributor).

Table 7 *Breakdown of roles between the general approach and the local approach.*

	General approach	Local approach
Knowledge	L - Review/compilation	C - Contribution
Prevent	L - Organisation/coordination	C - Information
Monitor	L - Coordination	L - Implementation
Intervene	C - Support	L - Implementation

L: Leader
C: Contributor

A "local" approach

Due to a lack of available knowledge and existing analyses on management situations, local approaches encountered various practical difficulties that have slowly faded over the years, in step with the lessons learned by managers. It would nonetheless appear useful to note here a basic procedure applicable to local IAS management (Dutartre, 2002), divided into three steps.

Define

- Site characteristics, e.g. types of environments, surface area, water depths, hydrological regimes, levels, connexity with other environments, types of bank, of riparian vegetation, plant and animal communities, etc.
- Uses and users, i.e. a complete listing of site uses (description of those uses, consumption of natural resources, etc.).
- Existing regulations for the site.
- Disturbances and their causes, a list of the expressed problems.
- The IASs causing the disturbances, including precise identification, their distribution in the environment, a review of the available knowledge on their biology and ecology, etc.
- Management issues and objectives (see Box 20).

Select

- One or more intervention techniques, taking into account the side effects of the techniques and the fate of the plants and/or animals taken from the site. "Mixed" interventions, comprising several complementary techniques, are a possibility in certain cases, however precise scheduling of the work is indispensable.
- An intervention strategy (organisation, funding, etc.), including from the start a programme of regular maintenance (a multi-year programme is a means to facilitate the work).

Assess

- The effectiveness of the intervention (duration, satisfaction of stakeholders, etc.).
- The ecological impact of the intervention.

Box 20

Intervene?

After defining the issues and analysing the context, it must be decided whether it is necessary to intervene. This question must be raised to ensure that any subsequent intervention is the result of a rational analysis and not simply the consequence of a desire to take action. A decision not to intervene is also a management decision.

It may be that the reported disturbances are overstated. In this case, the prior analyses can provide a more objective and comprehensive assessment of the situation, and possibly come to the conclusion that an intervention is not immediately necessary. A decision not to intervene must of course be explained to the stakeholders and does not mean that an intervention cannot take place in the future. A situation that, at a given moment, is deemed not to need immediate attention can evolve very rapidly to a more serious situation. That is why some monitoring of the site is useful in order to react to the changes within a time frame that allows for adequate management. The knowledge gained on the environment and species can be of assistance in estimating the future evolution and subsequent management needs. At certain points in time, a lack of technical means and tools suited to the precise context can also make it temporarily impossible to intervene effectively. However, it is better to avoid work poorly suited to the situation because it can often result further problems.

In some cases, interventions may not be repeated if their effectiveness is not evident or if they create side effects serious enough to durably disturb the treated site. An assessment of the issues at hand is always necessary.

Concerning this last point, local political considerations may prevail and result in interventions that certain partners, other than the managers themselves, see as not particularly useful or even harmful, but the only way to avoid such excesses is through continuous dialogue among all stakeholders.

A "general" approach

A general approach includes the local approach. It is possible to identify a number of key steps in the general approach that apply to different geographic and organisational levels (site, department, region, river basin, etc.). They correspond to the aspects discussed in this chapter (knowledge, prevent, monitor, intervene) and serve to inform managers on the practical components involved in the general approach.

Table 8 on the next page, drawn extensively from Soubeyran (2010), presents for each step in the general management approach the distribution of the roles played by the participants between the general and local approaches. It also attempts to list the interaction between the two approaches to analysing management situations.

The objective here is not to rigidly define roles or to codify the relations between stakeholders, but rather to describe how the relations might be organised.

The table is in any case incomplete because it is impossible to foresee the many possible situations, stakeholders and potential relations between professionals, institutions and people in general.

Table 8 *Breakdown of roles between the general approach and the local approach.*

	General approach	Local approach (manager)
Develop a strategy Propose an organisational framework to improve IAS management Clearly define management objectives Assist implementation of coordinated measures and cooperative efforts among all stakeholders	■ Review existing projects and data exchanges ■ Identify the roles and responsibilities of stakeholders ■ Include existing management work and coordination efforts ■ Mobilise local know-how ■ Comply with national and European strategies and in general with public policies on the management of water and biodiversity	■ Contribute to formulating strategy by providing information on needs and current measures ■ Learn about the strategy and participate in its implementation ■ Develop local management strategies adapted to the area
Inform the public and raise awareness	■ Formulate communication strategies, create and provide the tools ■ Inform financial partners and policy makers ■ Develop the priority measures to inform the public and raise awareness ■ Develop training courses	■ Inform local elected officials, property owners and people active in natural environments ■ Raise awareness of the general public ■ Inform higher levels on communication needs
Prevent the introduction and spread of alien species	■ Contribute to designing regulations suited to the local and national levels ■ Identify the concerned sectors ■ Propose codes of conduct ■ Formulate communication strategies ■ Organise meetings to share technical data, workshops, symposia ■ Provide training on species identification	■ Participate in drafting and implementing codes of conduct ■ Assist in identifying regulatory problems ■ Raise awareness of the general public ■ Provide training on species identification
Inventories, monitoring and surveillance	■ Mobilise experts and available knowledge ■ Propose and draft monitoring and inventory protocols ■ Centralise information and disseminate it (databases, GIS) ■ Keep technical and scientific watch to discover new monitoring options ■ Organise GIS training	■ Participate in drafting protocols ■ Constitute inventories, participate in collecting information on species ■ Map distribution ranges and establish local databases ■ Test innovative monitoring methods and contribute to improvements
Develop early detection and rapid response	■ Identify and set priorities for species not yet established ■ Assess risks ■ Identify the main introduction paths ■ Design action plans and assist in finding emergency funds ■ Serve as an information relay on the national level, contact taxonomic experts ■ Lead the monitoring network and organise discussions on management decisions ■ Draft and provide protocols for reporting and centralising information	■ Organise general surveillance in the field ■ Detect species and alert local networks ■ Organise surveillance of areas at high risk of invasion ■ Participate in the monitoring network ■ Execute rapid interventions
Set priorities for action	■ Set management priorities by defining criteria and drafting lists	■ Provide data on population dynamics ■ Manage priorities taking into account local demands and available funding

Table 8 (cont.)

Interventions	■ Provide regulatory support ■ Contribute to analysis of technical decisions ■ Assist in finding funds for the proposed strategy	■ Define objectives ■ Select the management technique ■ Implement the project ■ Assess the results ■ See Chapter 5
Develop synergies between research and management	■ Develop ties between researchers and managers (common language and objectives) ■ Conduct comprehensive analysis of situations requiring management ■ Draft specific requests for research, focussing on the species in the given area, in view of improving their management, particularly as concerns the dissemination of the results	■ Inform higher levels on needs in terms of improving management and monitoring species ■ Provide field data ■ Participate in research experiments and support them in the field
Reinforce regional cooperation	■ Participate in regional monitoring and intervention programmes, in collection and dissemination of information publicising the measures taken ■ Make proposals to harmonise management protocols and methods	■ Develop contacts between managers, share information on interventions and their results

It will take time to develop these approaches, to set objectives and to determine how to achieve them. Time is also required for the various participants to come to know and understand each other, though it is also clear that the time to design and organise a general approach may be perceived as wasted by managers confronted with urgent requests for intervention.

It is not easy to reduce the time required to develop approaches. Most of the work groups created since 2000 and operating below the national level required at least three years before becoming fully operational. Developing effective relations between experts and managers will also take time. That is why the national network for surveillance, early detection and rapid intervention (as per the European regulation) should be set up as quickly as possible. The network should also be deployed over the entire country, including areas where IAS pressures are currently low or negligible, in order not to be surprised by new invasions or by the rapid spreading of IASs already widely present in certain areas.

This network will be of great use in harmonising the analyses and approaches of the many stakeholders involved in IAS management. It is clear that the various stakeholders operate according to very different time frames, e.g. managers need to react and launch projects quickly ("we need to act now") whereas scientists need time for their research ("we need to understand before we take action"). To ensure optimum execution of a joint approach, these needs must be met and solutions may, initially, encounter difficulties due precisely to the different time frames. However, given that in most cases, management work initiated in compliance with regulations must be repeated over time, these difficulties should fade. It is nonetheless true that to maintain an operational situation and confident relations between the management and scientific sectors, it is necessary, similar to all human relations, to strive together to achieve the jointly approved objectives.

Other difficulties caused by differences in time frames may arise when certain persons, stakeholders or even elected officials suddenly discover, occasionally very late in the game, the implications of IASs management for their own needs and interests. This sudden "discovery" of the situation and the direct IAS-related risks can produce strong reactions on the part of these new stakeholders. The situation overnight becomes a major problem because they are directly concerned, whereas before they were unaware of the situation. These reactions often reveal a degree of irrationality, ignorance or even dishonesty, which makes it more difficult to dialogue with these new stakeholders in the management work.

This "late discovery" occurs fairly regularly in cases where the only information disseminated concerns situations that may require IAS management in the future or, in extreme cases, situations where interventions have already been regularly organised in the area. It is clearly the consequence of insufficient communication and awareness raising targeting the stakeholders in question.

It must be said that though regular efforts have been made over many years by a majority of managers, they nonetheless remain insufficient in some cases. For example, a few years ago, a town made an urgent request for equipment to harvest aquatic plants because the exceptional weather conditions (it was the hot summer of 2003) had caused a massive proliferation of a new invasive plant in its lake. The same town had for several years received a series of reports warning about the progression of the species and the growing need to manage it. Similarly, during the July 2013 symposium organised in the Brière region (see Figure 51 a and b) with the participation of the regional nature park to discuss local management of primrose[8], a number of farmers, who had recently discovered the problems involved with terrestrial primrose in wet meadows, criticised the participants from the regional nature park, Agrocampus Ouest and Irstea (and public authorities in general) for not having taken any action. They were unaware of the joint management of primrose by those organisations (involving both research and concrete interventions) for over a decade in that particular area.

Figure 51

a, b © A. Dutartre, Irstea

The symposium held in 2013 to discuss primrose in the Brière region was an occasion for researchers, managers and the general public to meet.

Group excursion in the Brière region to observe the colonisation of meadows by terrestrial primrose.

8. http://www.gt-ibma.eu/activites-du-gt-ibma/analyse-des-aspects-de-la-gestion-sur-un-site-pilote-application-a-la-gestion-des-jussies-par-le-parc-naturel-regional-de-briere/

Unfortunately, this "social inertia" is not limited to certain people or groups of people. It may be observed everywhere and anywhere, even in State representatives. It remains one of the main difficulties confronting the "management-science" partnership in this field and explains the need to improve the relevance and intensity of communication and awareness-raising efforts targeting all segments of the public, in order to overcome or at least reduce this inertia.

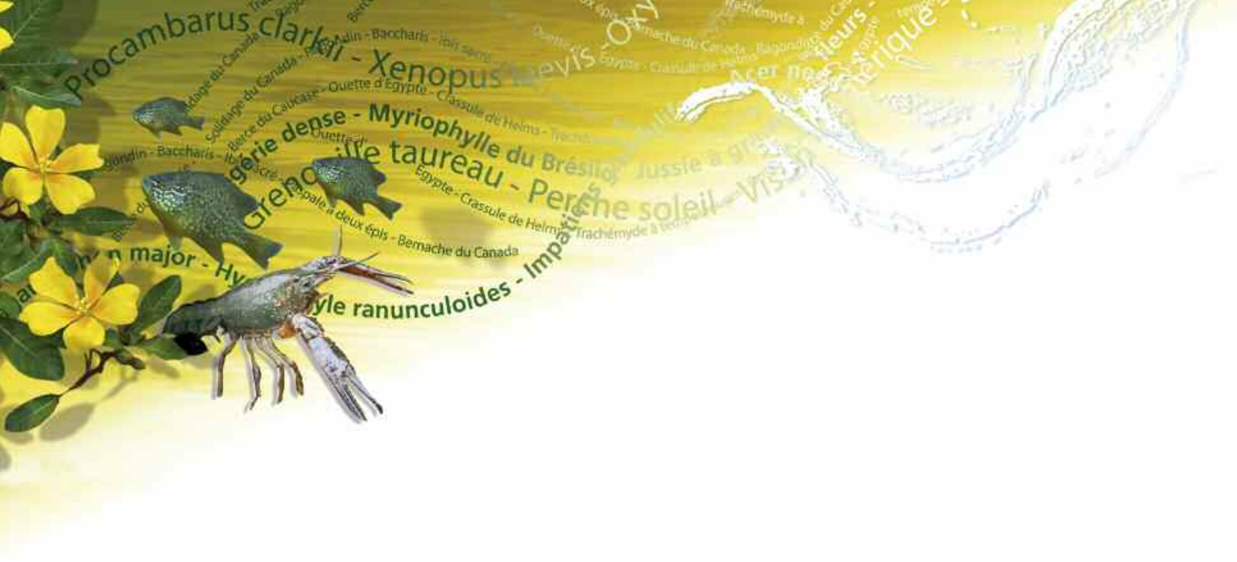
This chapter was drafted by:
Alain Dutartre (independent expert, formerly at Irstea)
and Emmanuelle Sarat (IUCN French committee).

The section titled "Organic transformation of invasive alien plants" was written by Hélène Gervais and Dorine Vial (Conservatory for natural areas for the Centre region).

With the collaboration of:
Jean-Patrice Damien (Brière regional nature park),
Nicolas Pipet (Sèvre-Niortaise basin interdepartmental institution),
Nicolas Poulet (Onema),
Jean-Philippe Reygrobellet (Board for balanced management of the Gardons basin),
Yohann Soubeyran (IUCN French committee).

Management techniques for invasive alien species in aquatic environments

5



Intervention guidelines step-by-step

Putting knowledge to work

The objective here is to work toward the actual intervention, on the local level, by gathering the available or accessible data on the situation requiring management, in order to make rational technical decisions. The local management approach (see Chapter 4), by collecting on-site information concerning the IASs and the needs of people, should facilitate these decisions.

■ Learning about the environment and how it is used

Site characteristics

Ideally, this phase of the approach should be used to collect all the available information on the environment(s) concerned by the intervention, e.g.:

- dimensions, surface areas, water depth(s), difference between high and low water levels;
- hydrological characteristics (flood and low-flow levels), development work and regulation of water levels;
- connections with other aquatic environments;
- plant and animal communities;
- types of banks and riparian vegetation;
- site accessibility;
- available or necessary equipment;
- regulations governing the site(s) and the planned work.

It is generally easy to collect this information, however it does not always exist in forms that are of immediate use for the analysis prior to setting up the intervention. In some cases, the information has already been collated in existing documents, however it is necessary to check the validity of the information.

Uses and the people using the environment

Effort should also be made to obtain the best possible information on how the site or the area are used. Uses may be defined in quantitative terms (energy production, irrigation, mitigation of low flows and of flooding in rivers, etc.) or qualitative terms (drinking water, swimming, hunting and fishing, etc.). They may take place in the specified environment or throughout the river basin. In the latter case, they may create functional limitations in the specific environment (Dutartre, 2002).

An analysis of uses on the site should indicate the types of uses, but also their geographic location and timing, the relative intensities of use and, if possible, their level of compatibility. Concerning the last point, many uses often take place in the same environment (see Figure 52), but the issues of how the available resources are shared and the interactions between activities are not always correctly assessed.

Figure 52

© A.Dutartre, Irstea

Dense beds of amphibious species, such as water primrose, can hinder the travel of boats in lakes.

For safety reasons, certain uses have for many years been regulated by the creation of zones (e.g. lines of buoys in a lake) or other limitations in order to reduce or eliminate the risks of accident. Examples are swimming areas cordoned off from boating sites, other areas where boating is forbidden, etc. (see Figure 53). These rules, intended strictly to ensure the safety of users, take into account only the physical characteristics of the environment (depth, etc.) and, in some cases, bank characteristics, but do not necessarily acknowledge the implications for environmental management.

Figure 53

© A.Dutartre, Irstea

These beds of parrot-feather watermilfoil block all access to parts of the pond where boating has already been prohibited. (Léon Pond, Landes department).

In other cases, contradictions may exist. For example, the presence of dense beds of submergent plants close to the surface may be highly troublesome for certain water sports, but very favourable for fish. Should efforts be made to eliminate or regulate the plants simply to benefit the water sports? At the end of the 1980s, the rapid colonisation of Blanc Pond (Landes department) by curly waterweed, in the form of dense beds covering approximately 100 out of the 180 hectares of the pond) elicited negative reactions on the part of all users, including anglers (see Figure 54 on the next page). A few years later, the reactions of the anglers had become more nuanced because it had been discovered that the plants enabled the development of a large perch population (*Perca fluviatilis*) thanks to the shelter provided to the alevins by the dense beds. Since that time, regular management work has been carried out on a part of the beds each year to enable boating activities (see the management report, vol. 2, page 23) and the pond continues to attract numerous anglers. Similar reactions of anglers confronted with such colonisations have been noted elsewhere.

Figure 54

© A.Dutartre, Irstea

Colonisation of Blanc Pond (Landes department) by curly waterweed (the dark section in the photo).

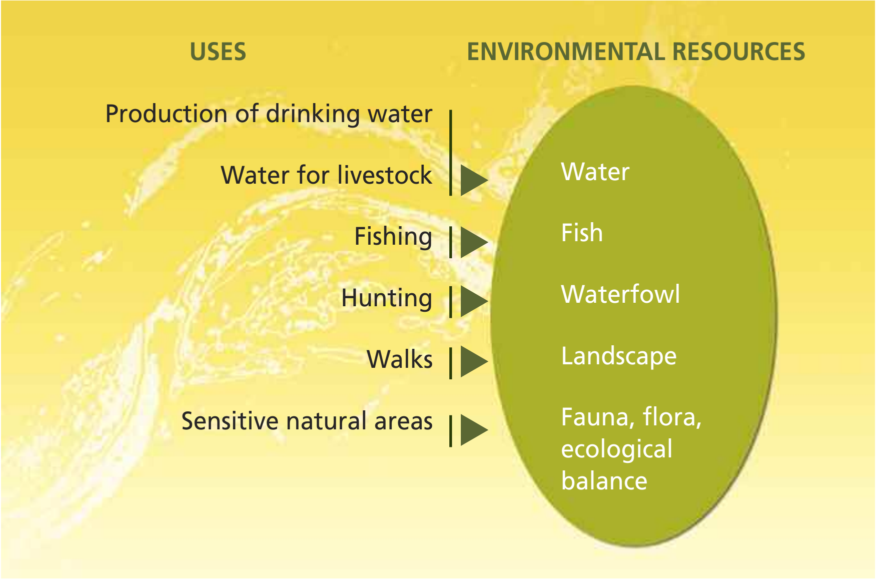
User groups, often organised in associations frequently try to highlight the importance of their particular use and in some cases neglect to mention the impact of that use on the environment. This lobby work increasingly focusses on the positive impacts that can result from growing tourism. These requests and defensive activities often lack any prior analysis of the issues and risks involved in the specific use, but they should be assessed taking into account the impacts they may cause for the environment. Their compatibility with the environment should also be examined. For example, if a large number of activities can co-exist in a large lake without endangering users, the same may not be true in a pond covering just a few hectares.

Similarly, certain uses in areas not conducive to that particular activity can rapidly oblige managers to undertake unforeseen interventions made necessary by the type of activity. For example, the creation of a swimming area in a lake or basin fed by a river, where algae or macrophytes may develop due to the high level of nutrients in the water, may turn out to be very costly in terms of maintenance. In some cases, an economic analysis of the maintenance work required could lead to the conclusion that a swimming pool may be a better choice that is less “natural”, but for which maintenance is easier in terms of planning, cost estimates and implementation

These uses consume, in the widest sense of the term, environmental resources (see Figure 55 for an example of how a lake may be used and the corresponding resources). However, the availability, evolution and renewal capacity of the resources are frequently not assessed, which can lead to significant differences between the expectations of users and the mid to long-term capacity of the environment, and consequently to dissatisfaction on the part of the users.

An analysis may therefore need to set priorities among uses (determining the main use and the remaining secondary uses), thus facilitating later decisions on intervention.

Figure 55



Uses and resources, the example of the Pen Mur millpond in the town of Muzillac (Morbihan department). According to Dutartre et al.*, 1997.*

Assess disturbances and damage

■ Disturbances and their causes, an analysis of the expressed problems

Another element in this initial approach is to identify the disturbances noted by users and/or managers. This consists of a subjective assessment of a problem for one or more uses caused by changes in one or more parameters in the environment, where the disturbance is defined in terms of these uses. The development of aquatic plants covering large surface areas or in places used by people, or the excessive quantities of bird droppings in lakes or on lawns in parks may be said to be disturbances if they hinder those uses.

A disturbance is therefore defined with respect to one or more uses and an analysis of the situation must attempt to reduce the subjectivity inherent in most definitions and develop the level of objectivity required to set up suitable environmental management. This analysis must take into account the uses and the management objectives, while respecting the functional consistency of the environment (Dutartre, 2002).

Disturbances are therefore not the same thing as the damage caused by IASs, which have to do with the impacts incurred by these species (see Chapter 1). Competition with native communities, uniform landscapes, local regression of biodiversity or predation by the invasive fauna are the damages most frequently observed on a site or in an area.

■ A necessary assessment of the damage

Ideally, an assessment of the damage should be carried out before launching an intervention, but the task is highly complex (see Box 21 on the next page). This is because the data on any damage caused by the invasive species are often not available on the site or in the area in question. In addition, managers generally do not plan on conducting assessments or analyses on the damage caused by IASs and to date very few studies to quantify the damage have been funded.

The historical data on species distribution ranges and ecosystem functioning are required to detect the mechanisms and processes involved in a colonisation and in the resulting spread of populations and disturbances. For comparative studies, undisturbed control sites are not always available and, finally, indisputable assessment protocols designed to detect and quantify damages must still be established (Haury *et al.*, 2010).

The history of a data sheet used to provide management advice

The continuous improvements in knowledge on species and on management techniques, in the training of managers, in the dissemination of information, etc. mean that it is now possible to offer solid information that can be easily transmitted by the internet. This is a relatively recent development, made possible by constant progress in the information and communication technologies. Three decades ago, prior to the arrival of the new techniques, the situation was quite different.

The first proliferations of aquatic plants, either native or alien, that were seen as sufficiently serious to provoke a reaction from stakeholders and managers date back, as far as we are aware, to the 1970s. In that no communication networks had been set up at that time, the requests were sent to various institutional contacts, such as the Departmental agricultural agencies and the Water agencies. These institutions did not have the necessary knowledge bases or human resources, consequently they transmitted the requests to other organisations seen as more likely to provide answers, such as INRA and Cemagref where research teams worked on aquatic environments, for example in Thonon-les-Bains (INRA) or in Lyon and Bordeaux (Cemagref).

Though few in number initially, these requests resulted in a joint assessment by INRA and Cemagref on a lake in the Charente-Maritime department (Dutartre *et al.*, 1981). The number of requests grew rapidly in the 1980s, arriving from departmental services, managers and even private land owners. Most presented the problem in simple, even simplistic terms because the perceived difficulty appeared very simple, i.e. too many aquatic plants! The requests could most often be summed up in the following sentence, *"This plant is creating a problem, what is the most effective herbicide?"*. At that time, a number of herbicides had been approved for aquatic environments and they were seen as effective, inexpensive and relatively inoffensive for the environment. However, it very rapidly became clear that without further information on the local situation, it was impossible to propose a consistent, structured response, capable of limiting environmental damage and the risks of ineffectual action.

At that time, regular meetings were held from 1978 to 1994 by the *Aquatic plants* group, set up under the auspices of the Weed committee (COLUMA) that subsequently became the National association for plant protection and finally the French association for plant protection (AFPP). The group produced over 35 documents on the biology, ecology and management of aquatic plants, presented during either internal meetings or *Aquatic plants* sessions held during COLUMA conferences in 1990 and 1992 (Dutartre, 1994). Its primary contribution consisted of updating a book containing identification sheets for the main aquatic plants, a procedure for plant identification and information on management methods (Montégut, 1987). The group also collectively prepared an "assessment-aid data sheet" used to collect, partially in coded format, information of use in preparing management plans and in providing consistent answers to questions. The information recorded on the sheet included sizing dimensions and the local uses of the area in question, the types of plants considered responsible for the disturbances and any work already carried out against the plants.

The person or entity requesting assistance was instructed to fill out the sheet as completely as possible. It was then used as the basis for management advice that in some cases led to more in-depth discussions on the difficulties of managing aquatic plants. Over time, we noted that by sending the data sheet as a first step prior to providing advice, it was possible to regulate the volume of requests. A return rate of 50% fairly rapidly revealed the overly dramatic nature of some requests.

An analysis of approximately 50 data sheets and of a similar number of answers to a survey run by the group in 1988 (Dutartre, 1992) confirmed that part of the difficulties encountered were due a lack of knowledge on the ecological functioning of environments. Other problems were the direct result of efforts by managers to develop multiple uses of environments without taking into account the capacity of the environments to fulfil those requirements. Among the major missing pieces in the puzzle was taxonomic information on the species in question, which led to serious management errors when the species causing the disturbances was incorrectly identified.

Since that time, the data sheet, with a summary of the theoretical management approach (a very short presentation) and, later, digital copies of articles on plants and their management, has been put to regular use. In many cases, it initiated more in-depth and functional discussions than would have been possible by simply sending informational documents and thus contributed to the progressive constitution of the current network of people working on the management of aquatic plants, even though, in the beginning, requests concerned both native and alien species, a situation arising much more infrequently today.

The data sheet is now fairly old and less useful due to the large amounts of information available via the internet, but it can still be used for requests from people who are not at all familiar with the topic. It remains the first step in discussions that can significantly improve the advice provided and make clear to the requesting person that they are entitled to ask simple questions, but any serious response first requires diverse information on the environment, the species and the uses to which the environment is put.

The data sheet, which must be improved and updated, is available on the IBMA site (www.gt-ibma.eu) with other tools to assist management (worksite progression sheets, monitoring protocols, etc.).

■ Difficulties involved in assessments

Very roughly speaking, it may be possible to say that disturbances are more qualitative in nature (*"I am not satisfied"*) and damages more quantitative, but in fact the situation is more complicated. The impacts of a species on an activity can in fact be rapidly quantified when those impacts interfere with certain economic activities such as tourism. For example, what would be the economic losses to boating in the Marais Poitevin marshes if the spread of water primrose were not regulated (Pipet and Dutartre, 2014)?

On the other hand, it is not always easy to quantify the damage done to nature by IASs. Cost assessments of the damage, generally on the national and international scales, have been carried out over the past decade. One of the better known assessments is that of Pimentel. He calculated that the economic and environmental losses for the basin of the Great Lakes in North America represented 5.7 billion USD (Pimentel, 2005) and the total annual loss for the United States as a whole represented 120 billion USD (Pimentel *et al.*, 2005).

In Europe, the work by Kettunen *et al.* (2009) is regularly used as a reference point in calculating the annual costs of damage caused by IASs and the management work required to control them. The total amount often mentioned in European documents is 12.5 billion euros.

But in fact, Kettunen and his colleagues wrote that *"According to existing data the total costs of IAS in Europe are estimated to be at least 12.5 billion EUR per year (according to documented costs) and probably over 20 billion EUR (based on some extrapolation of costs) per year)".*

The difficulties in obtaining relatively precise numbers do not necessarily decrease in step with a drop in the size of the area being analysed. The costs of interventions are, theoretically, relatively easy to determine because they are often covered by public funds. But the participation of volunteers in a wide array of management operations, e.g. environmental monitoring, warning networks and intervention work, is often not included in the calculations of the "social costs" of IAS management. Even if this participation is most likely limited, it should be taken into account so that the total cost is as accurate as possible and provides a better overall description of IAS management.

Concerning the costs of damage, some may be calculated on the basis of the direct economic losses caused by IASs for certain human activities in the area under consideration. On the other hand, damage to biodiversity, in terms of species, living communities, habitats and the ecological functions of environments, is not specifically taken into account and therefore not included in assessments.

That is why study and work have, for a number of years, been put into determining the ecosystem services provided by environments in order to widen the assessments of IAS impacts (Amigues and Chevassus-au-Louis, 2011). The generally accepted definition of "ecosystem services" states that they are *"benefits that humans gain from ecosystems without doing anything to obtain those benefits"*. It is therefore necessary to establish reference values for ecosystems that can then be used to calculate the reduced benefits caused, for example, by IASs and include the results in the overall economic analyses. These analyses generally deal with major types of ecosystem, e.g. forest ecosystems, mountain ecosystems, marine and coastal ecosystems. Current work by the IUCN French committee has already produced a number of documents on the topic (see http://www.uicn.fr/-Outils-et-documents-.html). For example, a report on continental freshwater ecosystems has already been published (UICN France, 2014).

In 2010, following the Grenelle environmental meetings, a report on the economic assessment of the services provided by wetlands (Aoubid and Gaubert, 2010) presented data on these environments (including alluvial plains, marshes, peat bogs, estuaries, artificial lakes, ponds, littoral wetlands). In that the Grenelle agreement foresaw, for their preservation, the purchase of 20 000 hectares of wetlands by the Seaside and Lake Conservation Trust and the Water agencies by 2015, the assessment produced figures for an equivalent surface area. The report took into account a wide range of direct and indirect services provided by wetland ecosystems. The resulting economic assessments showed that the loss of 20 000 hectares of wetlands, i.e. the loss of the corresponding functions and benefits, would over a 50-year period incur costs of between 405 million and 1.4 billion euros. When compared with the cost of purchasing and maintaining 20 000 hectares of wetlands, i.e. 200 to 300 million euros over the same time span, the benefits of preserving wetlands are clear.

A French programme to assess ecosystems and ecosystem services (EFESE) was launched in 2013 under the responsibility of the Ecology ministry (http://www.developpement-durable.gouv.fr/Levaluation-francaise-des.html). The objective is to establish a multi-disciplinary network of researchers working on ecosystem services. Finally, in 2014, the Sustainable-development division of the Ecology ministry (CGDD) started a survey titled *The cost of invasive alien species in France* and the results should be published in 2015.

Consequently, this approach to ecosystem services is not yet available for assessments on IAS damages in aquatic environments. That being said, the information on costs and measurable impacts, gathered by managers and researchers from past interventions, is increasingly well organised and available in the databases constituted to support this approach to ecosystem services.

Finally, though the assessments in some cases are sufficient to justify interventions and obtain the necessary financing, in many other cases managers are at a loss to present data on economic justifications. Locally, an assessment of the disturbances or damages cannot begin until they have become "perceptible", i.e. when the complaints of stakeholders or observations on IAS impacts in the area managed have become sufficient to trip a reaction. The preventive efforts set up in application of the European regulation should contribute to improving knowledge on IASs and facilitate assessments of the damages caused.

Learning more about IASs causing disturbances and damage

Clear identification of species (taxonomy) is indispensable in precisely defining the management problem, but is still neglected in some cases. One of the main advantages of identifying a species deemed responsible for disturbances is to gain access to the specific knowledge available on its biology, ecology and the techniques used to regulate its population.

For example, a species may proliferate via cuttings (the case for water primrose and Hydrocharitaceae), another may prefer biotopes protected from the wind (e.g. water fern), uprooted plants deposited on a site too close to water may cause a new contamination, etc. Concerning fauna, a healthy, alien species may carry mortal diseases for native species (invasive crayfish and amphibians are well known examples), another may be strictly nocturnal and efforts to shoot certain animal species may simply cause the populations to disperse.

In-depth knowledge on the geographic distribution of species is also required prior to management operations. An objective of interventions is to limit the dispersal of the local populations. Detection of colonised sectors, of invasion fronts and monitoring of adjacent areas (e.g. over a river basin) are means to identify the priority areas for interventions, depending on the objectives of the manager. An assessment of the dispersal potential of the species and of any favourable, nearby biotopes can usefully complement the information on the colonised sectors and serve to refine the monitoring strategy for the area. A number of mapping tools already exist and others are now being developed by managers and various IAS work groups (see Chapter 6). They can be of assistance in prioritising interventions.

Finally, in some situations, interventions have already been carried out, often without the necessary precautions and prior analysis required to reduce implementation risks. The information on past interventions and their results should also be taken into account (Haury *et al.*, 2010).

Assessing the ecological issues of management interventions

In general, management interventions themselves have impacts on the ecosystems in which they are carried out, either specifically on certain species or living communities (fauna and flora) not targeted by the work, or more generally on the functioning of habitats. In that interventions can cover large areas and given the currently clear requirements in terms of biodiversity protection, the need to better assess the consequences of management work would appear manifest.

The objective is not to limit intervention possibilities through the systematic application of the precautionary principle, but to base management decisions on as much information as possible by first comparing the IAS damage to the impacts of management. This assessment must obviously be based on the available data pertaining to the biology and ecology of the targeted species and the previously observed impacts of the potential intervention techniques on the living communities not targeted and on the environments involved.

Information previously acquired from other cases on IAS expansion dynamics (areas covered, populations) is most useful for the assessment. In some situations, that may lead to intervention techniques deemed “violent” and even debatable, but that may be justified in light of the ecological issues..

For example, New Zealand pigmyweed (*Crassula helmsii*), a small plant growing near water and considered particularly invasive in continental France on the basis of information from the U.K., has been systematically monitored for several years. Following its observation in a pond on a site to the east of Donges (Loire-Atlantique department), it was decided in 2012 to fill in the pond in order to eliminate the plant from the site (Sauvé and Rascle, 2012). But to enable the departure of the amphibians living in the pond invaded by the New Zealand pigmyweed, filling occurred in two separate steps (2012 and 2013) and a substitute pond was created near the invaded pond. No New Zealand pigmyweed was observed during the inspection of the site in July 2014 (Matrat, personal pub.). Work to uproot the same species has been carried out in a pond in the Deux-Sèvres department (see the management project in volume 2, page 47, and Figure 56) and proved the usefulness of the technique.

Figure 56

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Manual uprooting of New Zealand pigmyweed in the Deux-Sèvres department.

In other cases, the situation may be seen as critical and though the impacts of the proposed work may be high, even very high, the work is nonetheless carried out to avoid further worsening of the situation. For example, the shallow Turc Pond (Landes department) was colonised for over ten years by large-flower water primrose, to the point that the plant had totally invaded two of the eight hectares, completely eliminating the other aquatic plants and disturbing local uses. In 1993, a floating platform equipped with a mechanical claw was used to remove 5 600 cubic metres of plants and sediment (Dutartre, 2004). This technique provoked significant “mechanical pollution” by suspending superficial, organic sediment in the water, which may be detrimental to fish populations. Unfortunately, no other techniques were available in the given context. The same problems were created recently in the Sologne Pond where water primrose was mechanically uprooted and sediment was dredged (see the management project in volume 2, page 63).

Certain management techniques can impact native animal populations. For example, shooting invasive alien birds or harvesting new water primrose in the spring can trouble native species present on the same site. Precautions must be taken, e.g. using guns equipped with silencers or subsonic ammunition, organising shooting campaigns outside of reproductive and nesting periods, etc. For amphibians, mistakes may be made when removing eggs or destroying metamorphosed animals, particularly if this work is done by private persons with no training. In order to avoid mistakes for all species, work is systematically carried out or supervised by qualified personnel (National agency for hunting and wildlife, personnel from national reserves, environmental-protection associations, local governments). It is also regulated (prefectoral lists of persons authorised to carry out work).

Defining management objectives

Defining management objectives is indispensable, but often neglected as if it could be dispensed with. Is the objective to reduce the space occupied by the species in the environment? Has a request been made to do so? What damage or disturbances must be limited or avoided? What is the targeted future status of the site or area? Confusion is regularly observed in many situations. The technique used to regulate the species is often seen as the objective and this ambiguity leads in many cases to imprecise interventions and consequently to unsatisfactory results.

In environments used for a single or small number of purposes, definition of objectives may take place fairly rapidly. The same is not necessarily true for environments used for many purposes, where negotiations between stakeholder representatives may be necessary to set valid objectives for the subsequent work. For example, an invasive alien plant may hinder some water sports, but contribute to the landscape and fishing, an alien bird may contribute to eutrophication of the environment, but have ornamental value for the general public, etc. In addition, a simple reduction in numbers or in surface areas colonised by a given species is not in itself an objective. An assessment of the disturbances or damages taking into account the targeted species must be the starting point in defining objectives for management interventions. Certain invasive species may continue to cause problems, e.g. those carrying and transmitting pathogens such as alien crayfish and American bullfrogs.

However, in order to produce the objectives most likely to result in the management work best suited to the situation, the negotiations must be based on a complete description of the site, the observed damages and disturbances, the local uses and the relations between those uses. There should also be a discussion phase between stakeholders, even if it may appear to delay the actual work. The purpose is to define objectives shared by the stakeholders, that are realistic given the colonisation dynamics, the available technical resources and budgetary limitations.

Defining an intervention programme

Local interventions that are inexpensive because limited in scope (space and/or time) can be carried out directly by the local managers, generally without needing to involve higher echelons. However, as in all cases and to the degree possible, they must be suited to the targeted situation (type of IAS, the environment, the human needs, etc.). In some cases, local interventions, carried out with unsuitable or insufficient means (human, material, financial) or without the precautions required by the given species, have resulted in fiascos that occasionally have produced situations even worse and more difficult to manage than the original situation.

Figure 57

Adaptive management. According to Tu et al.*, 2001.*

When the management project requires successive interventions, as is often the case, they must be organised in a precise programme stipulating the objectives, the sites, the techniques used to collect and dispose of the plants or animals removed from the site, the schedule, etc. From the start, this programme should be designed in an adaptive framework (Tu *et al.*, 2001) (see Figure 57), including regular re-assessments of the situation on the basis of the results obtained by the interventions and recent scientific information likely to modify the objectives or the intervention techniques. This regular review of the situation ensures the best possible management results because it requires constant vigilance, it theoretically avoids falling into a routine lacking any analysis and it re-assesses the operational management conditions on the basis of the results obtained.

For many years, an intervention programme has been one of the key documents among the application forms for financial aid that local managers must submit to public authorities such as the Water agencies or to local governments providing such aid. The projected intervention programmes enable the funding entities to better assess the issues and determine whether the planned action will be effective. Intervention programmes may also include proposals for experiments on technical aspects for which uncertainty subsists or intervention techniques designed for special types of sites.

For example, the proposal for the management plan for lakes and ponds in the Landes department, prepared for the Géolandes management board (Dutartre *et al.*, 1989), included tests on several very precise sites, trials using herbicides (at a time when certain products were still permitted for aquatic environments) and a section explaining the value of subsequent monitoring. The great amount of information now available on most IASs makes it much easier to draft intervention programmes and a number of current and past programmes can also be of assistance in preparing and drafting the document.

That being said, in many cases, it remains very difficult to provide sufficiently precise information on future interventions, even from one year to the next, because various random factors can affect sites and the IAS populations. Concerning flora, plant development is influenced by winter and spring weather. For example, in south-west France, shifts of a full month in the flowering and maximum biomass production of water primrose have been observed, depending on spring temperatures and sunlight. In rivers, winter and spring flood regimes can have direct and strong effects on hydrophyte development.

In the adaptive management system mentioned above, the indispensable monitoring required to assess the effectiveness of interventions and improvements in situations must also be an integral part of a mid and long-term management plan and consequently a key element in provisional budgets. Depending on the local situation, monitoring can address the targeted IAS populations and the non-targeted living communities, any disturbances caused by the intervention, the risks of new invasions, etc.

Concerning fauna, species' development cycles are also linked to climatic conditions. For example, high spring temperatures bring forward the reproductive cycle of American bullfrogs and provoke early laying of eggs, and a mild fall encourages further activity of adults, whereas management work is generally programmed over a shorter time period. Heavy rainfall may inhibit nightly shooting campaigns and prevent access to the banks of ponds. Other unforeseeable events, such as disagreements with land owners on the proposed work (fishing and emptying of ponds, installation of trapping barriers) and conflicts concerning land use (management work inhibiting hunting and fishing), can also occur and complicate management.

These unforeseen events create difficulties for interventions, particularly concerning certain aspects of funding. Variability in the development of species can render some planned interventions totally useless or make necessary other forms of intervention that were not initially planned and cannot be carried out unless additional funding becomes available. As a result, continuous adjustments in planning are required, in turn leading to reorganisation of the human resources involved and, for fauna, modifications in the prefectoral authorisations for management operations.

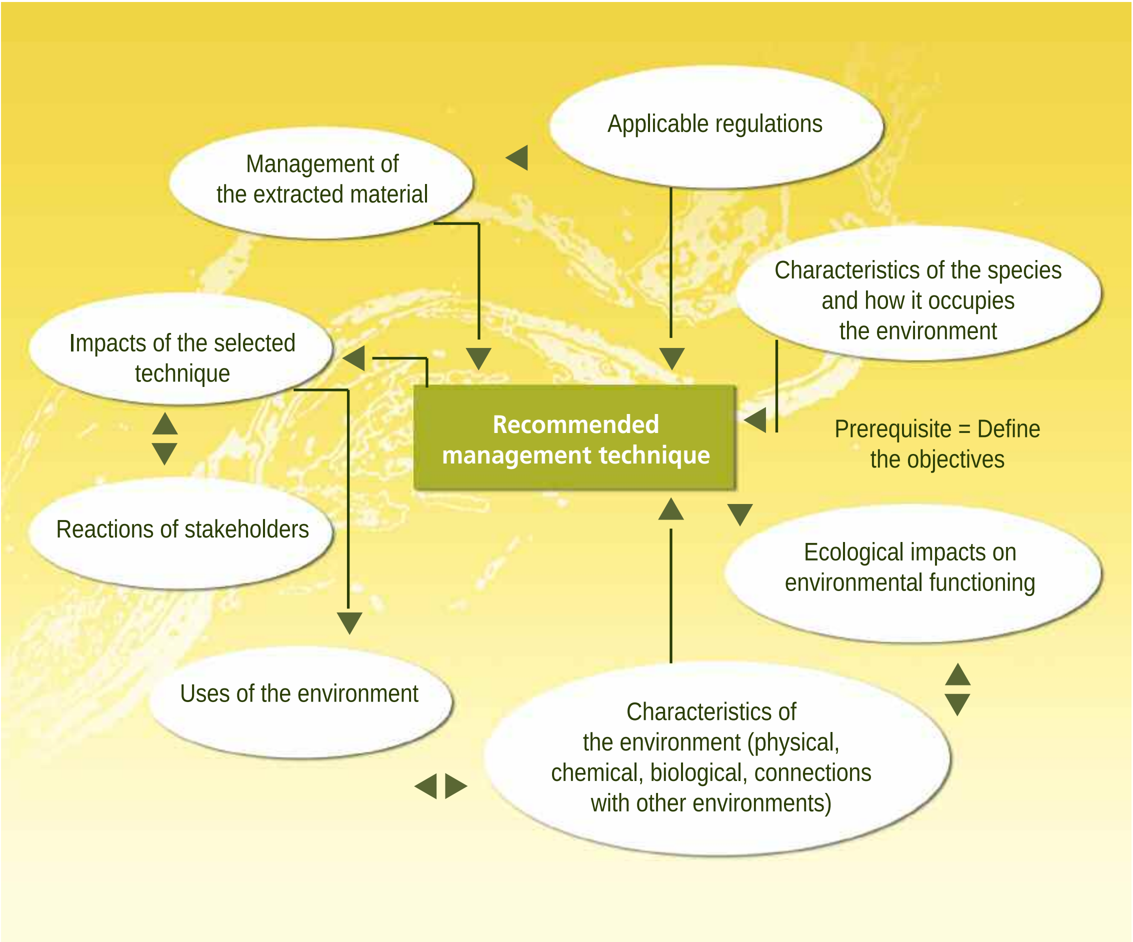
Selecting the intervention method

Intervention techniques should be analysed and selected depending on the previously defined objectives. Figure 58 presents the topics for analysis that can help in producing a rational choice. These elements include the available information on uses and disturbances, the species in question (biology, ecology), how it occupies the environment (distribution, colonised biotopes, etc.), the environment including its connexity with other environments where interventions may produce direct or indirect impacts (see Box 22 below), etc.

One indispensable rule is that "none of the available intervention techniques can be used for all situations". Each has a number of limitations that must be taken into account when making a selection. These limits to their application possibilities are now fairly well understood. In addition to guiding decisions, they must also be listed in the technical specifications for the work and discussed during the negotiations with the companies that will carry out the interventions.

The technical decision must then be analysed in light of the available human and financial resources to determine whether implementation is possible. The technical decision should be taken before examining the economic aspects because the overriding objective is to set up interventions suited to both the site and the species in order to obtain the best possible results. The point here is not to minimise or ignore the economic constraints that will come to bear even in the best of situations, but to target the most effective techniques in view of reaching the set objectives.

Figure 58



Topics for analysis in selecting intervention techniques. According to Dutartre et al.*, 1997; Dutartre, 2002.*

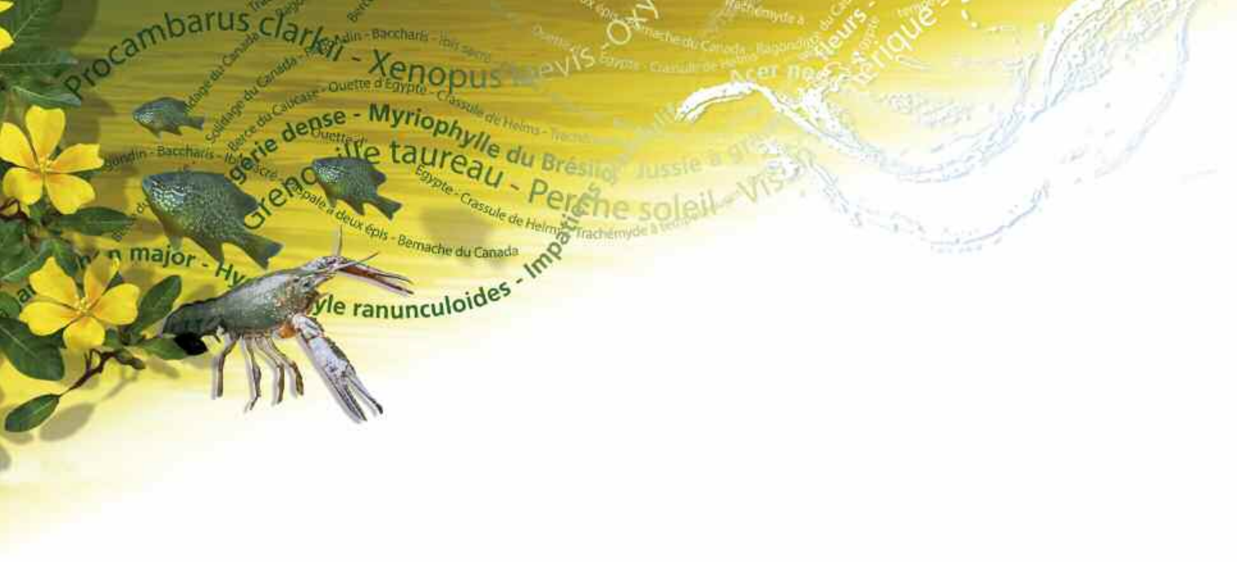
If the financial resources are insufficient or cannot be increased to the necessary level, it would be counter-productive in many cases to implement, for financial reasons, unsuitable technical methods that may cause unforeseen damage and not fulfil the set objectives. For example, a decision to use a given set of equipment simply because it is available, even though it is poorly suited to the species and the site in question, may result in severe failure and a worsening of the problems caused by the IAS. When funding is limited, it is always possible to prioritise intervention sites, targeting only the most important. But, similar to other fields of environmental management, the objective is rather to determine the "price" that can be assigned to the managed environment, i.e. the amount of money that society is ready to pay for the management in order to reach the set objectives.

Controlling the control method

Among the theoretical studies on management techniques, a common topic concerns the possibility of controlling the control method if the intervention produces unexpected consequences. It is not always possible to control the management techniques and it is worth putting thought into planning for the unexpected.

In terms of plant management, when manual or mechanical means are employed, the work can simply be stopped and the limits to the intervention are clearly defined. That was not the case when herbicides were used because spreading of the products, even when there was no wind or current in stagnant aquatic environments, could affect areas much larger (by a factor of 1.5 to 2) than the treated area. Finally, the use of biological-control agents cannot be confined and the organisms may progressively spread to the entire environment in which they were introduced, plus any other favourable, nearby or connected environments, if the targeted invasive species has dispersed significantly throughout the area. In addition, if the control agent shifts its consumption habits or pathological development in the area where it is introduced, it "betrays" the introducer and completely unforeseeable management difficulties may arise. One factor that differentiates manual/mechanical techniques from the others is the need to dispose of the waste produced in order to avoid any secondary dispersal.

Concerning fauna, the animals are generally trapped or shot. Trapping is a more precise management technique, but it is absolutely necessary to check that the means employed target the correct species and to assess their impact on non-targeted species. For example, the nets used to capture crayfish can also catch protected species such as eels (*Anguilla anguilla*) or European pond turtles (*Emys orbicularis*) (Poulet, 2014). Shooting is generally used for birds or amphibians. Though more selective, there are also more risks involved.



Panorama of management techniques

Before presenting the techniques used to manage invasive fauna and flora, it is certainly worthwhile to note that a "healthy" environment is generally thought to be less sensitive to invasions. A healthy environment cannot totally block the adaptation of one or more alien species, but it would appear increasingly clear to a wide array of researchers that a lack of degradation in an ecosystem means it retains a higher degree of resilience to biological invasions than a degraded ecosystem, with as a result lower management costs.

In addition, prior to a project, it is absolutely necessary to gather information from the relevant scientific and technical organisations (public agencies, National agency for water and aquatic environments (Onema), National agency for hunting and wildlife (ONCFS), universities, regional scientific councils on natural heritage, etc.) and to contact the State services processing applications (regional environmental directorates, departmental territorial agencies, etc.).

Panorama of management techniques for plant species

Management techniques for plant species can be divided into two groups, the first concerns means to prevent plant development and the second concerns work on the plants themselves.

Preventing plant development

Prevention consists of interventions that modify certain ecological characteristics of the biotope. These interventions fall under the heading of “habitat manipulation”. They may reduce or hinder the development of plants, native and/or alien. They can have an effect on water quality (nutrients, salinity), on the incident light, on water levels or on current velocities.

■ Reducing nutrients in aquatic environments

Aquatic macrophytes can feed either via their root systems or directly through the tissues of their stalks and leaves. It follows that the physical-chemical quality of water and sediment, in particular concerning the availability of nutrients, can directly influence the development of plant communities. The efforts undertaken over several decades to reduce eutrophication, consisting of work to limit the quantities of nutrients arriving from river basins, have effectively reduced the development of phytoplankton in many rivers and lakes (see Box 23 and Figure 59).

The results have not been as good for macrophytes, with the exception of floating plants that draw their nutrients from the water itself. This is because the links between nutrients and rooted plants are very complex and differ between species. The type of sediment can also play a role in the biomass production of submergent macrophytes (see, for example, Anderson and Kalff, 1988). In addition, an accumulation of organic sediment, which can occur in large rivers with slow to moderate currents and in all stagnant environments, can result in large quantities of nutrients. Given that there is often very little nutrient transfer between sediment and water, there is high potential for biomass development in macrophytes in biotopes where there are large quantities of organic sediment, even when the nutrient content in water has fallen considerably.

The development of submergent plants, both native and alien, observed for several years in a number of large rivers such as the Rhône and the Loire, are clear examples of these complex relations. Efforts against eutrophication have significantly reduced nutrient contents in water and consequently limited the development of phytoplankton, but have in the process increased the amount of light in the water and encouraged the growth of rooted macrophytes. The improvements in water quality can result in plant growth that is deemed excessive.

It should be noted that plants grew on the planet well before anthropogenic nutrient releases occurred in their ecosystems, consequently some are capable of colonising biotopes where nutrient contents are very low. The sediments most often colonised by certain submergent or amphibious invasive plants (Hydrocharitaceae and water primrose) are rich in organic matter (mud, peat). However, the same species can colonise biotopes that are apparently less favourable in terms of the available nutrients, but offer all the other environmental parameters required for their installation and continued development. For example, curly waterweed or large-flower water primrose can establish and maintain fairly dense stands in the relatively inorganic sand on the eastern banks of lakes and ponds along the Aquitaine coast. The simplistic relationships that are still regularly mentioned, e.g. between "water primrose and eutrophication" or "submergent Hydrocharitaceae and highly organic substrates", are not necessarily valid.

Though efforts to reduce nutrients in aquatic environments would still appear useful in order to pursue reductions in the ecological disturbances created by anthropogenic nutrient inputs, they cannot necessarily limit the development of macrophytes in many environments, except perhaps in special cases, e.g. the proliferation of floating plants in stagnant environments.

Box 23

Sediment treatments to inactivate nutrients or reduce organic matter

For several decades, various processes to block the phosphorous in sediment have been used in many lakes and ponds. In general, the water bodies were reservoirs used for drinking water in which phytoplankton had developed, causing problems for the potability treatment.

The products added to the water, either aluminium sulfate or iron(III) chloride, or a mix of the two, formed chemical compounds with the phosphorous that were thought to be stable. Another process used calcium nitrate to create an oxidised layer on the surface of the sediment and limit the release of phosphorous in the water.

The purpose of these treatments was not to reduce the macrophytes communities. And it turned out that the macrophyte communities, by blocking the even distribution of the products, reduced the effectiveness of the treatments. Furthermore, by increasing water transparency due to the flocculation of suspended particles, the treatments could even encourage the development of plants in the water bodies.

Over the years, other sediment-treatment products came into use. These products, theoretically non toxic because "natural" (consisting essentially calcium carbonate (Lithophyllum or coccolith chalk) or various hydrated aluminium silicates (zeolites, kaolinite), were proposed in great quantities to a large number of local governments by companies specialised in treatments for small water bodies.

Initially, the general objective was still to reduce the quantity of organic matter in sediment and to "reduce eutrophication" of the environment (Garnier-Zarli *et al.*, 1994), then, in step with the colonisations of plants in many water bodies, the sales pitch shifted to present them as "ecological" means to reduce sediment build-up and control (or even eliminate) macrophyte development. The next marketing phase was to incorporate in the mineral substrates a wide range of bacteria intended to enhance the effectiveness of the products that thus became "bioaddtives" and benefited from an aura of innovation, ecology and respect for the environment.

Given the large number of treatments carried out without any technical monitoring or assessments of their true effectiveness, it was decided to look at the results of their implementation throughout the entire country (Goubault de Brugière and Dutartre, 1997). The study revealed that almost none of the environmental treatments had produced the expected results. Since then, proposals for similar treatments in water bodies for various purposes, including control of alien aquatic plants, continue to be made, even though the products and techniques employed would not appear to have changed. However, in that no recent assessments on these treatments have been run and due to the uncertainties concerning their effectiveness, none of the recent proposals of which we are aware have received funding.

Figure 59

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Sediment treatment in a water body by projecting chalk powder mixed with water.

■ Water salinity

Freshwater aquatic plants are fairly sensitive to water salinity and regress to the point of disappearing when salinity increases. In certain littoral wetlands, the layout of sites may make it possible to inject or reinject water with varying degrees of salinity, particularly along the Mediterranean coast in the Languedoc-Roussillon region or along the Atlantic coast in western France. This technique may be a means to reduce the expansion of submergent and amphibious plants in these environments.

Among invasive plants, water primrose tends to colonise a wide array of wetlands. Lab tests by Grillas *et al.* (1992) on the resistance of large-flower water primrose to salt revealed that biomass production was impacted starting at salinity levels greater than 2 grammes per litre. On the other hand, it would seem that creeping water primrose (*L. peploides*) can accept up to 10 g/L (Mesleard and Perennou, 1996). In analysing the effectiveness of salt as a means of regulating the species in the Camargue area, Dandelot *et al.* (2005) noted reductions in biomass of almost 50% between the control plots and the treated areas on two of the three experimental sites (irrigation canal and pond), indicating a negative effect of salt on growth. However, the results on the third site (a marsh) were less clear and the authors concluded that "it was not possible to determine precisely the effectiveness of the technique", "even though the growth of the primrose beds was indeed slowed by the treatment. The effectiveness of the salt treatment was enhanced when combined with draining of the invaded site." Finally, the increase in salinity produced no perceptible effect on the invertebrate communities in the irrigation canal.

More recent work by Thouvenot *et al.* (2012) showed, under laboratory conditions and for the ends of plant stalks, that large-flower water primrose was sensitive to salt starting at 6 g/L. During this work, the same experiments carried out on parrot-feather watermilfoil revealed considerable differences in the resistance levels of the two species to salt. Increases in salinity (1.3 and 6 g/L) resulted in reductions in the photosynthesis and the growth of water primrose, but had no comparable effect on parrot-feather watermilfoil. The authors concluded that the reactions of the species depended on the season and on how each plant developed. Parrot-feather watermilfoil was deemed to be better suited for colonisation of brackish waters.

The potential for regulating water primrose using brackish water has been tested since 2013 in a section of the Brière marshes that in the past were naturally subject to tides and are currently heavily colonised by primrose. The three-year research programme comprises six, successive entries of brackish water, the first of which took place from the end of September to the beginning of October 2013. The monitoring programme intended to assess the effectiveness of the technique for water primrose and its impacts on water quality and fish communities (Thabot, 2013) effectively revealed plant mortality on certain sites. However, given the timing fairly late in the season, the mortality may have corresponded to the normal life cycle of water primrose, i.e. it could not be clearly attributed to the salt.

Following the first test, successive releases of brackish water were carried out starting in July 2014 in order to provoke a prolonged period (several weeks) with high salinity levels (10 to 20 g/L). This second test had a significant effect on the beds of water primrose with high levels of mortality. The monitoring also revealed high impacts on fish populations, including considerable mortalities on certain sites, probably due to the confined nature of the area receiving the brackish water from which the fish could not escape. The analysis of this full-scale experiment is still in progress and will not be complete until an assessment has been run on the spring regrowth of the water primrose in the tested areas and on the fish populations in the marshes. However, whatever the results of the analysis, this regulation technique for water primrose could be used exclusively in the sections of the Brière marshes closest to the Loire estuary and would have to be repeated each year in order to regulate primrose populations over the long term.

The effects of salt on groundsel bushes have been studied in Spain (Caño *et al.*, 2014). The species has a high tolerance level for saline environments, however its abundance is negatively correlated with the salinity level. High concentrations of salt in the environment are thought to have a moderate effect on plant mortality, but significantly reduce its growth rate and seed production. Greater loss of leaves was also observed under highly saline conditions. The combined effects may reduce the resistance of the species to pests such as fungus and scale insects. On the basis of these studies, comprehensive management techniques for ecosystems colonised by groundsel bushes, e.g. salt marshes, are currently being tested.

Recent work indicates that populations of Asian knotweed (*Fallopia* spp.) have been observed in coastal areas and salt marches in the United States (Richards *et al.*, 2008, quoted by Rouifed *et al.*, 2012). This capability of colonising saline habitats would seem to correspond to a tolerance on the part of the plants rather than to an adaptation to saline environments. For the thesis by Soraya Rouifed (2011), experiments were carried out to determine the degree to which Asian knotweed can tolerant salt stress.

In a first set of tests, adult plants from the three taxa (*Fallopia japonica, F. sachalinensis* and *F. x bohemica*) were subjected to treatments spanning a wide range of salt concentrations from 0 to 300 g/L, for a period of three weeks. In the second test, *F. x bohemica* plants were subjected to concentrations of 120 g/L following cutting of the aerial parts of the plants. The results of the tests showed that the aerial parts of Asian knotweed are sensitive to the highest concentrations, starting at 120 g/L, and that the biomass of their roots is significantly reduced by concentrations starting at 30 g/L. In addition, regeneration of treated *F. x bohemica* is delayed 20 days compared to the control group. “Saline shock” treatments, though somewhat effective under laboratory conditions, are not sufficient to prevent plant regeneration and the use of salt at concentrations exceeding 100 g/L would not appear feasible as a management technique for Asian knotweed in natural environments.

■ Light

Access to light, the indispensable factor for photosynthesis, determines the distribution of plants in aquatic environments, examples being light passing through water for submergent plants and light filtered by trees along rivers. Shallow waters in lakes and rivers are biotopes with high potential for submergent and emergent plants.

Among both native and alien species, needs in terms of light vary significantly. Some alien species need great amounts of light, for example water hyacinth and water primrose, whose beds are generally very sparse when riparian vegetation along rivers is dense. Other species can grow with less light, e.g. curly waterweed and large-flowered waterweed, which means they can colonise areas greater than five metres deep in lakes with highly transparent water.

It is possible to reduce or eliminate the available light for the targeted plants using different techniques such as tarps, subaquatic screens, dyes or management of riparian vegetation. A further technique consists of introducing burrowing fish, e.g. carp, a solution occasionally proposed to limit the growth of hydrophytes in lakes. Burrowing by such fish results in fine sediment particles being suspended in the water, which significantly increases turbidity, however this technique can be used, even in the best of cases, only in lakes where the increased turbidity does not hinder other uses.

All of these techniques have important limitations to their use.

Tarping has been used frequently in the past in attempts to eliminate the development of certain monospecific communities of terrestrial invasive species such as Asian knotweed and amphibious species such as water primrose (see Figure 60). This technique, often tested under experimental conditions, was judged insufficient in many cases because plants grew back through the tarp (knotweed) or recolonised the site once the tarp was removed (water primrose). However, it is still used and can produce worthwhile results on the condition that the sites are subjected to regular and relatively time-consuming monitoring and upkeep. The maintenance work on the tarp must be accompanied by additional management efforts, such as planting of other species (see the work done by the COEUR association in the Côtes-d'Armor department to manage knotweed in the management project in volume 2, page 91). Another tarping technique was successfully tested on water primrose by the “green team” at the Vistre public river-basin territorial agency (see the management project in volume 2, page 67). The tarps were put in place for short periods (10 to 15 days) during the summer on land colonised by the primrose. In the Mediterranean climate, the black tarps greatly raised the temperature underneath, thus weakening the plants and facilitating their uprooting once the tarp had been removed.

Figure 60

Installation of tarps and willow cuttings in an effort to manage knotweed.

Subaquatic screens intended to prohibit the colonisation of lake bottoms by submergent plants are a technique developed in North America over the past 40 years. These "benthic barriers" are generally used in sections of lakes heavily used by humans (for mooring, fishing, swimming). The term is used for various types of screen and sheets, some waterproof, some not. An array of materials, including burlap, plastic sheets, perforated black sheets, Mylar, woven synthetics, etc., can be used as barriers (Dutartre and Jan, 2012). Other materials have also been mentioned for this purpose, e.g. the bottom sheets for ornamental basins and pools or felt-type materials[9]. These screens have extremely variable service lives and maintenance conditions, up to 15 years for some if they are regularly cleaned to avoid clogging, an example being the type of screen installed in one of the basins in the port of Sainte-Eulalie (Landes department) to eliminate the beds of large-flowered waterweed (Dutartre and Jan, 2012). Some are biodegradable. Five hectares of burlap (a biodegradable geotextile) were placed in a section of Lough Corrib in Ireland as part of an effort to manage curly waterweed (see the management project in volume 2, page 27, and Figure 61). Very little information is currently available on the effectiveness of barriers over the mid-term. Given their cost and the anthropogenised nature of the resulting sites, they would seem to be reserved for areas heavily used by humans, such as ports, boating sites and areas in the immediate vicinity. By blocking the colonisation of these sites by submergent plants, they can contribute to reducing the "supply" of cuttings of plant stalks created by boat propellers to other areas of lakes.

Figure 61

Installing a biodegradable geotextile in Lough Corrib (Ireland).

9. http://www.ecy.wa.gov/programs/wq/plants/management/aqua023.html

The use of water dyes is another technique proposed by various companies. This technique was initially developed to reduce the growth of phytoplankton in ornamental basins and subsequently adapted to natural environments.

The products modify the colour of the water and thus limit the penetration of light in order to reduce or stop photosynthesis by the submergent plants. Their use is limited to small, stagnant environments and for aesthetic purposes. They must also be used prior to the development of the plants. This technique cannot precisely target any given species and must be repeated regularly. Its effectiveness varies significantly, depending on needs of the local species for light (see the management project in volume 2, page 50, and Figure 62).

Figure 62

A lake in the Netherlands receiving a dose of Dyofix.

A natural limiting factor for the development of macrophytes in watercourses and ditches is the shade created by riparian vegetation along the banks (Dawson and Kern-Hansen, 1979). Research in this field indicates that management of riparian vegetation could be an effective means to limit the communities of submergent macrophytes in these environments. For rivers less than 25 metres across, shade limiting 50% of the light would be sufficient to reduce plant development (both native and alien) to the point that they no longer create any significant hydraulic modifications. A sizeable percentage of invasions by knotweed and balsams along river banks is probably due to management methods for riparian vegetation over a number of decades that removed too many trees from the banks, thus greatly increasing the light reaching the soil and encouraging the establishment of opportunistic species.

A return to management techniques allowing the creation of denser riparian vegetation and consequently more shade could contribute to reducing the proliferation of certain plants. However, this would cause major problems for techniques currently used to maintain the edges of aquatic environments involving machines that would be severely inhibited by significant tree growth along banks.

■ Raising water levels

In some cases, it is possible to raise the water level over a long period, for example in reservoirs and in some lakes and ponds where the water level can be controlled by a dam. The rise in water level reduces the amount of light transiting the water and floods the banks, thus reducing the growth of submergent plants and riparian vegetation. For example, the work by Wallsten and Forsgren (1989) on Lake Tämnaren to the north-west of Stockholm showed that six years after a 30 to 50 cm increase in the water level, colonisation of the 35 square kilometre lake by plants had been sharply reduced. Calculations of surface areas using aerial photographs revealed reductions of over 80% for common reed (*Phragmites australis*) and the yellow water lily (*Nuphar lutea*), and over 60% for the common club-rush (*Scirpus lacustris*). The two submergent species in the lake, Eurasian watermilfoil (*Myriophyllum spicatum*), a native species, and Canadian waterweed (*Elodea canadensis*), an alien species, together occupied 236 ha of the lake in 1973, but were observed on only a small number of sites in 1983.

Similarly, research on the relation between the water level and the productivity of the main macrophytes in Lake Grand-Lieu (Marion *et al.*, 1998) revealed a clear correlation between the two factors, where higher water levels resulted in lower productivity. However, no clear correlation could be found between the water level and the surface area of the plant beds studied because the changes in surface area were in some cases due to other factors, e.g. eating of the plants by coypus.

In a guide drafted on water-primrose management in the Mediterranean region, Legrand (2002) wrote that a one-metre increase in the water level of a lake managed by the Fishing federation of the Hérault department eliminated the water primrose by exceeding its "flood tolerance". Whatever the case may be, this technique can be used exclusively in those cases where the dam controlling the water level can handle the greater mass of water, where the rise in water level does not risk flooding human activities and structures along the banks, and where the process is accepted by the lake owners and compatible with their management objectives.

■ Draining the water body

This is a technique traditionally used in drainable ponds for fish production. The objective is to facilitate harvesting of the fish, but also to reduce the accumulation of organic sediment due to its mineralisation in contact with the air during the time the pond is drained (see Figure 63). This technique may be used for all water bodies that can be drained, however caution is advised for water bodies containing invasive plants in order to avoid later problems in the water body itself and downstream.

In the water body, the type of sediment plays a critical role in the effectiveness of the draining technique. Even when there is no precipitation or input from the water table, the organic sediment often found in these environments can retain sufficient humidity over long periods to enable the survival of the subterranean parts (roots, base of stalks) of submergent and amphibious plants, meaning these plants can in many cases resume their growth once the water body has been refilled.

Figure 63

© A.Dutartre, Irstea

The drained pond in the town of Saint Pée-sur-Nivelle (Pyrénées-Atlantique department).

Among the invasive plants, submergent species such as the Hydrocharitaceae (tape grasses) resist poorly to drying and their foliated stalks, when exposed to air, are destroyed in a few days. The same is not true for amphibious species and for water primrose in particular. Its woody stalks resist drying much better and facilitate the regrowth of the species.

A few small ponds along rivers in western and south-west France were drained in the fall in an attempt to control the water primrose that had colonised the ponds. This technique, even when extended through the winter in the hope that the very low temperatures would kill the plants, did not produce the expected results. The water primrose was not totally eliminated from the ponds and, in at least one case, following a mild winter and a wet spring, the plants expanded their colonisation of the sediment before the pond was refilled, thus increasing their surface area in the pond.

The weather conditions during the time the water body is drained play an important role, e.g. freezing temperatures can be effective if the sediment is frozen to a sufficient depth. In the littoral marshes of the Languedoc-Roussillon region that have been colonised for a number of years by water primrose, more or less long drained periods, ranging from a few weeks to six months, have succeeded in reducing the invaded surface areas (Grillas *et al.*, 2001). The Mediterranean climate, with high temperatures and long periods without any precipitation, clearly contributed to the positive results.

In addition, the seed banks in the sediment can react quickly following the draining, thus enabling the development of species that are, in their majority, native and adapted to the new ecological conditions, but that then disappear rapidly when the water body is refilled. Among invasive plants, water-primrose seeds are capable of sprouting directly from the fruit lying on the sediment surface. Tests carried out in the lab and *in situ* have shown that initially the development of seedlings (and consequently of viable plants) was greater in organic sediment saturated but not covered with water (Dutartre and Petelczyc, 2005). Spring drops in water levels that can occur naturally or be caused by water management can thus encourage the development of water-primrose seedlings and of adult plants.

When draining a water body, particular attention must be paid to the diaspores of any invasive plants on site, e.g. entire plants, stalk fragments, the fruit and seeds of water primrose, in order to eliminate or at least sharply reduce diaspore flows downstream. Use of a filter (e.g. a fine screen) at the output of the water body during draining can reduce flows on the condition that the filter be regularly cleaned to avoid clogging (see Figure 64). Complete plants (with the possible exception of small floating plants such as duckweed and water fern) and the stalk fragments of submergent and amphibious plants can be fairly easily picked up by filters, however the probability that water-primrose fruit, that can float for several days up to a few weeks, and particularly the seeds will not be collected represents a major drawback to the filtering technique.

Figure 64

© A.Dutartre, Irstea

Filter to collect water-primrose fragments following uprooting in the Boudigau River, in the Landes department in 2002.

It should be noted that draining operations are subject to strict regulations. Draining of a water body created by a dam greater than 10 metres high or covering a surface area greater than 0.1 hectare requires an authorisation and may be carried out only during approved periods, generally in the spring and the fall. If the drained water flows directly or via a ditch or outlet to a category-1 river for fish, the water body may not be drained during the months of December to March included (decree dated 27 August 1999, modified by decree dated 26 July 2006). In addition, the Prefect may prohibit draining during water shortages. It is advised to check with the local authorities as to whether and when draining is authorised.

■ Cleaning and dredging

The accumulation of organic sediment in stagnant aquatic environments and those with a low discharge is a continuous process that can progressively modify the ecological functioning of these environments and hinder their use. The most common physical modifications are reductions in the depth of lakes and in the wetted cross section of rivers and ditches. This accumulation of organic matter proceeds in parallel with an increase in dissolved nutrients (notably phosphates and ammonia) that are consumed by the rooted plants, a positive factor for their development if the amount of light reaching the bottom is sufficient for photosynthesis.

Cleaning is part of the regular maintenance work on ditch networks in wetlands because it ensures the flow of water through the network (see Figure 65). The use of excavators with buckets up to two-metres wide is a means to combine cleaning operations with the removal of plant rhizomes, young plants, cuttings and, in some cases, the seeds stored in the sediment (Haury *et al.*, 2010). Particular attention should be paid to the timing of operations, taking into account local constraints, but wherever possible prior to the full development of the plants, particularly water primrose, in order to limit the dispersal of seeds in the environment. Similarly, precautions should be taken to recover the stalk fragments of plants that remain after cleaning.

The sediment extracted by excavators equipped with buckets is generally spread along each bank of ditches. The aquatic plants in the cleaned sections are extracted with the sediment. Spreading on the banks is not a problem for submergent plants because they rapidly dry out and die. However, amphibious plants, that are generally more resistant to drying, may be able to survive and even pursue their growth if the banks are fairly damp. The spreading of sediment can have other impacts, e.g. colonisation by groundsel bushes. On the slightly upraised and bare mounds, groundsel seeds carried by the wind can sprout. In regions where groundsel bushes are present, precautions should be taken to limit their expansion, for example by removing the extracted sediment from the site or by spreading it over a larger area when removal is not possible, or even by sowing the sediment (Damien, personal pub.). In all cases, it is advised to monitor the site following the work.

Figure 65

© A. Dutartre, Irstea

Cleaning a ditch.

To limit the risks of dispersal, parrot-feather watermilfoil and water primrose require specific treatment. Water primrose is particularly resistant. Sediment spread a few years ago without taking any special precautions on various sites, e.g. the Barthes area along the Adour River, is probably responsible for the later colonisation of nearby wet meadows. It was to avoid these problems that the Sèvre-Niortaise basin interdepartmental institution (IIBSN) published a brochure on what not to do (http://www.sevre-niortaise.fr/IIBSN_/wp-content/uploads/plaquettejussieenZH-2013.pdf). The plant matter of the concerned species extracted from ditches should be deposited outside of wetland areas. Finally, concerning water primrose, the fruit and seeds will be present in the spread sediment. Special monitoring of any sprouting and development of seedlings should be planned in order to launch, if needed, an intervention to remove the plants.

Cleaning and dredging are carried out in both natural and man-made water bodies in which the accumulation of sediment creates problems for the intended use (see Figure 66 a and b). The objective is generally to increase the depth and avoid problems by "cleaning up" the environment.

Figure 66

a, b © A. Dutartre, Irstea

(a) Dredging the Moysant Pond (Landes department).
(b) Cleaning the Forges reservoir at Ychoux (Landes department).

The main problem with these interventions concerns the extracted sediment. The volume of watery sediment can be considerable and spreading should take place only on sites correctly prepared for the temporary or definitive storage of the sediment. Sediment-extraction techniques may use an array of equipment depending on the type of environment, the type of sediment and the size of the area to be treated. Frequently employed devices include buckets, similar to those used on excavators, installed on pontoons and barges, or pumps, in some cases equipped with a cutter.

The presence of aquatic plants in the sectors to be dredged is a problem that must be taken into account when planning the intervention. In submergent, rhizomatous plants, e.g. Nymphaeaceae (water lilies), or alien, amphibious plants (parrot-feather watermilfoil, water primrose), the solidity of the tangled rhizomes/stalks can slow the work by hindering extraction (the mix of plants and sediment can block the bucket or the cutter). In that dredging can severely modify the ecological conditions in biotopes, interventions can be followed by rapid reactions of seed banks. Concerning invasive plants, the only species producing seeds that can react to this type of ecological modifications are the water primroses and, to our knowledge, no observations on this point have been published.

That being said, the presence of invasive plants in the treated area means precautions should be taken during sediment extraction and disposal, and the water body and disposal site should be monitored. The techniques used to extract sediment can result in plant fragments that can potentially recolonise the area. Dredging should therefore be followed by manual collection of the plant fragments and regular monitoring over a fairly long period in order to intervene if necessary on any new growth (see the management project in volume 2, page 63).

On the disposal sites, draining of organic sediment can take some time, meaning that plants may grow in the storage basins. Monitoring is required in order to intervene if necessary. For example, monitoring of the disposal sites for sediment extracted from a section of the Sèvre-Niortaise River, where water primrose has been managed for over ten years and consequently no large beds still exist, revealed in 2014 strong growth of water primrose on sediment that had been dredged (the plants were not dredged) a few months earlier in March (see Figure 67). This colonisation is an additional problem requiring management on the disposal sites.

Figure 67

© Nicolas Pipet, IIBSN

Water primrose developing on dredged sediment.

On the other hand, monitoring of the disposal sites for sediment recently extracted from the Marans canal that was severely infested by large-flowered waterweed did not reveal any new growth of the species (see the management project in volume 2, page 15). The water primrose noted in the sediment extracted by hydraulic dredging was rapidly eliminated by replanting the sediment (Fonteny, personal pub.).

■ Increasing current velocities

Local systems designed to direct or accelerate water currents have been used for decades to reduce the erosion of certain sections of river banks or to guide the flow of water toward the centre of the river bed. They can also be used to modify the local flow conditions to the point of limiting certain plant colonies, depending on the type of sediment and how solidly the plants are rooted in the sediment. However, these systems are difficult to create and to maintain, and their impacts on plants are extremely local (see Box 24).

The links between sediment types, current velocities, aquatic-plant morphologies and root systems are fairly well known, which means it is possible, at least approximatively, to foresee which biotopes will be colonised by which species. Certain species clearly prefer environments with fast currents (many Ranunculus species, e.g. water crowfoot), others tend to colonise organic substrates and are generally found in stagnant environments or those having very slow currents.

Most invasive aquatic plants fall into the second group (Peltre *et al.*, 2002). Amphibious species such as water primrose and parrot-feather watermilfoil, and submergent species such as the Hydrocharitaceae (tape grasses) almost invariably colonise biotopes that are stagnant or have very slight currents.

The idea of rapidly increasing river discharges (“artificial flooding”) is also occasionally mentioned as a means to control aquatic plants.

Once again, the links between the hydrological regimes of rivers and the development of aquatic plants are now fairly well understood. Major floods destabilise sediment and can pull out the parts of the plants (stalks and root systems) in the biotopes subjected to the flows. For example, the development of macrophytes was monitored in the Charente River (Dutartre *et al.*, 1994). No major winter floods occurred in 1992, but the two following years saw strong floods and plant colonies in the river were sharply reduced. At the Nersac monitoring point downstream of Angoulême, the percentage of colonised spots fell from 70% in 1992 to approximately 35% in 1993 and less than 20% in 1994.

Box 24

River flows and the adaptation capacities of certain aquatic-plant IASs

The links between the hydrological regimes of rivers and the development of aquatic plants are now well understood. However, no absolute rules may be derived from this information. For example, water primrose is capable of surviving in certain shallow, river biotopes where continuous flow rates can reach 30 to 40 centimetres per second. However, under these conditions, plant characteristics are somewhat different. The work by Charbonnier (1999) on water-primrose development dynamics in different biotopes showed that plants established on a primarily sandy substrate and subject to currents at a monitoring point in the Isle River, a tributary of the Dordogne River, had significantly lower productivity rates, biomass, stalk sizes and number of branches than plants in stagnant environments also studied. Average stalk lengths did not exceed 50 cm, whereas they reached two to four metres in other environments.

The Hydrocharitaceae species are also capable of resisting, temporarily and permanently, flow conditions that would theoretically appear to be incompatible with relative weakness of their stalks and root systems. For example, large-flowered waterweed (Egeria) may be observed in the Dordogne River, downstream of Bergerac, where currents exceed 50 cm per second (Breugnot, 2007). The beds are generally located just downstream of boulders or outcrops creating biotopes without any current where the plants can put down roots in the fine sediment deposited there. The same is true for curly waterweed that has been observed in the Adour River, just downstream of large beds of Ranunculus species where it is protected from the current (Delattre and Rebillard, 1996).

Under such conditions, neither water primrose nor the Hydrocharitaceae species can produce sufficient amounts of biomass to become pests, but these colonies contribute to the flow of propagules travelling downstream.

The floods at the end of the spring in 1994, even though they were not as strong as the winter floods, had a major impact on submergent plants just starting to grow. The evaluations of plant biomass at the Nersac monitoring point, taking into account the distribution and biomass data of the various species, revealed a drop in biomass by a factor of ten between 1992 and 1993 (approximately 1 000 tons of dry matter in 1992, 105 tons in 1993).

Monitoring of colonisation by large-flowered waterweed since 2010 by the Thouet valley board also showed the high impact of winter floods on the development of hydrophytes, including Egeria, in the river (see Figure 68). Starting with the strong floods in December 2011, followed by other significant floods in 2012 and 2013, plant colonies decreased greatly in size to the point of disappearing completely from certain monitoring points (Charruaud, personal pub.).

Figure 68

© A.Dutartre, Irstea

Stalks of large-flowered waterweed (Egeria) uprooted by floods (Thouet River, Deux-Sèvres department).

This type of change in hydrological regimes can be considered a natural means to control certain plant colonies, both native and alien, by eliminating the least rooted and the most fragile species. That is why, theoretically speaking at least, artificial floods created at the correct moment, e.g. when submergent plants develop their stalks and become easier to uproot, could produce the same results. Unfortunately, in the current context of efforts to improve the quantitative management of water, this approach is virtually inapplicable. It should also be noted that aquatic plants uprooted by floods can have serious consequences on human facilities. In addition to masses of plants gathering at certain weirs, dams and locks, where they can hinder flows, water intakes at facilities can be blocked, with variable consequences. Water intakes at nuclear power plants can occur, leading to the temporary shutdown of reactors. This type of incident occurred at the Cruas nuclear power plant on the Rhône River in December 2009 (Carrel, 2009), when 50 cubic metres of plant matter blocked the intakes, resulting in an level-2 incident (on a scale of eight levels from 0 to 7, with levels 1, 2 and 3 representing incidents and levels 4 to 7 representing accidents). Virtually all the biomass consisted of Nuttall's pondweed (*Elodea nuttallii*). Among the half-dozen other hydrophytes noted was large-flowered waterweed (*Egeria densa*). These two Hydrocharitaceae are among the species that have difficulty resisting currents.

Interventions to limit plant growth

The types of curative intervention available to managers are now fairly well known, but they have a number of limits and produce impacts that must be understood if we are to improve these management techniques. A number of books are available on the subject, but of particular interest is the management manual for invasive alien plants in aquatic environments in the Loire-Bretagne basin (Haury *et al.*, 2010).

■ Manual interventions

Manual interventions have existed since it became necessary to launch control operations against aquatic plants, probably around the beginning of the 1900s. Changes in the cost of labour, in the available techniques and notably the use of herbicides since WWII, as well as the rather negative perceptions of manual labour (tiring and often dirty) have resulted in the progressive halt to manual interventions on many sites.

In a report on mowing plants in rivers, Isambert (1989) discussed the various techniques used in the Seine-Normandie basin to control aquatic plants. Manual maintenance work was carried out on some 15 rivers with a cumulative length of approximately 250 kilometres. Virtually all the work was organised by river boards. The tool used for this work was a “châtelaine”, a cutting bar drawn manually across the river bed by two workers on the river banks. This type of tool is suitable for rivers less than 12 metres wide and where the banks are easily accessible. Two experienced workers could mow approximately one kilometre of river per day. The use of part-time labour and volunteers was also mentioned. Unfortunately, no information is available on recent updates to these traditional techniques.

Concerning alien plants, the management plan for aquatic plants in the lakes and ponds of the Landes department, prepared in 1989 for Géolandes (Dutartre *et al.*, 1989), recommended manual uprooting for “sections invaded to a limited degree” by curly waterweed, water primrose and parrot-feather watermilfoil.

At that time, the proposal for manual interventions elicited a number of negative reactions from both elected officials and the concerned technical services. Some people perceived the proposal as a “return to the Dark Ages” given that an array of available machines and herbicides were seen as effective in meeting the management needs of the plants. Other, rather excessive, reactions spoke of prison camps and the use of inmates to do the work.

A number of practical demonstrations and experimental interventions were organised on several sites to dispel those impressions. For example, the manual interventions in 1992 and 1993 on the banks of the Noir Pond (a nature park) and another nearby pond produced five cubic metres of water primrose the first year, but just 0.05 cubic metres the second, a reduction by a factor of 100 that demonstrated the effectiveness of the work (see Figure 69).

Figure 69

a, b © A.Dutartre, Irstea

*Manual uprooting of large-flower water primrose (*Ludwigia grandiflora*) by volunteers in the Noir Pond (Landes department).*

At the same time, efforts to explain the rationale, noting for example the risks of cuttings being dispersed by the machines used and the lack of selectivity by herbicides, resulting in the disappearance of not only the targeted plants, but of all plants on the site, produced a change in opinions concerning manual interventions. This change was fairly rapid because in just 20 years, manual interventions were regularly organised for amphibious plants, water primrose on a large number of sites and parrot-feather watermilfoil on a smaller number sites, on lakes in the Landes department, the Marais Poitevin marshes, the Brière marshes and many other sites, primarily in western France.

An analysis of the change revealed the main reasons (Menozzi and Dutartre, 2007), namely the precision and effectiveness of manual work, leaving the "non targeted" plants in place, something that mechanised techniques cannot achieve. The authors even wrote about "manual uprooting of water primrose, an age-old technique that is truly an innovation" (Menozzi and Dutartre, 2008). It is, however, clear that this type of intervention is justified only under certain conditions, e.g. at the beginning of a colonisation, for collection of plant fragments remaining on site after a mechanised intervention or in areas that machines have difficulty in reaching, and on the further condition that the quantities of biomass to be extracted are not excessive.

The physical difficulties involved in manual interventions should not be exaggerated. The work is physically demanding, occasionally under difficult outdoor conditions, but a considerable number of the negative opinions mentioned above concerned poorly organised work sites involving persons having received little or no training. Similar to any other type of intervention, the objective is to correctly organise the work and consequently to reduce its difficulty and any harsh conditions.

The easing of the physical conditions may concern, for example, the movement of personnel if the sediment is highly liquid or the water is excessively deep. Boats may be necessary, if possible with flat bottoms to improve stability. Similarly, transportation of the extracted plants from the site may be a complex and tiring task. Suitable bags, sufficiently large boats and equipment on the banks to discharge the plants from the boats are examples of means that can be employed to facilitate the task. Considerable efforts have been made by IIBSN to improve the operational conditions for the team working on water primrose in the Marais Poitevin marshes. A boat was purchased to provide the workers with a place to eat out of the weather and to store their tools, etc. (see Figure 70).

Figure 70

© Nicolas Pipet, IIBSN

The work conditions for manual interventions were improved by providing the workers with a boat for their meals and to store their tools.

Other efforts to improve hygiene and safety include training sessions on first-aid and ergonomics, vaccinations and a safety manager to implement a Special plan for work safety and health (PPSPS) (Pipet and Dutartre, 2014) (see the management projects in volume 2, pages 34 and 67).

As already noted, these interventions concern almost exclusively amphibious species. Manual uprooting of submergent plants is possible, but more complex and less effective due to the fragile stalks and the deep water conditions in some cases. However, when manual interventions are carried out rigorously and taking the necessary precautions, in particular when a maximum quantity of plants and stalk fragments, even very small pieces, are removed from the site, the work is very effective and sharply reduces regrowth of the targeted species. Because of their targeted nature and the very limited use of equipment, their impact on environments and habitats is very slight and even inexistent because the non-targeted species are not affected, which means they can continue to develop because the targeted alien species no longer exerts any competitive pressure within the living community. For example, the regular management work on water primrose in the Marais Poitevin marshes paved the way for the re-installation of various native submergent species or those having floating leaves (Pipet, personal pub.).

On banks where invasive plants have appeared, they can be uprooted by hand as long as they have not developed too much, otherwise tools (spade, pickaxe, hoe) must be used. It is very important to remove the entire root system, particularly for suckering plants, to avoid regrowth and even multiplication of the plants if removal is only partial. The uprooted plants must be completely removed from the site to avoid leaving any plants capable of putting down new roots. Manual cutting of these species is also possible if the installation process has just begun or if the site is only sparsely colonised, or in those cases where, given the ecological value of the habitats or of the native species, mechanised interventions are not possible (see the management project in volume 2, page 99). Depending on the diameter of the stalks, the plants can be cut using billhooks, sickles, secateurs, saws, chainsaws, etc. (see Figure 71).

Figure 71

© ONCFS

Manual cutting of groundsel bushes using a billhook in the Lège-Cap-Ferret National salt-meadow nature reserve.

This work can be done by volunteers under management, temporary or permanent staff of local governments, "make-work" companies for the unemployed or private companies. Whatever the case may be, minimum training is required concerning identification of plant species, the precautions required during plant uprooting and transport, and safety conditions for work in areas that are generally difficult to access. The existence of technical specifications for each type of intervention facilitates the work and improves its effectiveness. For a number of years, several private firms have specialised in manual techniques and offer their services to local governments.

In a number of other cases, very small firms offer manual uprooting by scuba divers. Generally speaking, the treated sites are fairly limited in size, e.g. ports where the presence of docks, chains and other factors hinder or make impossible the use of machines to harvest the plants. This technique can be used in deep waters, however its cost even greater than other manual techniques, the specialisation of the personnel employed and the difficulties involved in subaquatic work mean that this technique is restricted to limited operations on sites having high added value.

■ Mechanised interventions

Mechanised techniques to manage submergent plants have been used since the 1920s. The equipment used has very often been adapted from agricultural devices (cutting bars used for mowers, conveyor belts, etc., see Figure 72). The wide range of equipment can be used in many types of situation (Dutartre and Tréméa, 1990). The “châtelaine” mentioned above for manual interventions (Isambert, 1989) is still used today for certain types of work. The weighted cutting bar or bars can be dragged along the bottom by a boat.

Figure 72

© A.Dutartre, Irstea

Cutting bar that is dragged along the bottom by a boat.

Some of the devices used simply cut (mow) the plants. They generally consist of an upside-down T-shaped cutting bar positioned at the front of the boat. The horizontal bar at the bottom enables the boat to cut its way through the plant beds (see Figure 73). On this type of device, the horizontal cutting bar can rarely cut more than one metre below the water surface. Until recently, the cut plants were not harvested. They simply floated along with the current or the wind, either downstream in rivers, usually ending up at dams, or to the edges of lakes, not far from where they were cut. Given that one of the main criticisms of mowing was the fact that masses of cut plants were left in the environment, at the risk of causing oxygen deficits when they rotted or proliferating via cuttings, a number of manufacturers now propose harvesting systems that can be set up on the boats once the cutting bars have been dismantled (see Figure 74). Other devices specifically designed to harvest the plants are now available and used by a few specialised companies in addition to the mowing boats for large operations in lakes.

Figure 73

© A.Dutartre, Irstea

Mowing boats equipped with cutting bars in front and on the side.

Figure 74

© A.Dutartre, Irstea

Harvester rake for cut plants.

The most recently developed systems can simultaneously mow and harvest the plants. Given their size and the difficulty of moving them, these combined harvesters are better suited to stagnant environments or those with slight currents, having regular bottoms (Dutartre and Tréméa, 1990). In addition to U-shaped cutting bars (two vertical and one horizontal bar, or simply one vertical bar), these systems are equipped with a least one conveyor belt to extract the plants as they are cut. These systems are capable of cutting at depths of up to two metres (see Figure 75).

Figure 75

a © N. Pipet, IIBSN
b © A.Dutartre, Irstea

Harvesting vessels.

On the largest combined harvesters currently available (see Figure 76), two other conveyor belts can be used to store and then unload the plant mass. The plants can be unloaded either directly to the shore or to containers on barges near the harvesting zone, in order to reduce the time required for travel by the harvester. Smaller harvesters are equipped with only the one conveyor belt to extract the plants from the water. Storage on board and unloading of the plants are carried out by on-board personnel. Cutting bars are relatively fragile. They break

Figure 76

© A.Dutartre, Irstea

Harvester with the cutting bars and the conveyor belt used to extract the plants from the water.

easily when they encounter obstacles, either along the bottom or, for example, stakes and various other objects installed by humans. The areas in the aquatic environments to be harvested should be inspected to pinpoint where there is a risk of accidents and broken tools.

Depending on their size, these combined harvesters can store up to several cubic metres of plants and transport them to the unloading site. The fact that they can simultaneously cut and harvest is an advantage compared to systems limited to just one function, particularly for the management of submergent plants whose cuttings are likely to cause subsequent proliferation of the plants. The combined systems limit the production of stalk fragments and the conveyor belts are generally effective in limiting the release of cuttings to the water.

Mowing and harvesting work is most often carried out on sites where human activities (navigation, fishing, hunting, etc.) are hindered by dense beds of native and/or alien hydrophytes close to the water surface. The work is of value in that it facilitates human activities, but its effectiveness over time is highly variable depending on the site and the species. At best, it can be effective for up to one year, but in general it does not exceed a few months, the time required by the plants to regrow and reach the water surface.

The risks involved and the side effects of mechanised interventions are well known. In particular, it is not possible to select among the plants cut and harvested. In addition, the passage of the harvesters momentarily stirs up the upper, fluid layer of sediment. Finally, the invertebrates living among the extracted plants are also removed from the environment, as well as larger vertebrates such as turtles and fish that may be trapped in the plants.

To determine the damage caused to fish populations by harvesting operations, a study was conducted under the responsibility of IIBSN in 2002 and 2003 on Lake Noron, along the Sèvre Niortaise River downstream of Niort (Dutartre *et al.*, 2005). This lake, used essentially as a tourist attraction, was heavily colonised by mostly native hydrophytes, including the largely dominant rigid hornwort (*Ceratophyllum demersum*). A preliminary review of the literature indicated that a majority of the fish captured during this type of intervention were juveniles (born the year in question) and that losses in terms of numbers or biomass varied from 2% to 25%, depending on the author.

The study confirmed the data on the age of fish and the losses calculated over the reach in which Lake Noron is located amounted to 5.6% and 1.3% respectively for the years 2002 and 2003, which corresponded to the “low estimate” indicated in the literature. These relatively low values would seem to indicate that for the reach in question, the regular harvesting work undertaken for tourism activities in Lake Noron had a very low, if not negligible impact on fish populations. Though the observations made over the two years of experimentation are not sufficient to draw any firm conclusions, it was nonetheless noted that a smaller quantity of fish (in number and biomass) was captured during afternoons and when the harvester travelled from upstream to downstream. This information suggests possible modifications in harvesting techniques in this type of environment. However, depending on the period when the work is done and the type of environment, capture rates can increase and it is important to pursue this type of observation on the side effects of this type of intervention.

Regular harvesting is conducted in lakes that are heavily used for tourism. For example, that is the case of Blanc Pond in the southern section of the Landes department (see the management project in volume 2, page 23), where the work makes possible the continued use of the lake for summer tourism, fishing and hunting by clearing each year a part of the very dense beds of curly waterweed that have colonised over 100 of the 180 hectares of lake. Noting a reduction in the extracted quantities of biomass over the past few years, the Géolandes management board funded a study to assess the impacts of regular harvesting and determine the reasons for the apparent slowing in the development of the species (Bertrin *et al.*, 2014). The investigation did not detect any notable differences in water and sediment quality between the different monitoring points (colonised and non-colonised areas, harvested and non-harvested areas, etc.), which could have explained the trend and contributed to modifications in the management strategy for the species in the lake.

Other devices such as mower buckets, claws, etc., installed on a hydraulic arm attached to a land vehicle (tractor, excavator) or a floating vehicle (boat, barge, etc.) can be used to uproot and/or remove submergent and amphibious plants. Buckets used for this purpose are often equipped with screens to let water and fine sediment fall back into the water during the extraction of plants and they also have more or less evenly spaced teeth to better grasp the plants (see Figures 77, 78 and 79).

Figure 77

© Nicolas Pipet, IIBSN

A bucket designed for the mechanised uprooting of water primrose.

Figure 78

© A.Dutartre, Irstea

A claw used in the Marais Poitevin marshes to transfer water primrose from a barge to a trailer.

Figure 79

Uprooting of water primrose using a claw in Blanc Pond (Landes department).

This type of equipment is capable of extracting great quantities of plant biomass and conveying it directly to trucks for transportation to the disposal site. The work would appear to be more effective when the system is installed on a floating platform rather than on land (Haury *et al.*, 2010). Buckets and claws can be single or two-sided and the space between the teeth depends on the type of plants extracted (teeth slightly separated for submergent plants, more distant for amphibious plants). Equipment configuration and operator dexterity all contribute to the effectiveness of interventions.

This technique can be used to remove all or part of the root systems of the plants, but it also pulls up variable quantities of sediment around the roots, thus creating temporary pollution that depends largely on the type of sediment. Consequently, the type of sediment, which can range from muds with high levels of organic matter to mineral elements having highly variable grain sizes, is a factor that must be taken into account when attempting to assess the potential impacts, the effectiveness of the intervention and how to recycle the extracted matter.

The risks of creating cuttings due to fragmentation of plant stalks during this type of intervention is fairly high (Haury *et al.*, 2010) and should be taken into account during the assessment of the potential impacts, namely the dispersal of plants from the work site.

Native plants along banks may be cut or mowed using the equipment currently available for maintaining road sides and river banks (see Figure 80). However, the same techniques should be used very sparingly for most invasive alien species, e.g. groundsel bushes (*Baccharis halimifolia*), giant hogweed (*Heracleum mantegazzianum*), garden balsam (*Impatiens* spp.) and the Asian knotweeds (*Fallopia* spp.), because they risk stimulating the plants. Repeated cutting over several years, on the other hand, can exhaust these species, notably groundsel bushes and knotweed, and eliminate any seed banks (Haury *et al.*, 2010). Particular care must be taken when transporting cut stalks to avoid losing them en route and thus reduce subsequent dispersal of the alien species.

Figure 80

Flail cutting of a river bank in the town of Dropt (Gironde department).

The use of mulching machines is possible on fairly flat terrain that is sufficiently stable to support the passage of the large, often tracked machines (see the management project in volume 2, page 102 and Figure 80). The shredded organic material remains where it was cut. This technique can generally not be used on river banks.

Using an excavator to uproot plants on banks can be very effective if it succeeds in pulling out the entire root system, which is fairly easy for species having superficial root systems, e.g. garden balsam, but much harder for species with deeper root systems such as knotweed. This technique should therefore be limited to interventions on fairly small sites where important ecological issues are involved (Haury *et al.*, 2010). Any soil remaining from grading operations can be removed taking care not to allow any stalks or rhizome fragments to escape during transportation. Concerning knotweed, care must be taken if the excess soil is to be reused elsewhere given the capacity of rhizomes to produce new plants. Soil drawn from sites colonised by knotweed, transported to other sites and used as land fill without paying attention to the rhizomes is one of the reasons for the rapid dispersal of knotweed species in continental France.

Management of soil contaminated with rhizome fragments is very difficult. Prohibiting any future use would not seem feasible because it would then be necessary to store the soil somewhere, for example by burying it. Currently, no generally applicable solutions are available. Depending on the type of soil, it would be possible to screen it to remove the rhizome fragments. That is a solution proposed in the U.K. to manage knotweed-contaminated soil (see http://www.wiseknotweed.com/japanese-knotweed-removal-treatment/screening-sifting/).

Experiments involving grinding the soil containing rhizomes, then burying it and covering the site with tarps until the rhizomes have completely decomposed have shown that it is possible to avoid the risks of dispersal (see the management project in volume 2, page 81). Though expensive, if conducted rigorously over fairly small sites, this technique is effective, however its use along rivers is problematic due to flooding and erosion risks, particularly for the plastic tarp that is an essential element in the success of the intervention. This technique cannot be used over long distances for cost reasons, however it is useful for installation sites upstream in river basins in order to prevent later colonisation downstream. It should be noted that a second mechanised intervention is required one or two years later.

Figure 81

© SMAGE des Gardons

Mechanised management of knotweed in the Gard department, a) soil grinding, b) grinding rotor in the bucket.

■ Information on the use of herbicides

For decades, herbicides were commonly used in France to control the growth of aquatic plants until they were totally prohibited at the end of 2009. The ban was preceded by a fairly rapid drop over a few years in the number of marketed products authorised for this specific use. The use in "aquatic environments" was made possible by a waiver concerning the general ban on herbicide use in or near water. Numerous debates and disputes arose around this use, particularly concerning the toxicity of these products (acute toxicity, persistence) for the living communities not targeted by the products and the contribution of this management technique for aquatic plants caused by plant-protection products used in agriculture to water pollution and consequently the drop in water quality.

Over the years, regulations were modified in an attempt to better control the environmental consequences resulting from the use of these agricultural inputs. A number of European directives contributed to these improvements, notably the directive EEC 80-778 on the quality of drinking water, which set maximum contamination levels, directive EEC 91/414 on marketing authorisation for plant-protection products, reinforcing the toxicological and ecotoxicological criteria for approval of new substances and programming the re-evaluation of older substances, and more recently the Water framework directive (2000/60/EC). The latter directive, adopted in the year 2000, requires that Member States achieve by 2015 good chemical and ecological status of surface waters and good chemical status of groundwater. Finally, the framework directive 128/EC (21 October 2009) established a framework for EU action in view of achieving sustainable use of pesticides. In France, the directive resulted in the launch of the Ecophyto plan developed during the Grenelle environmental meetings in 2008. The objective of the plan is to progressively reduce the use of plant-protection products in both agricultural and non-agricultural areas (see the pages concerning the plan at http://agriculture.gouv.fr/ and http://www.ecophytozna-pro.fr/).

The decree dated 12 September 2006 on the marketing and use of the plant-protection products listed in article L.253-1 of the Rural code rural stipulates the code of conduct governing the use of the products (http://www.ecophytozna-pro.fr/data/arrete_du_12_09_06_7.pdf). In particular, it makes mandatory pesticide-free zones at least five metres wide along or around all water resources (rivers, lakes, ditches and all permanent or seasonal resources shown as points, lines and dotted lines on the 1:25 000 scale maps published by the French National geographic institute (IGN). No pesticides may be applied directly in a pesticide-free zone. The width of the zone can vary from 5 to 100 metres, depending of the water resource and the type of product. The list of water resources protected by the decree may be modified by prefectoral order to take into account any special local conditions. The reasons for the order must be explicit (see for example the prefectoral orders for the Deux-Sèvres, Loire-Atlantique, Maine-et-Loire and Vendée departments, with explanatory documents that may be downloaded from http://www.sevre-nantaise.com/espace-publications/).

Management techniques using herbicides are still very common in many countries, including the United States and the U.K., for example. In the U.K., glyphosate is used to eliminate water primrose from the few sites where it has become established, even if *"repeated applications over many years are required to eliminate the plant. Tiny rhizome fragments can survive the treatment and form new plants that are easily overseen in the field"* (Renals, 2014).

It should be noted that these uses of herbicides generally do not attain the objective of eliminating the targeted plants often presented by the advocates of this technique and that their effectiveness is in fact limited to one or two years. In addition to their toxicity, these products are not selective, i.e. they completely clear the treated zone, thus making them a method that must be used "with the utmost caution" (Dutartre, 2002).

Necessary precautions

The objective of work on invasive plants should be to eliminate them (in the rare cases that is possible) or to control them (in the vast majority of cases) by taking the necessary precautions to make sure that interventions do not become an indirect cause of additional dispersal of the species. Among the potential problems inherent in many alien species, the capacity of small cuttings (fragments of stalks or rhizomes just a few centimetres long) to produce new plants is probably the issue to which environmental managers should pay the most attention.

This capacity has now been extensively assessed for hydrophytes such as the Hydrocharitaceae (tape grasses), amphibious species such as water primrose and species growing on banks along water such as the Asian knotweeds. That is why it is very important that the methods employed fragment the extracted plants as little as possible, or if fragments are produced, that additional measures be taken during the work to collect as many fragments as possible before they can disperse. Nets are often used to retain hydrophytic or amphibious species within the intervention zone (upstream and downstream in a river or ditch, the work perimeter in a lake) (Haury *et al.*, 2010), however the nets must be frequently cleaned. In certain special cases, for example in sections of a ditch, temporary cofferdams may be used to limit dispersal during the intervention.

In addition to the above techniques, it is now acknowledged that manual collection of any fragments remaining on site following the mechanised intervention is an indispensable step that improves both the quality of the work and its effectiveness over time. Collection of fragments by hand or using a dip net, called “skimming” in the book by Haury *et al.* (2010), is a way to gather fragments of all sizes and in places that are difficult to access. This technique is particularly effective for amphibious plants such as water primrose.

If knotweed is temporarily stored prior to transportation for its elimination (e.g. by burning), care must be taken to ensure that the plants do not touch the ground to avoid any risks of regrowth on the site. It is advised to lay tarps or to create a thick mat of branches from other species on which the knotweed can be laid to avoid any contact with the ground. Another possibility is a non-woven geotextile fabric that is not as heavy as a tarp and is not waterproof, thus allowing the cut plants to dry more rapidly (Reygrobellet, personal pub.). It is now proven that many knotweed stands can produce viable seeds, which means it is better to intervene before they flower (Haury *et al.*, 2010), thus reducing the dispersal of the species and possibly limiting the development of fertile hybrids (*Fallopia x bohemica*).

The site and equipment (machines, hand tools, equipment used by workers) must be cleaned at the end of an intervention to avoid the accidental dispersal of stalk fragments and of rhizomes. Particular care must be given to amphibious species and species growing on banks that can resist drying. Many introductions of water primrose and of Asian knotweed are caused by fragments transported by machines that were not cleaned (Haury *et al.*, 2010). Cleaning equipment (in particular high-pressure cleaners) should be a basic on-site component for companies or teams conducting interventions to ensure that cleaning effectively takes place before machines leave the site, thus limiting the risks of propagule dispersal.

Grouping of plants and their transportation away from the site to a temporary storage place before being definitively recycled also requires extensive precautions to reduce to a minimum the fragments left on site or escaping during the transport (see Figure 82). For example, a tarp can be laid on the bank where the barge lands to unload the extracted plants onto a trailer or truck. Any plants falling to the ground can be easily recovered and shipped following the cleaning of the site (see the management project in volume 2, page 70). Temporary storage on a bank, even on a tarp, involves serious risks of dispersal. The vehicles used for transportation must be selected using the same criteria, i.e. to avoid any dispersal of plants.

Finally, certain invasive plants produce seeds that represent a further means of dispersal, in addition to stalk fragments and rhizomes. Specific examples are water primrose among the amphibious species and groundsel bushes among those growing on banks. The size of seeds and the ease of dispersal by water and wind makes it virtually impossible to control them. The only solution is to intervene, where possible, prior to the development of the seeds (e.g. by cutting groundsel bushes before they flower) and to monitor sites from which invasive plants have been removed in order to react rapidly if new plants appear.

Figure 82

© Hélène Gervais, CEN Centre

Safe unloading of knotweed on a tarp.

Panorama of management techniques for animal species

The various methods, both direct and indirect, of controlling invasive alien animal species are listed in Table 9, page 182.

Direct control of animal populations

The main methods used to manage invasive alien animal species consist of limiting population numbers. An array of techniques are used, most of which are highly regulated and require authorisations.

■ Trapping

This technique is used to remove individuals and thus limit population numbers. Regulations governing the trapping of animals have undergone major modifications since the 1980s. Certain types of traps are totally prohibited (e.g. steel-jaw traps and firearm traps), others are regulated. The list of animals considered harmful and that may be trapped has been reviewed yearly since 2012 and is published in a ministerial decree. The types of traps are grouped in categories and those provoking immediate death of the animal must be approved. Trappers operating in the natural environment must have received an authorisation (granted following a mandatory training course), except for those persons trapping coypus and muskrats using cage traps.

The latter is the most commonly used type of trap for invasive rodents and American mink (see Figure 83). This category-1 trap is a non-lethal, selective device has limited impact on non-targeted, native species such as beaver, otter and the European polecat, etc. Trappers are required to check their traps daily. The conibear trap is used to kill invasive rodents. It is a category-2 trap and its use is prohibited in areas where beaver, otter and European mink are known to live. Consequently, it is rarely used in aquatic environments.

Figure 83

© Anaïs Borrell

An American mink captured in a cage trap.

The use of bow nets (see Figure 84) to capture invasive alien species of amphibians, reptiles, fish and invertebrates is also regulated. On public property, the use of bow nets is regulated on the departmental level (number and types of bow nets depending on the river fish category, recreational or professional use, etc.). In general, if the intention is to manage an invasive alien species, a prefectoral order is required.

The partial immersion of bow nets can limit their impact on native, air-breathing species because the animals can remain on the surface and not drown. Regular checks on bow nets are mandatory. However, partial immersion does not limit the impact on non-targeted water-breathing animals, e.g. fish or amphibian larvae. For this reason, in the framework of management work on red swamp crayfish in the Brière marshes, highly selective traps were designed precisely to limit the capture of sensitive species such as eels (Paillisson et al., 2013).

Figure 84

© Guillaume Koch

Partially immersed bow-net trap set to capture African clawed frogs.

A number of other selective traps have been developed or adapted for the management of invasive alien animal species. An example is the “Fresquet cage” designed to trap red-eared slider turtles (see the management project in volume 2, page 175). The trap is cage made of wire grid with, at the bottom, an entryway in the form of a tunnel (see Figure 85). Contrary to a bow net, it is placed on the bottom of the pond or lake to catch turtles that move and hunt along the bottom. The top of the cage always remains above the water surface to allow the captured animals to breathe (Cases, personal pub., 2014).

Figure 85

© SYMBO

“Fresquet cage” used to capture red-eared slider turtles.

Nets can also be used to catch fish as well as birds during their postnuptial moulting when they cannot fly. Their use in aquatic environments is governed by the applicable departmental regulations on fishing techniques other than angling. For birds, use of nets is subject to hunting regulations. In all cases, if the intention is to manage an invasive alien species, a prefectoral order is required. Great skill is required to net birds during the moulting period, however a large number of birds can be captured in a limited amount of time. This technique is difficult to use in urban settings and on sites where the general public is present in number, and it often results in misunderstandings if no prior effort was made to inform the public on the purpose of the management work.

Concerning the use of gillnets to capture invasive fish species, it should be noted that their effectiveness depends greatly on the targeted species. For example, they work poorly for the Wels catfish (Silurus glanis), due to its size and morphology. They also lack selectivity and are often a lethal technique for many species.

Finally, it is important to note that trapping is not an effective means to ensure control of invasive populations or to limit their impact on the environment. Further, side effects such as an increase in recruitment have been observed (the case for alien crayfish, Poulet, 2014).

■ Shooting

The elimination of IAS animals takes place during interventions conducted or managed by the responsible oversight agency (ONCFS, wolf-hunting officers, etc.). A shooting campaign requires a prefectoral order complying with article L411-3 of the Environmental code. Interventions to limit certain populations must take into account all safety measures and avoid impacts of the shooting campaign on other species. The most commonly used weapons are smooth-bore guns (12-gauge shotgun) and various calibre rifles (222 REM, 22 Long rifle, 17 HMR and 22 Hornet) (see Figure 86). These weapons may be equipped with scopes and moderators. Air rifles are also used to shoot American bullfrogs. it is now mandatory to use steel shot and not lead shot when shooting takes place in aquatic environments (ministerial circular dated 4 April 2006).

Figure 86

© JF. Maillard

Shooting campaign for ruddy ducks. Note that shooting on water or ice is prohibited due to ricochet risks. These interventions are strictly regulated and numerous precautions must be taken to avoid any risk of accident for the shooter and for the accompanying personnel.

■ Hunting and fishing

Hunting is a means to reduce the numbers of certain IAS animals. However, it is limited to the authorised hunting species, the annual hunting season and a valid hunting license is required. In 2014, six invasive alien vertebrates were listed as game and pest species, i.e. they could be hunted. The six were coypus, muskrats, American mink, northern raccoons, raccoon dogs and Canada goose. Because of potential confusion with European mink, a protected species, it is prohibited to shoot American mink in the eleven French departments where the species is present.

To the best of our knowledge, angling was never an effective means to manage fish, crustaceans or "frogs" designated as invasive and it could even worsen situations due to the dissemination of the captured animals. That being said, angling of non-native species of fish, crustaceans and frogs is authorised for people who have a valid fishing license, are members of a certified association for fishing and protection of aquatic environments (AAPPMA) and respect the season dates (if applicable) and the legal capture sizes. It should be noted that legally, some species may be considered "non-listed" or even "likely to provoke biological imbalances". In which case, it is prohibited to release live animals to the natural environment or to use them as bait. The transport of living red swamp crayfish requires a written permit (see Chapter 2 for more details on regulations).

Some of these activities may cause more or less severe disturbances for species not targeted by the intervention, which may in turn cause tensions with the people hunting or fishing those species. This aspect must be taken into account when planning interventions.

■ Sterilisation

Sterilisation of bird eggs and the gathering of eggs (spawn) are means to limit the populations of invasive alien animals. Sterilisation is more discreet than shooting or trapping, which explains why it is frequently used in areas where the public is present (see Figure 87). Gathering of amphibian spawn is also used for invasive species such as the American bullfrog (see Figure 88). These techniques require a great amount of time in order to thoroughly cover the site and should be used in conjunction with other methods (shooting, trapping) to ensure maximum effectiveness (see the management project in volume 2, page 201). Sterilisation of bird eggs is regulated by prefectoral orders.

The sterilisation of grown animals is a technique not yet widely used. In continental France, it has been tested on signal crayfish (Duperray, 2010; Basilico et al., 2013). Large males are sterilised and released prior to the reproduction period in order to progressively reduce reproduction rates (see the management project in volume 2, page 139).

Figure 87

© Daniel Serre

Sterilisation of Canada goose eggs.

Figure 88

© SEBB

Gathering American bullfrog spawn.

■ Chemical control

Chemical controls consisting of poisoned bait have been widely used, particularly for invasive rodents. These methods are inexpensive, but can impact non-targeted species and provoke secondary poisonings. They were regulated in 2007. The use of Bromadiolone to limit coypu and muskrat populations was prohibited in 2007 (decree dated 6 April 2007). Rotenone, an organic substance produced naturally by certain tropical plants that is toxic for many cold-blooded animal species, has been used to control invasive alien fish and amphibians. For topmouth gudgeon, following removal of the native fish species from ponds, Rotenone was applied and the native fish were returned. The result was the elimination of the invasive species and increased development of the native species (Britton et al., 2010). However, the product can prove lethal for other species when used in the natural environment, which explains why Rotenone was finally prohibited on 30 April 2011 (notification by the Agriculture and fisheries ministry dated 21 April 2011). Other biocides are also available and are effective against species such as alien crayfish (Poulet, 2014), but the regulations governing their use are complex and subject to a number of European directives and regulations. Before they may be used, special authorisations from the Ecology ministry are required.

Indirect control of animal populations

■ Draining and emptying of ponds and lakes

This method is used for certain invertebrates, fish and amphibians. Prior to draining and emptying, barriers and traps must be set up around the entire water body to make sure the targeted species cannot leave the area and disperse into the nearby environment (see Figure 89). The traps must be checked daily in order to free any native species that might have been captured. Filtering systems must also be operational to avoid the escape of the targeted species. Any remaining animals in puddles of water can be fished or eliminated using lime. If the water body is emptied several consecutive years, the success of the management operation is virtually guaranteed. It should be noted that emptying of water bodies requires an authorisation (see the management project in volume 2, page 158).

Figure 89

Barrier and traps set up for American bullfrogs in the Sologne area.

This method could be tested on molluscs. The observations by Leuven *et al.* (2014) on a section of the Nederrijn River in the Netherlands during a five-day low-flow period in the winter of 2012 revealed a significant reduction in the populations of zebra mussels (*Dreissena polymorpha*) and quagga mussels (*Dreissena rostriformis bugensis*). Over the short period, daily air temperatures ranged from -3.6°C to -7.2°C and daily water temperatures measured 10 centimetres below the surface ranged from 0 to 1.8°C. The densities of the two species dropped to almost zero, then started increasing slowly after six months before returning more or less to the previous densities 18 months after the low-flow period. The authors concluded that changes in water levels under severe winter conditions could serve as a technique to temporarily reduce populations of invasive molluscs. Mollusc populations could take two to three years to return to their former status and the authors recommend work to assess the long-term effects of repetitive interventions on this type of living community. The difficulties of this technique should be noted however, in that it can be used only in environments where the water level can be significantly modified and on the condition that very low temperatures occur at the time of the intervention.

■ Modifications of the environment

Another way to limit the disturbances caused by invasive alien animals is to restore and conserve habitats. It is precisely modifications to habitats that often lead to the regression of native species and the installation of alien species. One means to reduce the likelihood of ecosystem invasions is to avoid creating favourable conditions for the installation and development of IASs. Management of natural areas must adapt to these conditions and take into account the risks of biological invasions, including in urbanised environments. For example, to avoid the installation of Canada and Egyptian geese, techniques such as the creation of planted zones along banks, strips planted with flowers to break up meadows and grassy plots, and the elimination of artificial islands are all much less expensive than putting up fences. However, these management techniques are rarely used in France because they are not well accepted by the public.

Table 9 *Table listing the various control methods for populations of invasive animal species (X = can be used, NA = not applicable, ND = no data). Note that the methods listed as usable are not necessarily effective in all situations.*

Taxonomic group	Trapping	Shooting	Hunting / fishing	Sterilisation	Chemical control	Draining / emptying	Biological control	Modified environment
Invertebrates (crayfish)	X	NA	X	X (male reproducers)	X	X	ND	ND
Fish	X	NA	X	ND	X	X	ND	ND
Amphibians	X	X	NA	X (collect eggs)	X	X	ND	ND
Reptiles	X	X	NA	X (collect eggs)	ND	ND	ND	ND
Birds	NA	X	X	X (eggs)	ND	NA	NA	X
Mammals	X	X	X	ND	X	NA	NA	ND

Exclusion of animal populations

Exclusion of animal populations simply means blocking their establishment on certain sites where they can cause disturbances or damage. These techniques are used in particular when crops have been damaged. They can also be used in complex situations where direct population-control measures are difficult to implement, e.g. in urban areas where the public is present. They serve to reduce the disturbances to a tolerable level, but have no effect on population numbers. They can, however, by used in conjunction with other measures to limit numbers. These techniques are not selective, meaning they can also prohibit the access of non-targeted species.

■ Physical exclusion

Physical exclusion of IASs consists of installing physical barriers and fences. These systems must correspond to the site conditions and the targeted species. Their height, type, configuration, mesh sizes, etc. must be correctly selected and installed to ensure their effectiveness. Currently, these techniques are used primarily for invasive alien birds and rodents (see Figure 90).

Figure 90

© Parcs Québec

Net set up to avoid the presence of Canada geese on a beach in Québec.

However, they are also effective in slowing and even stopping the progress of alien crayfish in colonising upstream sections of certain rivers. Unfortunately, this solution blocks the upstream migration of many fish species and should be considered only in very specific cases where important crayfish issues are involved such as the presence of native crayfish upstream or the existence of a habitat thought to be favourable for their re-introduction. Finally, this solution may not be used in rivers falling under article L214-17 of the Environmental code (Poulet, 2014).

■ Repulsion

Repulsion consists of inducing a behavioural change in the targeted species and making it move away from sites where disturbances have occurred. This short-term method is used primarily against birds. Repulsion may be visual (balloons and kites in the form of birds of prey, scarecrows, flags, barricade tape) or consist of noise (noise makers).

Table 10 sums up the advantages and limits of the main techniques used to control invasive animals.

Table 10 *Advantages and limits of the main techniques used to control invasive animals. Adapted from Soubeyran, 2010, according to Courchamp* et al.*, 2003.*

Control method	Advantages	Limits	Regulations
Trapping	Effective in accessible areas. Selective (category-1 traps).	Often depends on networks of voluntary trappers. Requires a large amount of equipment. Traps can be stolen or damaged. Traps must be checked daily. Trappers must be trained to recognise non-targeted species. Significant trapping skill is required. Special bait must be used. Ethical problems may arise. Selectivity can vary depending on the type of trap. Limited effectiveness for exclusively aquatic species in open terrain (rivers, large lakes, canal networks, etc.). Possible side effects, e.g. stimulated population.	Regulations on pests. Authorisations and certification of trappers.
Shooting	Highly effective and selective. Ethical method.	Access to sites required (private property). Mandatory training of shooters. Need to inform and educate the public. Not possible in all situations (e.g. urban areas or protected sites). Strict safety rules.	Prefectoral authorisation stipulating the time, site, techniques employed and authorised persons.
Hunting / fishing	Done by holders of hunting licenses and fishing permits. Inexpensive. Possible on private property.	Poor results in terms of limiting populations without sufficient reason to target specific species and establishment of a register. May result in population dispersal. Hunters/anglers must be trained to recognise species.	Regulations on hunting, fishing and pests.
Sterilisation	Acceptable method for the general public and possible under difficult conditions. Low technical level.	Searching for eggs and spawn is time consuming. Interventions must be repeated over several consecutive years and include other management techniques. For certain species, a large number of sterile animals must be released to be effective.	Prefectoral authorisations.
Chemical control	Inexpensive and effective. Easy solution.	Non-selective. Requires special authorisation. Need to inform and educate the public.	Mandatory ministerial and/or prefectoral authorisation.
Draining / emptying	Respects the environment and is effective. Low costs.	Requires authorisations from owners of private property. Poorly accepted by pond/lake users. Effective if left dry for several years. Barriers, traps and filter systems must be installed to avoid escapes.	For lakes larger than 0.1 hectare or created by a dam, the decree dated 27 August 1999 applies.
Biological control	Can be implemented in all target zones (e.g. no difficulty in accessing remote areas). Self-sustaining results over the long term. Fewer risks for the environment (no use of biocides or of non-selective techniques). Long-term costs lower than for repeated, standard, management techniques.	Duration and cost of the preliminary research programme to identify, verify and test the potential agents. Time required by the agent, following release, to disperse and provoke the desired effects among the target population. Uncertainty concerning the degree of effects on target population caused by the control agent. Unforeseen impacts caused by the control agent on non-targeted, native species or communities. The biological-control mechanism can reduce densities, but not eliminate the target species.	Regulations on the introduction of biological-control agents (Agriculture ministry).
Modified environment	Preventive and curative approach. Respects the environment. Effective over the long term..	Must be done before developing the site. Poorly accepted by the public.	Regulations depend on the type of site (natural environment, public or private property).
Physical exclusion	Applicable in areas where the public is present and where killing is not possible. Inexpensive (if exclusion systems already exist). Durable over time.	Expensive and complex to set up if exclusion systems do not already exist, require maintenance. Also excludes non-targeted species.	For rivers, check the river classification (EC L214-17).
Repulsion	Applicable in areas where the public is present and where killing is not possible.	Short term only. Can trouble non-targeted species.	No particular regulations.

Biological control of invasive alien species in aquatic environments

This section was drawn and adapted from the second News Bulletin of the Biological invasions in aquatic environments group (see http://www.gt-ibma.eu/activites-du-gt-ibma/lettre-dinformation/lesdossiers-de-la-lettre-dinformation/).

In agriculture, biological control is a technique used to combat a pest or weeds by bringing into play natural organisms that adversely affect the pest or weed, e.g. plant-eating insects, parasitoids, predators and pathogens (viruses, bacteria, fungi, etc.). Following significant developments in agriculture, this technique used to eliminate or regulate pests impacting human activities was expanded to include IASs colonising natural environments. Generally speaking, biological control can be defined as the use of "a living organism to regulate species seen as pests" (Beisel and Lévêque, 2010).

The ecological and economic damage caused by the proliferation of IASs has now been somewhat better assessed, as have the costs of management work intended to repair the damage. The control techniques commonly used in the past (mechanised techniques, plant-protection products, etc.) are expensive, often difficult to implement, not always effective and in some cases they can have negative impacts on the environment. Given current efforts to reduce management costs and improve results, the issue of biological control frequently arises during debates. The method would appear ideal in that it is apparently inexpensive, easy to implement, applicable over large areas and without adverse effects for the environment. But what do we actually know about it? What lessons can be drawn from past experience and what improvements have been made since?

The history of biological control in aquatic environments

Research in this field goes back over a century and even though the example from South Africa presented in the IBMA document addressed only terrestrial plants up until the 1970s, it illustrates the work accomplished and the approaches of that time.

Starting soon after 1900, questions arose concerning the need to study how an invasive species developed in the countries where it was native, whether it was pervasive in those countries, whether natural enemies kept it in check and whether it was possible to import those enemies from the countries in question. A further issue had to do with whether all plants imported to areas where the natural enemies did not exist became pests.

Toward the end of the 1970s, the work in South Africa on aquatic plants addressed a majority of the most troublesome species in the tropical areas of the world, namely water hyacinth (*Eichhornia crassipes*), the topic of the initial work, followed by giant salvinia (*Salvinia molesta*) and water cabbage (*Pistia stratiotes*) at the end of the 1980s, and more recently by parrot-feather watermilfoil (*Myriophyllum aquaticum*) and water fern (*Azolla filliculoides*) (Moran *et al.* 2013).

A great deal of research work was undertaken in the 1970s and in drafting a review of biological control issues for aquatic pests, Schuytema (1977) consulted over 500 documents and discussed all the organisms available for biological control. He also included the possibilities of biomanipulation consisting of modifications to the environmental conditions of species, e.g. the reduction or total deprivation of light, changes in the nutrient content of water, etc., and of interspecific relations, e.g. selecting fish species to control phytoplankton or plants capable of competing with invasive plants. In his report, he noted that a great deal of the listed research consisted of lab work and that there were *"relatively few well documented instances of large-scale control projects"*.

His analysis showed that grazing and predation were the most commonly used techniques, particularly the control of macrophytes by fish. Many of the plant-eating animals and predators do not attack only the targeted species and therefore represent a risk for other organisms in the ecosystem. For this reason, great care must be taken in using them. Single-target insects can be much more effective. According to the review, pathogens were already seen as potentially effective control organisms, but had not yet been used in large-scale control projects. Similarly, biomanipulation was seen by many as a promising set of management techniques.

The review dealt with aquatic plants in particular, including water hyacinth (*Eichhornia crassipes*, see Figure 91). For that species, the review mentioned that *Neochetina* coleoptera were then undergoing an evaluation and were thought to be promising. Since then, these coleoptera (*Neochetina eichhorniae* species) have been extensively used. Beisel and Lévêque (2010) noted that among the one hundred insect species tested for water hyacinth, approximately one dozen "turned out to be capable of inflicting major damage to leaves" and that weevils are used in the United States, Africa and China.

Figure 91

© A.Dutartre, Irstea

*Water hyacinth (*Eichhornia crassipes*).*

Schuytema also mentioned a fungal pathogen (*Uredo eicchorniae*), that was then being studied in Argentina to control water hyacinth. Since that time, at least half a dozen fungal species have been studied and at least one, *Cercospora rodmanii*, is thought to have been successfully tested on water hyacinth.

Potential for Europe?

Since the beginning of these research efforts, worldwide over 7 000 introductions of approximately 2 700 biological-control agents have taken place, primarily in South Africa, Australian, New Zealand and North America (Pratt et al., 2013). In Europe, to date only one biological-control agent has been introduced to control an invasive alien plant, namely the psyllid *Aphalara itadori* (see Figure 92), that was released in the U.K. in 2010 to control Japanese knotweed (*Reynoutria japonica*) (Shaw et al., 2011).

Figure 92


© R. Shaw

The psyllid Aphalara itadori*, a potential biological-control agent for Japanese knotweed.*

In the past, several cases of failed biological control (a recent example being the coccinellid beetle, aka Asian ladybugs) drew significant attention and may be the reason for the reticence in European countries to use biological-control agents against invasive species. That being said, biological control is already used in the overseas territories, notably on Reunion Island (against wild raspberry, *Rubus alceifolius*) and French Polynesia (against miconia), where the results are positive for the time being (Le Bourgeois et al., 2004; Meyer et al., 2007).

Europe is slowly taking an interest in the subject, in order to reduce costs and diversify the methods used to manage invasive plants, but it is limited by the Water framework directive which requires that good ecological status be achieved by 2015, meaning that IAS management must be large scale, but without using phytocide products which are increasingly prohibited in aquatic environments.

In their 2006 review of the potential of biological control for invasive aquatic plants in Europe, André Gassmann and his colleagues at the Centre for Agricultural Bioscience International (CABI) (Gassmann et al., 2006) noted that floating and emergent species such as water fern (*Azolla filliculoides*), least duckweed (*Lemna minuta*), water primrose (*Ludwigia* spp.), water pennywort (*Hydrocotyle ranunculoides*) and New Zealand pigmyweed (*Crassula helmsii*) were "good targets" for standard biological control using host-specific *Chrysomelidae* and *Curculionidae* coleoptera (see Figure 93). They also noted the potential of fungal pathogens against floating and submergent species, and that the use of native pathogens (mycoherbicides) appeared promising.

Figure 93


©S. Reeder

The weevil Stenopelmus rufinasus*, a potential biological-control agent for water fern.*

In the U.K., Japanese knotweed was targeted for the development of a biological-control programme. Annual management costs of the species, known for its impact on biodiversity and river banks, have been estimated at 255 million euros. Standard management (mechanised and manual uprooting) is expensive and must be carried out over many years, yet remains relatively ineffective. The idea of developing biological control was then discussed and a research programme was launched by CABI and its partners in the year 2000 (Pratt et al., 2013).

During the first phase, the natural enemies of the species in Japan were identified and a number were selected for tests on knotweed in areas where it had been introduced. The tests highlighted the high effectiveness of two agents, of which one was the psyllid *Aphalara itadori*, a very host-specific insect. Three years of tests confirmed the specificity of psyllid consumption (90 other native plant were also tested). Following a survey of public opinion and after obtaining the necessary authorisation, the control agent was released in 2010 on a dozen sites in the U.K. The insects survived the winter, but the population numbers were too low to have any significant effect. Another 150 000 insects were released in 2013 and no impacts on native plants and invertebrates were noted. Research is now being conducted on the impact of a mycoherbicide (*Mycosphaerella polygoni-uspidati*), which may be used as an additional biological-control agent.

The results of this initial experiment are not yet available, but CABI has already drawn up a number of recommendations on how to run a biological-control programme (Shaw et al., 2011).

- Take care in selecting the target plant, notably in terms of its sensitivity to biological control, but also taking into account public opinion as well as the economic and political aspects.
- Use the existing legislation concerning plant health and protection, notably when analysing the risks of the biological-control agents and in order to obtain, in a completely legal manner, the authorisations to import, transport and release the agents to the environment.
- Draw up a list of plants on which the biological-control agent will be tested (safety procedure). This list should include economically significant plant species and take into account public opinion. The list should also be confirmed well in advance of the test phase.
- Prepare a monitoring plan before releasing the agent in order to detect any unforeseen impacts on the environment. This plan should be designed and funded for at least five years, cover several sites and include safety measures (insecticides and herbicides if native species are threatened).
- Provide ample information to the public, including clear messages on the objectives of a biological-control programme (a reduction in the numbers of the target species to below a tolerable threshold, but not total elimination) and on how the programme will be carried out, and answers to frequently asked questions, e.g. what will the insects eat once the knotweed has been consumed, what about the cases where biological control "failed" (cane toads in Australia, Asian ladybugs in Europe), etc.

This type of programme requires a very high research budget that, generally speaking, only national and international organisations can muster. Programmes often last over a decade, an example being the programme against Japanese knotweed. This time is required to run the tests to check the specificity of the control agent with respect to the living communities into which it will be introduced.

Box 25 presents the generally accepted steps in the procedure leading to a management decision concerning a species seen as sufficiently troublesome to justify the release of an effective, host-specific agent.

Box 25

The steps in a biological-control programme for an invasive alien plant

1. Launch of the biological-control programme (selection of the targeted invasive plant, analysis of any conflicting interests, bibliographical review of the targeted plant and of its natural enemies).
2. Research and monitoring of the introduction area (identification of any natural enemies for the targeted host, check that no local, effective control agent exists).
3. Work abroad in conjunction with the research organisations in the native region of the target species, research on and monitoring of any natural enemies, prioritisation of the species demonstrating high potential as a control agent, obtaining the necessary authorisations to monitor and export the agents.
4. Study the ecology of the target species and its natural enemies. Compare the ecology of the species in its native range and in the introduction area, study the climatic and ecological conditions required for the development of the biological-control agent.
5. Study the specificity of the biological-control agent. Assess in the lab and in the field the physical, chemical and nutritional factors that will determine the specificity of the control agent's consumption, run tests on a wide range of native species (the test plants).
6. Release the agent to the environment and monitor it. Once all the scientific studies have been conducted, draft the report file for the oversight authorities including the monitoring programme and an analysis of the risks.

Advantages and unknowns

Similar to any other management technique, biological control has a number of advantages over the other techniques as well as a number of inherent unknowns or risks (see Table 11). These unknowns or risks have to do with our insufficient knowledge on the species, both those to be controlled and those to be introduced, as well as on the ecological functioning of ecosystems, both before and after the introduction.

Table 11 *Advantages and unknowns of biological control. According to Shaw* et al.*, 2011.*

Advantages
■ Can be implemented in all target zones (e.g. no difficulty in accessing remote areas) ■ Self-sustaining results over the long term ■ Fewer risks for the environment (no use of biocides or of non-selective techniques) ■ Long-term costs lower than for repeated, standard, management techniques
Unknowns
■ Duration and cost of the preliminary research programme to identify, verify and test the potential agents ■ Time required by the agent, following release, to disperse and provoke the desired effects among the target population ■ Uncertainty concerning the degree of effects on the target population caused by the control agent ■ Unforeseen impacts caused by the control agent on non-targeted, native species or communities ■ Numerous administrative authorisations required (import, breeding and release of control agents) and difficult to obtain

Economic factors are an important aspect of the studies on biological control, representing much higher initial budgets than other techniques (roughly speaking, several years of research compared to the purchase of equipment), but subsequently lower costs because the agent continues to produce an effect whereas equipment is a source of continuous costs. The fact that a degree of uncertainty remains concerning the later development of the management programme is not a sufficient reason to cancel the programme, but means that the programme should be monitored to keep an eye on its status and to gather knowledge on the species and ecosystems in question. A further element of uncertainty, in addition to all the others, lies in the increasingly perceptible effects of climate change.

If we accept the wider definition of "biological control" from Schuytema (1977), grazing is also one of the management techniques. For at least 20 years, extensive grazing has been a technique commonly implemented for emergent and amphibious plants in wetlands located on protected sites (nature reserves, hunting reserves, etc.), using either local breeds of animals suited to wetland conditions or imported species. That is why the silhouette and the large, upraised horns of Highland cattle, a rustic breed of cows from Scotland, are now well known to the visitors of many nature reserves in continental France where the animals consume most of the plants in those habitats.

Occasionally, cows or horses have been observed eating the water primrose that had colonised the grazed sites. In at least one case, a local breed of cows is thought to have eaten some of the water primrose along a lake, but that was not observed in other cases. In the Barthes de l'Adour area, horses were placed on a site heavily colonised by water primrose, but refused to eat the plants and had to be removed before they starved. The wide discrepancies between these observations and the absence of monitoring protocols means it is not possible to draw any conclusions concerning "extensive" management.

Unfortunately, experiments on "intensive" grazing, undertaken with monitoring protocols using herbivores targeting a specific plant species, did not produce any clear results. For example, a test conducted according to a precise protocol in the Barthes de l'Adour area, with buffaloes, animals with a reputation of being very effective herbivores, did not produce the desired results, i.e. the animals did not eat the water primrose. On the other hand, an experiment, using domestic goats (*Capra aegagrus hircus*) (see Figure 95) to eat knotweed, produced excellent results (see the management project in volume 2, page 94).

Figure 94

© CG 53

*An experiment using domestic goats (*Capra aegagrus hircus*) to browse knotweed in the Mayenne department.*

The use of sheep to control invasive, terrestrial plants, often in urban and periurban areas, is now increasingly mentioned in the media, including in North America where the animals and their consumption habits are presented as an alternative to herbicides (see for example http://www.beyondpesticides.org/dailynewsblog/?p=11473).

In addition to the issue of the monitoring protocol used to determine the effectiveness of this technique, one of the main difficulties lies in monitoring the introduced animals, particularly in terms of their health and the evolution of the population. It would be necessary to run the tests over long periods in order to fully judge the effectiveness of this technique, unfortunately this is not possible given that most experiments are relatively short. The need for regular monitoring is probably the main disadvantage of this technique because unforeseen events can occur, e.g. the death of animals (see the management project in volume 2, page 94).

The unforeseen events are occasionally very surprising. Certain aquatic birds, very common in continental France, are effective herbivores, e.g. swans, red-crested pochards (*Netta rufina*) and Aythya ducks (*Aythya* spp.). The joint assessment conducted by INRA and Cemagref in 1981 (Dutartre et al., 1981) resulted in a proposal to test ducks and swans as a means to control hydrophytes in a small lake that had been totally colonised by the plants. The lake, less than two hectares in size and located on the premises of a school where the birds could be regularly monitored by a competent person, appeared to be well suited to the test. The monitoring protocol stipulated the presence of areas where the birds could not enter to eat the plants. A dozen couples, including three couples of swans, were established on the lake. According to the monitoring results, the birds were effective (the criterion being no notable development of the hydrophytes) for the first two years, then the plants started developing again and subsequently the situation rapidly worsened (Dutartre and Dubois, 1986). The main cause of the failure was the instability of the bird population over time, due to the arrival of outside birds and in-breeding with mallard ducks in spite of the regular monitoring.

For a long time, grass carps (*Ctenopharyngodon idella* Val.), aka the white amur, were one of the plant-eating fish most commonly mentioned as a biological control for aquatic macrophytes, initially in tropical zones and then in temperate zones. They have been present in Europe for approximately 30 years. Their introduction in France is prohibited, however their story illustrates not only how human needs, perceptions and opinions can change over time, in step with events, but also the new knowledge gained and the difficulties in sharing information (see Box 26 and Figure 95).

Box 26

Herbivorous carps (grass carps)

The grass carp (*Ctenopharyngodon idella*)[10], also known as the white amur, is a plant-eating fish with an undeniable taste for aquatic plants and, if the fish has exhausted the aquatic resources, even for the leaves of plants growing along the banks that dip into the water, to the point that it has often been called a mowing fish. Though its capacity to consume plants is undeniable, the fish shows no real appetite at temperatures below 15°C, which means it is much less effective in cooler waters. The incomplete digestion of the consumed plant material means that the fish releases to the water significant quantities of organic matter and the degradation of this waste can create oxygenation problems in smaller, stagnant water bodies.

What is more, grass carps are picky about what they choose to eat. This led, some 20 years ago, to a study on the subject (Codhant and Dutartre, 1992) which showed that, at least in the lakes in the Landes department, the plants preferred by grass carps were not waterweed and water primrose, but rather native species such as watermilfoil and pondweeds, which was not the desired outcome! These food choices are obviously one of the limitations weighing on this plant-eating species because they can substantially hinder the introduction of the fish in environments where the native plant communities are ecologically important or, more generally speaking, in aquatic environments used for multiple purposes where the native communities often serve to protect the multiple uses.

*10. Not to be confused with silver carp (*Hypophthalmichthys mollitrix*) or bighead carp (*Aristichthys nobilis*), two species that feed preferably on zooplankton and phytoplankton.*

In their review of the ecological impacts of grass carps, Dibble and Kovalenko (2009) noted that in lakes and ponds (i.e. in the absence of reproduction), grass carps can degrade water quality. The stirring of sediment during feeding and the decomposition of its digestive waste produce an increase in the concentrations of nitrites, nitrates and phosphates, followed by a drop in dissolved oxygen and, often, by algal blooms. These changes may persist over the long term and even become irreversible. Adverse impacts were also noted for the communities of aquatic plants, macroinvertebrates and fish. Given the complexity of the interactions and the lack of study on the ecological mechanisms involved when grass carps are released in an ecosystem, it is very difficult to foresee the consequences (Dibble and Kovalenko, 2009). Consequently, caution is advised before introducing this species into environments where protected species are present.

Starting in the 1970s, various publications highlighted the plant-eating capacities of the species and the review by Schuytema (1977) did not neglect this aspect. One of the arguments used to promote the species was the fact that it was possible to control it, given that it could not reproduce in the new environments. The species requires the current conditions prevailing in Asian rivers, from where it came, in which its pelagic eggs can develop through their complete cycle until they become alevins. However, efforts to reproduce the fish under controlled conditions succeeded, which made it possible to produce the species commercially in Europe and North America.

As a result, this species could demonstrate its “mowing” capabilities in many ponds and lakes. Then, approximately a decade later, researchers in the United States started to wonder why the populations of certain fish species were falling in large lakes. They discovered that the massive introductions of grass carps had eliminated the plant beds and the corresponding fauna used by the other fish species for laying their eggs and/or as a source of food.

A further surprise arrived when natural reproduction of the species was observed in the Mississippi. It would appear that grass carp succeeded in adapting to the ecological conditions of at least one of the major rivers in North America, a feat previously considered impossible. In continental France, according to a study conducted by the University of Nancy, only adult fish have been observed or occasionally captured (approximately 20 per year) in rivers (Teletchea and Le Doré, 2011). This lack of reproduction in European rivers is still today an argument for the sale of this fish in France and numerous requests to market the fish have been made by fish farms. Currently, it is possible to introduce grass carps into the natural environment, but only in “closed” water bodies and with a prefectoral authorisation (decree dated 20 March 2013).

Figure 95

© USGS

Ctenopharyngodon idella.

Concerning invasive alien fauna, a few attempts have been made in continental France to introduce native predators, e.g. the introduction of eels to control red swamp crayfish in the Brière marshes (see the management project in volume 2, page 129), but these efforts remain relatively marginal. The available knowledge on the predation by carnivorous fish of invasive animals (crayfish, African clawed frogs, etc.) has raised doubts concerning the usefulness and the effectiveness of these introductions. The characteristics of the targeted prey (size, ease of consumption, etc.) and the presence of non-targeted, protected native prey such as amphibians make introductions in the natural environment a complex and risky undertaking.

Management of waste produced by interventions on invasive alien species

The regulations governing the management of waste produced by management interventions on IASs is presented in detail in Chapter 2.

One of the difficulties of management work that managers have systematically encountered since the first interventions on invasive species concerns the waste produced. What should be done with the plants and animals that are withdrawn from sites, occasionally in very large quantities?

Organic transformation of invasive alien plants

Given that a large number of interventions on invasive alien plants take place each year, the future of the resulting organic matter must be foreseen as an integral part of the management system. This aspect was long neglected and as a result no generally applicable solutions were developed, the waste was often simply deposited nearby or in a landfill. In a few cases, the plants were spread directly in fields where farmers first let them dry, then ploughed them under. 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).

A number of methods were extensively used, each with a set of disadvantages and consequences that were analysed in view of progressively selecting those methods comprising the least risks, short term and long term, for the environment. For example, burying the plants near aquatic environments and burning them after drying were two techniques used in an array of situations, but the difficulties involved (excavation work, destabilisation of soil, etc. for the first, safety concerns for the second) led to a progressive halt in their use.

Depositing the plants on the banks, either spread or in piles, was a much more widely used technique (see Figure 96). In general, this technique did not cause any particular problems when the waste was made up of submergent plants that dry quickly and do not regrow. Problems arose for amphibious and terrestrial plants that better resist drying and are capable in some cases of striking roots or of surviving at least one or two years on piles where the decomposition of the middle of the pile enables the plants on top to survive. For these reasons, implementation of this technique as well dropped significantly.

Figure 96

© A.Dutartre, Irstea

Parrot-feather watermilfoil deposited on the banks of the Léon Pond (Landes department).

In parallel, a number of studies addressed the agricultural and forestry use of water primrose waste and that of certain submergent species. For example, for several years water primrose has been spread under trees in the Landes or on dry agricultural land prior to being turned under near the Marais Poitevin marshes[11]. Large quantities of waterweed extracted from the Dordogne River have been mixed into the green waste of the Bergerac urban area and composted. The primary objective is to dispose of the waste produced by interventions in a manner avoiding the environmental risks involved in depositing the waste in natural areas. The reuse of the waste is a secondary issue that nonetheless facilitates the overall approach given its positive aspects.

Studies on management methods for invasive-plant waste continued over the years and dealt increasingly with the possibilities of reusing the large quantities of organic matter.

Though it may be tempting to see invasive plants as a form of ultimate waste (see Box 27) because they are difficult to treat given the risks of dispersal, years of experimental work have proven that the organic matter can be put to use. There is no reason to put this waste in a waste-storage centre or to send it to a household-waste incineration centre. Once they have been withdrawn from the natural environment, invasive plants are a form of green waste (see Box 27) that should be processed in a manner limiting the emission of greenhouse gasses and that returns the organic matter to the earth. According to the ministerial circular dated 10 January 2012 concerning on-site sorting of biowaste (see Box 27) by large producers (see the Grenelle 2 law), the two available techniques are composting and methanisation. They produce an organic fertiliser that can be directly used in soil, i.e. compost and digestate (methanisation residue), where the second can also be transformed into compost.

Depending on the type of plants, the quantities harvested and the site location, it may be worthwhile to ship the waste to an industrial processing plant (see Box 27) for processing under controlled conditions. The reason is that optimum composting conditions, notably in terms of the temperature, cannot be maintained in rudimentary systems. It should be noted, however, that not all processing plants offer the same technical conditions and they may be more or less equipped to process this type of waste. It is preferable to avoid any intermediate steps, e.g. depositing the waste in a dump, and to ship the waste directly to the processing plant, thus reducing any risks of dispersal and the costs.

11. A technical report is available at: http://www.pays-de-la-loire.developpementdurable.gouv.fr/IMG/pdf/Proposition_d_une_methode_de_recyclage_et_de_valorisation_agronomique_des_jussies_extraites_des_milieux_aquatiques_cle5d3578.pdf.

Definitions for the waste of invasive alien plants

■ According to article L541-1 in the Environmental code, "waste, whether or not the product of processing of other waste, is considered ultimate, in the sense provided for in this chapter, when it cannot be processed using the technical and economic means available at the time, notably by extracting the useful part or by reducing the danger and/or the polluting nature of the waste".

■ Green waste is organic waste produced by cutting grass, trimming hedges and bushes, cutting branches, clearing land and other similar activities (ministerial circular dated 18 November 2011 on prohibiting open-air burning).

■ Biowaste is any non-dangerous, biodegradable waste from gardens and parks, any non-dangerous kitchen waste or food, notably produced by households, restaurants, caterers and retail stores, as well as any other comparable waste produced by companies producing or transforming food.

■ Methanisation plants and composting units are professional facilities listed according to the Regulated installations for environmental protection (ICPE) criteria because they may be dangerous or create problems for the neighbours, for public health and safety, for agriculture, for nature, the environment and landscapes, for rational energy use or for special sites, monuments and the architectural heritage.

■ Hygienisation is a process employing physical and chemical means to reduce to a non-detectable level the presence of pathogenic micro-organisms in an environment (decree dated 8 January 1998 on the spreading of WWTP sludge, articles 12 and 16).

■ Industrial composting units

Composting principles

Contrary to anaerobic methanisation, composting is an aerobic process (with oxygen) for fermenting matter under controlled conditions. The organic matter may be similar in nature or a mix of different types of feedstock. In the latter case, one speaks of co-composting, i.e. a combination of biowaste and/or WWTP sludge, livestock effluents, waste from food industries, etc.

Composting produces CO_2, heat and an organic residue with a high humus content, namely compost. The high temperature during composting, greater than 55°C to 60°C over several consecutive days, results in hygienisation of the final product. In some cases the temperature can reach 80°C and care must be taken to avoid fires. The rise in temperature takes place during the fermentation when the most easily degradable matter decomposes. Fermentation is followed by a maturation phase that stabilises the compost and removes any phytotoxicity. The temperature then drops, producing the humic compounds.

Prior to processing, the waste can be shredded to facilitate its degrading and, depending on the types of waste, mixed. The waste is then arranged in large mounds. During fermentation, frequent mixing or managed aeration may be required to achieve accelerated processing (for slow composting, the mounds are mixed less often, generally once per month). Between the fermentation and maturation phases, or following the maturation phase, the compost can be sifted to sort the different grain sizes depending on the subsequent uses.

Depending on the process employed, complete composting may take from four to six months.

The different types of composting units

There are three types.

- Local governments, under their own or external management, can make use of the green waste and/or biowaste produced in their area (see Figure 97). They are often not interested in receiving waste from other areas because their facilities are generally sized precisely for the foreseeable quantities from their local area.
- Private companies see compost production as a profitable activity. The resulting product is sold to farmers, landscape professionals and the general public.
- Farmers often undertake co-composting, mixing green waste (from local governments, the public, companies or from their own farm) and their agricultural waste (livestock effluents, crop residues, etc.).

Figure 97

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Composting unit.

Methanisation plants

Methanisation principles

Methanisation is a natural, biological process that degrades organic matter due to the combined action of different anaerobic bacteria (bacteria that develop in the absence of oxygen). The feedstock is placed in a tank, the digester, then heated and mixed for a period of 40 to 60 days. The process produces the digestate, a fertiliser in the form of a viscous residue, and biogas, which is a renewable energy. The digestate may be spread in compliance with a spreading plan as is or following separation of the liquid and solid phases. The biogas is composed primarily of methane. It can be vaporised during cogeneration (combined production of heat and electricity) or injected, following purification, into gas-distribution networks.

The different methanisation techniques

There are different types of methanisation units. They are often created by a group of farmers wishing to make use of their livestock effluents and crop residues, in which case one speaks of farm methanisation units. Larger, collective methanisation units can receive waste from a wider area, in which case one speaks of territorial units. Whatever the type, they select a methanisation technique suited to their specific needs. There are two main methanisation techniques.

- The continuous, liquid process (currently the most common) involves complete mixing, where the digester receives a daily "ration" of organic matter in which dry matter must not exceed 18%.
- The discontinuous, dry process where at least four digesters mounted in parallel and operating simultaneously are supplied on different days (e.g. each digester every ten days). A particular feature of this dry process is that the digesters can receive larger waste in which the dry matter can extend well beyond 25%.

Depending on the process selected, more or less fresh plant waste can be used. In the liquid process, mixing of the plant waste with other waste in the daily ration is a means to create a degree of flexibility. It is essential, however, that the waste not have started to ferment during prior storage because the quantity of available methane is reduced.

The temperature produced during the process is a critical factor for IAS waste. If there is a risk of seeds being present in the IAS waste, it is necessary to exceed a temperature of 50°C to eliminate the germination capacity of water-primrose seeds and 60°C for knotweed. Certain facilities attempt to produce an optimum quantity of biogas in a limited amount of time. This type of process, called themophilic, can reach temperatures between 48°C and 60°C. However, the most common processes are mesophilic, i.e. they operate at a temperature of around 38°C, the ideal temperature for the bacteria.

The necessary conditions for effective methanisation

Woody debris cannot be used in the digester because the bacteria involved are incapable of degrading it. For this reason, it is preferable to use aquatic and amphibious plants that have low or no ligneous content. For the liquid methanisation process, it must be easy to pump the organic matter, i.e. it must have been previously shredded (10 cm maximum in size) to facilitate handling. In that not all methanisation units are equipped with shredders, it may be necessary to plan on shredding the waste before shipping it. Finally, similar to all other methanisation waste, it must not contain any inert material (sand, gravel, glass, plastic) that could alter the methanisation process by provoking sedimentation, phase separation or surface deposits. This explains why waste produced by mowing is preferable to that produced by uprooting.

The daily ration input into the digester is adjusted as a function of the methane-producing capacity of the various types of waste used (animal waste including liquid and dry manure, bird droppings, crop residues, food-industry waste, waste from local governments including biowaste, WWTP sludges and greases, cut grass) and it is possible to modify the ration if the arrival of the IAS waste can be planned a few weeks in advance. Unfortunately, the methane-producing capacity is not precisely known for all aquatic and amphibious invasive species of plants and this constitutes a limitation in efforts to adapt their treatment. Finally, methanisation units rarely dispose of the necessary space to store feedstock not included in their normal production schedules, consequently the timing of the arrival of invasive-plant waste for use in the digester must be carefully planned.

■ Selecting a process for the waste of invasive alien plants

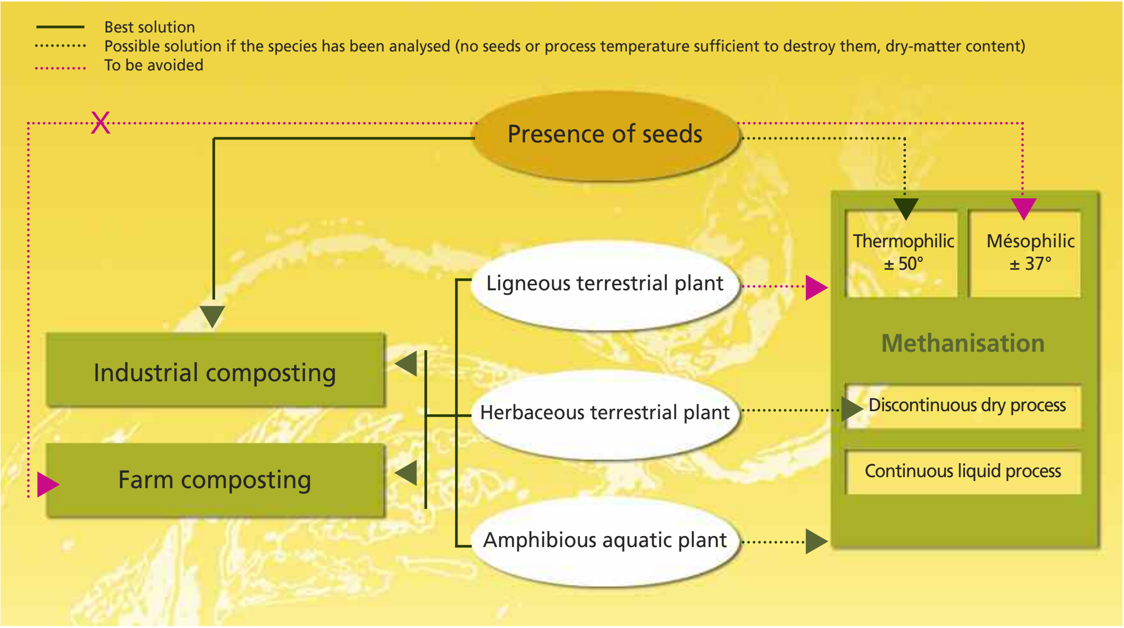
Figure 98 indicates how to select the best process (composting or methanisation) depending on the type of waste and the presence or absence of seeds. Not all composting centres and methanisation units accept invasive-plant waste and it is necessary to contact them first in order to discuss the processing possibilities.

■ The limits to these solutions

Increase in management costs

Processing invasive-plant waste to transform it into a useful product represents an additional cost that the manager must take into account. The first step of transporting the waste away from the intervention site is one part of the cost, whether it is carried out by the manager or by an outside supplier. Some processing centres may be in a position to organise the transport or to provide containers. The cost of processing depends on the pricing policy of each centre. Some do not require any payment, particularly methanisation units if the waste is known to have high methane-producing capacity, whereas others set their price per ton depending on the constraints weighing on the type of waste. In general, prices are set on a case-by-case basis.

Figure 98



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Selection of the best process depending on the type of waste and the presence or absence of seeds.

Shifting from waste to valuable product

Processing of organic waste in view of creating a product results in the production of compost or of digestate and biogas. Compost is covered by standards[12] and is a valued fertiliser that can be freely marketed. Digestate, on the other hand, is considered a waste product that may be spread only under highly regulated conditions. There are two ways to turn digestate into a product. The first is via a certification procedure (lasting 12 to 18 months and costing approximately 40 000 euros) to prove its agricultural value and its innocuity, the second is to use it in a composting centre to produce compost. The biogas can be used to produce electricity that is then sold to EDF (the national electricity company). In this manner, a valuable shift can be achieved when processing aims not only to eliminate the waste, but to create a marketable product.

Unfortunately, that may be difficult for two reasons. First of all, invasive plants are a seasonal source of waste. Consequently, the processing centres cannot count on this source for a regular supply. The processing centres may also be reticent to accept invasive plants if they are unfamiliar with how they react during composting or methanisation. Centres aiming to create a marketable product will not take the risk of reducing the performance level of their facilities by incorporating invasive plants.

■ Possible futures?

Invasive plants and their waste need to be managed and current research for solutions aims to develop processing techniques, either specifically for invasive-plant waste or by adapting it to the existing processes, while limiting the geographic scale of operations and transportation distances, thus reducing the cost of this indispensable, final phase of management for invasive plants.

Selection of the “short” recycling process (composting) must take into account all aspects of the local situation, i.e. the type of plant (including the germination capacity of seeds) and environment, the intervention objectives, the type of waste, the possibilities for transportation, storage and recycling, etc. Though it will not pay for an intervention, recycling may be a means to limit the overall cost of the work.

12. Standard NFU 44-051 for compost made of plant and animal waste and for urban compost made of household waste, or standard NFU 44-095 for compost made of WWTP sludge.

Management of animal waste

Management work for invasive alien animals can produce relatively large quantities of waste that must be eliminated. To provide a general idea, interventions against invasive rodents can produce over 50 tons of dead animals in certain departments in France (FEVILDEC, 2014). Health standards require that processing of this waste comply with certain regulations. European regulation 1069/2009 addresses the problem of animal waste. For wild animals drawn from the natural environment, which is the case for interventions on invasive species, the regulation applies only to animals suspected of being infected by a transmissible disease.

The Rural code (articles L226-1 to 226-9) lists the requirements for the management of "animal waste". It is necessary to distinguish between two categories of animal waste, the dead bodies of wild animals and animal by-products. Following an intervention on invasive alien animals, the dead bodies constitute the waste.

The bodies are the responsibility of the public rendering service. The rules stipulate that if the animals weigh less than 40 kilogrammes, they may be buried on site if the land owner agrees. If they weigh over 40 kg, they must be handled by the rendering service.

■ Rendering

Removal is free of charge if the animals weigh more than 40 kg and it is possible to freeze smaller animals in order to reach the 40 kg threshold. Town officials must make a request to the rendering service and set up a pick-up service for the bodies of wild animals as well as a temporary storage system. Departmental collection plans have been established by towns in order to organise and rationalise the collection of animal bodies as well as dispose of them in compliance with the applicable regulations. Approved equipment must be used, e.g. rendering containers, freezers, special plastic and paper bags, etc.). In some departments, towns have created certified collection points that are georeferenced to facilitate their use. It is necessary to contact each town for more information before launching a management intervention.

■ On-site burial

If the animal waste produced by the management work does not exceed 40 kg, the waste may be buried on site. A ditch should be dug in compliance with the following recommendations (Fédération des chasseurs du Languedoc-Roussillon (LR hunting federation), 2010):

- burial with the permission of the land owner;
- on terrain sloping less than 7% (4°);
- outside of wetlands, floodable areas and protection perimeters for drinking water;
- more than 100 metres from a river, lake or abstraction for household use;
- more than 200 m from homes;
- more than 50 m from a road, path or trail;
- more than 50 m from farm (livestock) buildings.

The waste must be covered with quicklime (equivalent to 10 to 25% of the waste weight or one-quarter of the waste volume). The ditch must be deep enough (1.3 metres deep for the largest bodies) and access for animals must be blocked (fence) if possible.

Assessment of interventions

Given the human, technical and financial investment of an intervention and the expected results, a two-pronged assessment is required.

- The first must determine the actual effectiveness of the intervention with respect to the planned results. It is generally based on relatively simple observations and data collection following the intervention. The environmental managers themselves can often conduct the assessment or provide the information using a pre-established protocol. Various methods have already been used to conduct this assessment which is essentially a comparison, before and after the intervention, of certain parameters selected according to the type of species and the environment.
- The second deals with the ecological impacts that may be directly attributed to the intervention. This assessment is much more complex because it requires specific monitoring procedures that the managers can generally not implement themselves. This monitoring, awarded to an external supplier such as a consulting firm or a research lab, fills out the first assessment and requires additional funding that may be difficult to obtain, which explains why these assessments are carried out relatively infrequently. This is probably one of the important aspects that must be improved in the coming years in order to more precisely determine the impacts and include them in the work to enhance IAS management. This would hopefully make it possible to reduce the damage to biodiversity caused by interventions. It would be a very positive step forward if this second assessment were progressively included in the planning for management interventions, this providing the information required to make decisions with a clear idea of the management issues and impacts.

Assessment of intervention effectiveness

If it is to serve as the basis to analyse interventions and their results, this assessment must include information on how the intervention was carried out, indicating at least the dates and the duration, the site, the type of environment, the equipment and methods used, and the number of people involved. The above information is required for all interventions, for all types of species.

However, other information on the specific species, fauna or flora, is also required. For plants, quantitative data alone are sufficient, for example the surface area or the linear distance treated, the relative abundance of the plant beds over the entire site or on specific geographically identified plots, the weight or the volume of the plants harvested on the site or from each plot. For animals, quantitative data, e.g. the number of animals of the targeted species removed from the site, their total weight, etc., and qualitative data, e.g. the reproductive stage of the animals, are required.

Various observation sheets and site-report sheets have been devised and used for approximately 15 years, an example being the site-report sheet used by the Loire-Bretagne work group (Haury et al., 2010) (the sheet is available on the www.gt-ibma.eu site). In addition to the general information on interventions listed above, the sheet includes information on the entity doing the work, the cost of the work and on the recycling technique and cost for the harvested plants.

Subsequent analysis of the sheets provides information on how interventions are conducted, on their effectiveness when two or more sheets are available for successive interventions on the same site, and information of use for the economic analyses that are now increasingly carried out, for example the analysis by Matrat *et al.* (2011) presented during the symposium titled "Invasive plants in the Pays de la Loire region".

(http://www.pays-de-la-loire.developpement-durable.gouv.fr/2011-colloque-regional-les-plantes-a1338.html).

Other, more specific sheets for a given territory or type of plant are also available. That is the case, for example, of a recent sheet prepared by the Vendée departmental council, the Vendée fishing federation and IISBN, that concerns a small number of terrestrial and "near-water" plants such as knotweed, groundsel bushes and common ragweed. The sheet, used to "report on the study and/or monitoring of invasive terrestrial plants", serves to collect information on the location and the type of environment in the wet marshes, a description of the colonisation and information on any management work done.

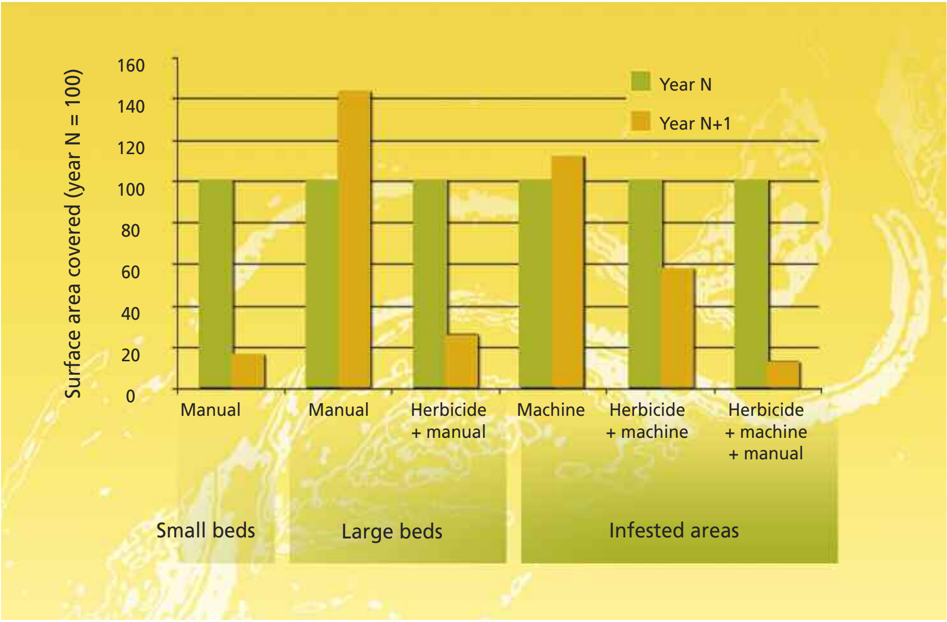
(http://www.sevre-niortaise.fr/accueil/des-thematiques-du-bassin-versant/les-plantes-exotiquesenvahissantes/).

For both plants and animals, the "before and after" comparison can be carried out either using each parameter separately or by creating indicators combining two or more parameters.

For plants, for example, the assessment can be carried out fairly easily by measuring any changes in the surface areas on a site or section of the site. The results of experiments carried out by IIBSN to devise the best management strategy for water primrose in the Marais Poitevin marshes (Pipet, 2007) were analysed in this manner.

The experiments tested, either alone or in combination, three intervention techniques that at that time appeared feasible for wet marshes, namely manual uprooting (manual), mechanised uprooting (machine) and the use of herbicides (herbicide). Effectiveness was assessed by calculating the surface area covered by water primrose the year following the work (year N+1), given that the surface area prior to the work was assigned a value of 100. Figure 99 shows that manual uprooting alone is sufficient for small plant beds, that for large beds it is first necessary to use a herbicide, and that for heavily infested areas, the three techniques must be successively used to obtain the best results, i.e. a value of approximately 15 for year N+1. The results of these experiments convinced the IIBSN to implement the combination of three techniques for at least as long as the herbicides remained effective against the emergent water-primrose leaves (Pipet and Dutartre, 2014).

Figure 99

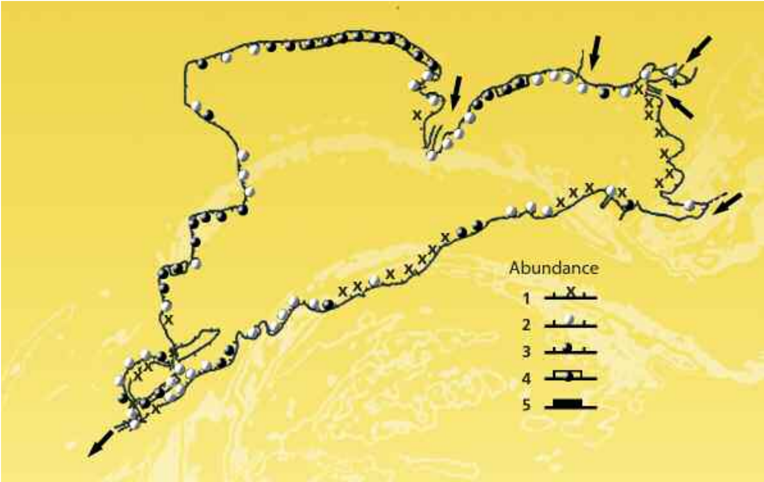


Effectiveness of management techniques measured as a function of surface areas covered by water primrose in the Marais Poitevin marshes. According to Pipet and Dutartre, 2014.

Another assessment possibility is to compare from one year to the next the relative abundance of the species in specific bank sectors of a river or lake. This was the method used in studies and monitoring of colonisation and for the management of invasive aquatic species in lakes and ponds in the Landes department (Dutartre et al., 1989). An assessment of plant abundance (ranging from 1 to 5, i.e. from "very rare" to "very abundant") was conducted in each sector, ranging from 50 to 100 metres long depending on the water body, but identical within a given water body. This system made it possible to identify the most heavily colonised sections and to observe the intervention results the following year, sector by sector.

The sectors were initially marked on a map (scale 1 : 10 000) and subsequently using a GPS. Comparisons of the degree of colonisation were thus possible over time, species by species and sector by sector. An example is provided in Figure 100, with a map showing the locations of large-flower water primrose in the Aureilhan Pond (Landes department).

Figure 100



Assessment of water-primrose abundance in lakes and ponds in the Landes department. Example of the Aureilhan Pond. According to Dutartre et al., *1989.*

For animals, the most easily accessible data generally consist of capture reports. The data may cover an entire territory (see the management project in volume 2, page 211) or provide more detailed information on the number of animals trapped or killed per segment of territory. Table 12 presents the number of coypus and muskrats trapped per kilometre of river in the Basse-Normandie region. The authors note that numbers greater than 15 to 20 per kilometre correspond to high densities ("infestations") (FDGDON Manche, 2007). Here again, comparisons from one year to the next provide an idea on the effectiveness of management work.

Table 12

The number of coypus and muskrats trapped per kilometre of river in the Basse-Normandie region. According to FDGDON Manche, 2007.

Department	River basin	Number of coypus per km	Number of muskrats per km
Orne	Upstream Orne	42	5
	Risle	20	11
	Huisne	11	1
	Varenne	14	8
Calvados	Downstream Orne	6	7
	Drives	10	17
	Touques	10	8
	Seuilles	3	15
	Aure	20	36
	Vire	10	14
Manche	Saire	10	12
	Divette	3	9
	Douve	14	7
	Taute	10	13
	Ay	6	9
	Sienne	29	NC
	Sée	3	7
	Séline	7	7

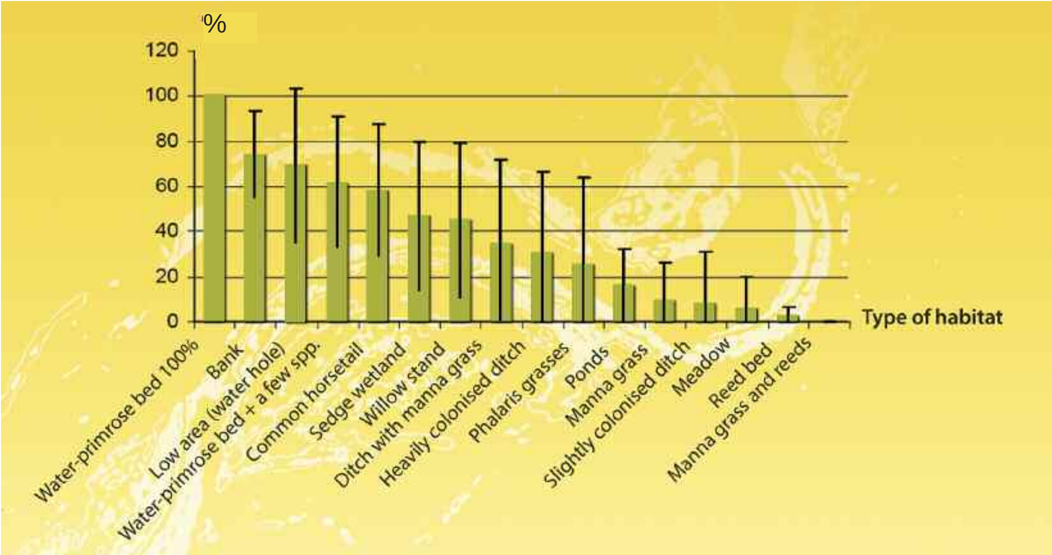
This multiplicity of assessment methods is not in itself a problem. The important aspect is the precision of the data-acquisition protocol and that the observations and/or measurements be systematically carried out in the same manner to enable comparisons.

Assessment of the ecological impacts

For plants, the most common monitoring technique is that of phytosociological surveys carried out before and after management work, thus making it possible to precisely monitor changes in native plant populations.

In the work by Haury *et al.* (2009) on the Gannedel marshes, densities of water primrose varied significantly between the different plant formations sampled, with high densities in low areas and certain ditches, and no plants in areas where common reeds (*Phragmites australis*) and great manna grass (*Glyceria maxima*) were prevalent. This variability in the densities of water primrose appeared to be related to densities of the other species, which were also highly variable, ranging from 0% (a bed comprising only water primrose) to total (or almost total) cover by large helophytes (see Figure 101). The average specific richness of native species in the quadrants was also highly variable, with up to a maximum of almost six species in the quadrants colonised by large helophytes.

Figure 101



Colonisation by water primrose as a function of the type of habitat in the Gannedel marshes. The figure shows the averages and standard deviations of plant cover in 20 quadrants (0.25 square metre) per habitat. According to Haury et al.*, 2009.*

Analysis of the cover by each species in the 324 quadrants studied, representing a total of 55 taxa, not including the water primrose, revealed the continued colonisation by the species primarily in ponds comprising lilies, its low penetration in areas with high levels of manna grass and phalaris grass (relatively tall and dense plant formations), and its adverse effect on species richness and cover by other macrophytes.

More general and consequently less precise assessments can also provide information on ecological processes modified by invasive species. Monitoring carried out on the Turc Pond (Landes department) before and after mechanical uprooting of very large beds of large-flower water primrose present in the shallow pond for over a decade provided information on the modifications caused by the removal and the return of the water primrose (Dutartre, 2004).

Only a small number of native hydrophytes, rigid hornwort (*Ceratophyllum demersum*), two species of pondweed (*Potamogeton crispus* and *P. lucens*) and the yellow water lily (*Nuphar lutea*), were present in the 8-hectare pond prior to the work. The work had a major impact on these species, but they rapidly recolonised the area. Other hydrophytes were observed in the following years, both native species such as large waternymph (*Najas major*) and Eurasian watermilfoil (*Myriophyllum spicatum*), and alien species such as curly waterweed (*Lagarosiphon major*).

Due to a lack of regular maintenance in the pond, water primrose recolonised in less than five years the riparian biotopes where the hydrophytes had appeared, pushing them back once again. The competition for light was easily won by the amphibious alien species. The regular manual maintenance that was subsequently carried out eliminated the water primrose from the pond and facilitated the strong development of the large waternymph.

For animals, the monitoring protocols to assess the ecological impacts following interventions depend on the invasive alien animal species in question and on the available information concerning the native plant and animal species that the alien species consumes or hunts. Counts or population-abundance measurements are occasionally carried out during the year following an intervention, however no standard protocols exist.

One of the difficulties in setting up monitoring of ecological impacts is often the lack of data on the site prior to the intervention and the lack of nearby control sites not yet colonised by the species that could serve for comparisons. In addition, as was shown by the examples mentioned, to our knowledge there are no studies addressing the impacts of IAS management on all the living communities, both fauna and flora. A fairly large amount of information is available on the invertebrate communities colonising aquatic macrophytes, including invasive species, but that information has not been consolidated. Some data may show, for example, the impact of the strong growth of certain invasive plants on the living communities, but no studies are available on the modifications caused in the same environment by the removal of the invasive species.

The difficulty in setting up long-term monitoring programmes, often a result of the lack of long-term funding, is another major handicap in conducting assessments. As the funding needs have risen in step with the increase in the need for management of invasive species, efforts have been made to set priorities for interventions targeting the most troublesome species. The main difficulty in setting priorities lies in selecting the criteria. It is relatively easy to assess the perceived disturbances and, over a fairly large area, to target the species most frequently causing them, however that cannot be the sole type of criterion.

The available knowledge on a species just arriving in an area and that is known to have demonstrated strong invasive capabilities in other parts of the world should result in that species being placed on the list of priorities for intervention, if possible taking into account the data on the potential management techniques and on the impacts of those management techniques. For example, the management techniques for New Zealand pigmyweed are manual uprooting (not always easy) and scraping/stripping of the topsoil or sediment colonised by the species, which also removes the seed banks and the invertebrates from the soil or sediment. Such adverse side effects should be a factor in this species being declared a priority in order to intervene as soon as possible, thus limiting the number of sites requiring work (see the management project in volume 2, page 47) and the corresponding impacts.

The launch of studies to enhance our knowledge on both the ecological impacts of IASs and the impacts caused by their management are indispensable in view of improving our collective capacity to handle the difficulties encountered while minimising the adverse side effects. A further component in this wide-ranging analysis should be the work already being done on assessing the ecosystem services of aquatic environments (Amigues et Chevassus-au-Louis, 2011).

Outlook for improved management of invasive alien species in aquatic environments

IAS management is necessarily based on knowledge and various scientific and technical fields that are all contributing factors to human activities and discussions.

In this context, any possible improvements will be diverse and will probably result from the development of:

- stronger, more effective regulations (see Chapter 2);
- better dissemination and circulation of information (see Chapter 3);
- enhanced knowledge on species biology and management techniques (this chapter);
- monitoring and early-detection networks for IASs (see Chapter 4);
- programmes for applied research (see Chapter 1);
- strategic networks on the various management levels (see Chapters 3 and 6).

In the sections below, two aspects requiring major improvements are presented, namely biosecurity and cost analyses of management interventions in aquatic environments.

Improving biosecurity

This section was drawn and adapted from a report in the first News Bulletin of the Biological invasions in aquatic environments group (see http://www.gt-ibma.eu/activites-du-gt-ibma/lettre-dinformation/lesdossiers-de-la-lettre-dinformation/).

All persons using or simply visiting aquatic environments can, unknowingly, become vectors of pathogens and invasive alien species. Unfortunately, our knowledge on the risks involved in dispersal is totally insufficient. For these reasons, it is important that biosecurity issues be addressed as fully as possible in order to gain new knowledge that can be widely disseminated. Greater awareness of the risks of dispersal and implementation of suitable biosecurity rules could limit the geographic dissemination as well as the disturbances and damage caused by a number of easily transportable invasive species.

Three recent examples of research on this subject will demonstrate the value of this work.

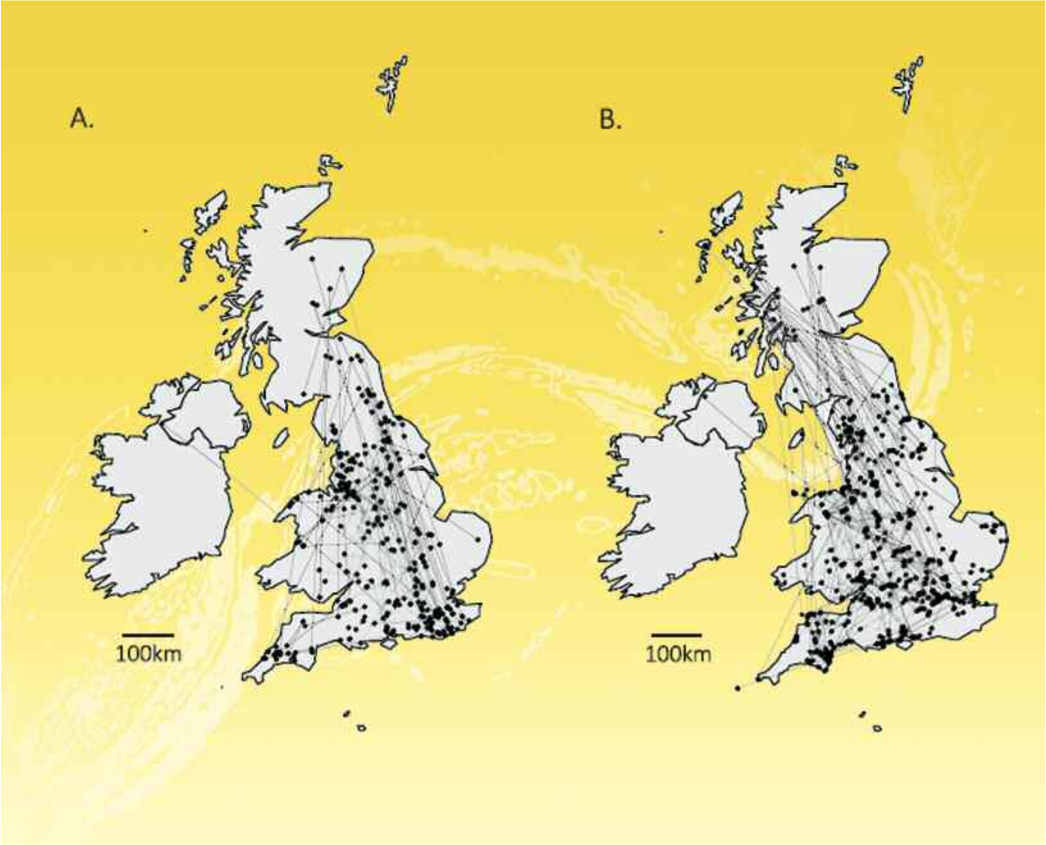
■ Survey of fishing and boating associations in the U.K.

The purpose of the internet survey carried out by Anderson *et al.* (2014) on all British fishing and canoeing/kayaking associations was to study the practices of these people active in aquatic environments to determine the impacts on the dispersal of nine pathogens and ten IASs (plants and animals previously identified as clearly invasive). The questions on practices addressed the cleaning and drying of equipment after use, travel (distances, frequencies and destinations), the number of river basins concerned by travel over short periods, etc. Anglers were also questioned concerning their use and disposal of live bait. The responses to the survey were then analysed in terms of the dispersal risks, ranging from 1 (low risk) to 5 (high risk).

One of the interesting results of the survey is that a majority of anglers (64%) and of boaters (78,5%) used their equipment in more than one river basin in a given two-week period, the time that several of the pathogens and IASs studied could potentially survive. In addition, 12% of the anglers and 50% of the boaters did not clean or dry their equipment between two uses. What is more, almost half of the anglers and boaters used their equipment abroad, primarily in European countries, though in this case only a small percentage did not clean or dry their equipment.

Maps drafted on the basis of the information collected indicate the sites visited by anglers and boaters that travelled to more than one river basin over a two-week period without cleaning or drying their equipment between uses. On the maps, lines linking the sites visited by a person over the two-week period in question clearly illustrate the multiple interconnections that exist between river basins (see Figure 102).

Figure 102



Sites visited by anglers (A) and boaters (B) travelling to more than one river basin over a two-week period without cleaning or drying their equipment between uses. The lines indicate travel between sites. According to Anderson et al., 2014.

Given that over one-third of species introductions in Europe are caused by fishing, recreational boating and other recreational activities, the authors concluded that these uses of aquatic environments risk becoming serious vectors of pathogens and IASs and highlighted the importance of improving the biosecurity aspects of those activities and of raising the awareness of the general public.

If it is acknowledged that the equipment used for these activities can serve as vectors for pathogens and IASs if used without the necessary precautions, what methods could be used to reduce these risks? For example, what cleaning products could be used to eliminate any organisms from the equipment once it is removed from the water?

■ Biosecurity measures to reduce secondary propagation of Asian clams

The work by Barbour *et al.* (2013) on tests of disinfectants for Asian clams (*Corbicula fluminea*) in Ireland produced very useful initial results. The Asian clam, *Corbicula fluminea* (Müller, 1774), is one of the most widely spread invasive bivalves in fresh waters worldwide. The species was first observed in Ireland in 2010. Its rapid spread in the Shannon River confirmed its high colonisation capabilities. The risks of secondary dispersal, caused by human activities, to aquatic environments subject to intense fishing and boating pressures such as the Shannon River were deemed to be high. The objective of the study was to test the effectiveness of methods to remove Asian clams from fishing equipment (nets, waders, other equipment used in fresh water).

The tested products were salt, bleach and a product, Virkon®, specifically developed to disinfect aquaculture equipment (see Figure 103).

Figure 103

© Inland Fisheries Ireland

Disinfection of fishing equipment using Virkon®.

The tests revealed that Virkon® was the most effective product in terms of biosecurity and that it resulted in mortality rates of over 90% for Corbicula fluminea after very short exposure times. According to the authors, to obtain 100% mortality rates, further research would be required concerning both the species biology (stimuli tripping opening of the animal's valves) and other chemical products or combinations of products that could develop synergistic effects.

Greater awareness of our potential responsibility in the dispersal of troublesome species may result in biosecurity directives that are seen as further constraints on the use of aquatic environments.

■ The Dydimosphenia geminata diatom

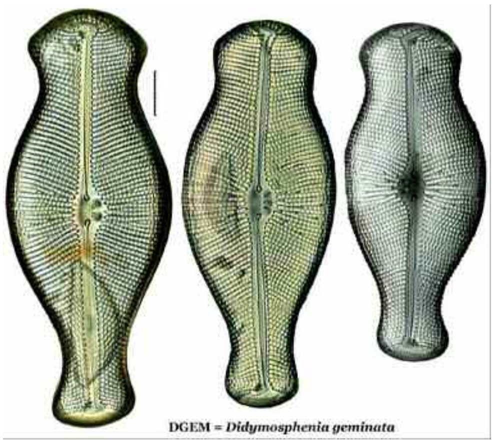
A well-known example of dispersal of an alien species due to certain activities is the *Dydimosphenia geminata* diatom (see Figure 104). This fairly large diatom produces viscous stalks that can attach to sediment and plants. This species can completely cover river bottoms. It originated in the high latitudes and mountainous regions of the northern hemisphere, but has dispersed widely since middle of the 1980s, notably to New Zealand, where it is considered "undesirable", as well as in North America and Europe. Its proliferation impacts the living communities in the colonised rivers. Fishing has been considerably affected in certain areas and clumps of its stalks can block water intakes.

The stalks can attach to the equipment of anglers, boaters and other river users, which explains the great spread of the species. A great deal of information on the species has been disseminated over the past few years in an attempt to draw the attention of people to the dispersal risks and inform on how to avoid them. For example, a document published by the Sustainable development, Ecology and parks, and Natural resources and fauna ministries in Québec in 2008 (www.mddelcc.gouv.qc.ca/eau/eco_aqua/didymo/didymo.pdf), presented the recommendations drafted on the basis of the methods developed and tested by the authorities in New Zealand (*Biosecurity New Zealand*). They deal with how to examine a boat and equipment in view of removing algae before leaving a river and how to clean and dry objects that were in contact with the water, stressing notably how to deal with absorbent materials such as the felt pads beneath the boots of anglers.

Figure 104

a

b



a © A.Dutartre, Irstea
b © Coste et al.

The Dydimosphenia geminata *diatom attaches to sediment and plants. It has spread widely via the equipment used for recreational activities.*

In the field of biosecurity, we are confronted with our insufficient information (that must be improved) and with the need to modify certain practices in aquatic environments (here the public must be convinced). These changes will necessarily take time, but they would appear indispensable if we are to improve IAS management.

Better understanding the costs of IAS management and the comparative economic analyses of the potential methods

One of the constant difficulties encountered by management projects is their justification in economic terms. The high and steadily rising costs of IAS management on all levels, national, European and worldwide, are increasingly seen as difficult to accept and, particularly in Europe, as directly competing with the funding needs for the restoration of aquatic environments undertaken in compliance with the Water framework directive.

Most of the available economic studies assess the damage caused by IASs and their management costs in consolidated terms, combining all species, which is of course necessary, but not sufficient. The world is confronted with multiple biological invasions, each causing specific damages and requiring different management techniques. They can be analysed from the financial standpoint, but studies should distinguish between the different types of IAS in order to highlight the issues of each management situation.

The dispersion of the invasive species to be managed in environments is one of the difficulties involved in correctly determining the economic costs. Concerning aquatic plants, the management technique selected is not the only parameter. For example, two inventions may use the same equipment, but for the first, the plant beds are dispersed, resulting in "downtime" travel between the beds (see Figure 105), whereas for the second, the equipment works continuously on a single, dense bed (see Figure 106). The average cost per unit volume of extracted plants or per unit of treated surface area is directly related to the dispersion of the plants, to the distances travelled by the equipment, to the conditions for access by the equipment and for unloading/loading, etc.

Figure 105

© A.Dutartre, Irstea

Dispersed beds of large-flowered waterweed in the Pen-Mur reservoir (Morbihan department).

Figure 106

© A.Dutartre, Irstea

Dense beds of curly waterweed in Blanc Pond (Landes department).

As part of the Water-primrose project in the INVABIO programme (Dutartre et al., 2007), management costs for water primrose were analysed in order to determine the best management conditions in economic terms (Million, 2004). The main results expected from the analysis dealt with the intervention frequencies and time periods as a function of the type of environment, and with the regular management of the water primrose remaining on the sites. The study could not answer all the questions raised, however it did provide a rough estimate of the costs for the two main techniques (manual and mechanised uprooting) used to regulate water primrose.

The average cost per ton of fresh biomass of uprooted water primrose ranged from 1 100 to 1 330 euros for manual work and from 51 to 64 euros for mechanised work.

One of the conclusions of the study was that the solution for water-primrose management that seemed to produce the best results was an intervention severely reducing water primrose on a site followed by regular work on the remaining plants, i.e. precisely the solution already adopted on a number of sites such as the Marais Poitevin marshes.

The analysis of intervention costs for invasive aquatic plants in the Pays-de-la-Loire region conducted by Matrat *et al.* in 2011 (http://www.pays-de-la-loire.developpement-durable.gouv.fr/2011-colloque-regional-les-plantes-a1338.html) used the data from 317 of the 449 sites listed since 1994, thanks to the documents filed by managers prior to 2006 and the site-report sheets used since. The total cost of the interventions amounted to approximately 3.5 million euros. This analysis produced a number of data points including average costs for plant uprooting, all species combined, as a function of the surface area treated and of the volume extracted. The average costs per square metre ranged from 0.40 euros for surface areas greater than one hectare to approximately 35 euros for surface areas of less than ten square metres. The average costs ranged from 4.20 euros for volumes greater than 100 cubic metres to approximately 2 300 euros for volumes of less than 0.1 cubic metres.

These results for costs per unit of surface area or per unit volume/biomass of extracted plants are very useful for future studies on management techniques, but they provide very little information on the issues surrounding interventions. They do not reflect the specificities and ecological value of the environments managed, nor the characteristics of the targeted invasive species and the site, e.g. dispersion of the plant beds, access conditions for equipment, etc.

The management costs for water primrose paid by IIBSN in the Marais Poitevin wet marshes exceed 200 000 euros per year (Pipet and Dutartre, 2014). That is a great deal of money, however a comparison between the management costs for water primrose and the cost of “doing nothing” puts the management costs into perspective.

An economic assessment of the theoretical costs of the damage if the entire hydrographic network of the wet marshes were to be colonised by water primrose was carried out by Aline Issanchou in 2012. She included in the calculations the human uses of the site, notably tourism and boating in the Marais Poitevin marshes, the risks in terms of flooding and other values, e.g. recreational and aesthetic values. For example, she estimated that annual tourism revenues in the Marais Poitevin marshes amounted to almost 145 million euros, a figure that puts the annual management costs for water primrose into perspective given that the attractiveness of the marshes is due in great part to boat rides in the “Green Venice” that would become impossible if the channels were invaded by water primrose. Though this analysis requires more work due to the lack of precise data concerning certain elements, the author nonetheless concluded that according to the assessment method implemented, the costs of the damage caused by water primrose, *“not all of which were taken into account in the analysis”* would appear to be far greater than the management costs effectively incurred. According to her calculations*, “starting at 200 tons of fresh, water-primrose biomass, the total damage is estimated at 82 million euros”* (Pipet and Dutartre, 2014).

The Sustainable-development division of the Ecology ministry is currently conducting a study on the national level to ascertain the overall costs of the damages caused by IASs on the environment, for human health and the economy, and the costs of management interventions. Following an initial review of the literature, a questionnaire was sent to the main stakeholders in the beginning of the summer of 2014. The study is an element in the implementation of the new European regulation. In addition to the assessable economic losses, data on *"harm to the well-being of stakeholders and on any non-market benefits (recreational activities, aesthetics, amenities, etc.)"* will be included in the analysis.

These economic aspects do not include the ecological impacts of interventions nor the ecosystem services provided by environments. Invasive plants can occupy the same biotopes as important, native plants (see Figure 107). Which criteria should be used to decide whether to intervene? Should the entire site be cleared, knowing that bogbean is not very competitive and will probably not recolonise the site, or should the intervention target just the two invasive species, knowing that the cost of the intervention will be much higher?

With manual uprooting, only the invasive plants are removed and the native species remain (see Figure 108), even when the surface areas are very small. For example, a trained operator can differentiate between large-flower water primrose (*Ludwigia grandiflora*), with alternating leaves, and Marsh seedbox (*Ludwigia palustris*), a native species with a red stalk and opposing leaves.

Continued work on these analyses, on the national or regional levels, or species by species, would appear necessary to improve IAS management strategies. This work would be of assistance in defining a comprehensive strategy driven on the national level, in compliance with the European regulation, as well as more specific regional and local strategies. But in all cases, this work should be accompanied by an assessment of the ecosystem services provided by aquatic environments (Amigues and Chevassus-au-Louis, 2011) to ensure that all aspects of the ecological, social and economic issues involved in the management of invasive alien species are fully taken into account.

Figure 107

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In the foreground is a stand of yellow iris (Iris pseudacorus) surrounded by a small bed of bogbean (Menyanthes trifoliata), a species that is slowly disappearing from lakes along the Aquitaine coast. Just behind is a dense bed of parrot-feather watermilfoil with some water primrose. Léon Pond (Landes department).

Figure 108

© A.Dutartre, Irstea

Manual uprooting of water primrose in a ditch linked to the Noir Pond (Landes department).

This chapter was drafted by:
Emmanuelle Sarat (IUCN French committee),
Alain Dutartre (independent expert, formerly at Irstea),
Emilie Mazaubert (Irstea).

With the collaboration of:
Benjamin Bottner (Development agency for the Vilaine River basin),
Anne-Laure Gourmand (MNHN),
David Happe (Auvergne regional environmental directorate),
Jacques Haury (AgroCampus Rennes),
Nicolas Poulet (Onema),
Yohann Soubeyran (IUCN French committee).

Resources and techniques to improve management of invasive alien species

6

The need for an organised and coordinated approach

The different stakeholders and the value of a network

As noted in Chapters 4 and 5, IAS management is necessarily a collective effort with links between various categories of stakeholders, including researchers, managers and people active in natural environments. This means that it is necessary to designate the people best suited to set up an organisation and decide on the techniques employed, but also to determine how the many actions should be coordinated on the various geographic and administrative levels, i.e. the local, regional, national and European levels. Given the very wide range of stakeholders, the creation of an organisational structure for IAS management is not an easy task. For example, on the local level, there is no one type of stakeholder that has been designated to take charge of IAS management. It can be any stakeholder in a position to have an effect on these species, i.e. environmental managers, the general public (hunters and anglers) in some cases, the technicians of local governments in others, the employees of State services or volunteers from non-profit groups (Menozzi and Pelligrini, 2012).

All these stakeholders differ in type, organisation, resources and objectives, as well as in the techniques they select to manage IASs. The legal status of each species is also an element in determining the applicable stakeholder. For example, for fauna, pests and game (see Chapter 2, page 67) are managed mainly by hunters, trappers and the personnel of the National agency for hunting and wildlife (ONCFS). The same is true for the environment where the disturbances and damage occur. The stakeholders involved are not the same for terrestrial and aquatic environments, nor for protected natural areas. Effective management of species throughout the country thus depends on the stakeholders involved and on their degree of participation, to the point of directly influencing the selection of the techniques employed (Menozzi and Pelligrini, 2012).

IAS management thus leads stakeholders to create new types of partnerships in order to succeed because it is widely acknowledged that a lack of coordination is a significant factor of failure. This interdependence may be observed on the local level, i.e. horizontally, but also between the various management levels, the local, national and international, with each level playing a different role (Menozzi and Pelligrini, 2012). Generally speaking, the national level provides funding for strategic coordination or for specific projects (notably via calls for projects). It can also institute a strategic framework (see Chapter 3). The regional level coordinates and funds management work, the local level actually does the work. The interactions between these levels are, however, very complex and require sharing of information, of knowledge and know-how, and collaborative preparation of projects.

Highly simplified diagram of the relations between the main stakeholders in IAS management, on the main management levels. According to Sarat, 2014.

Figure 109

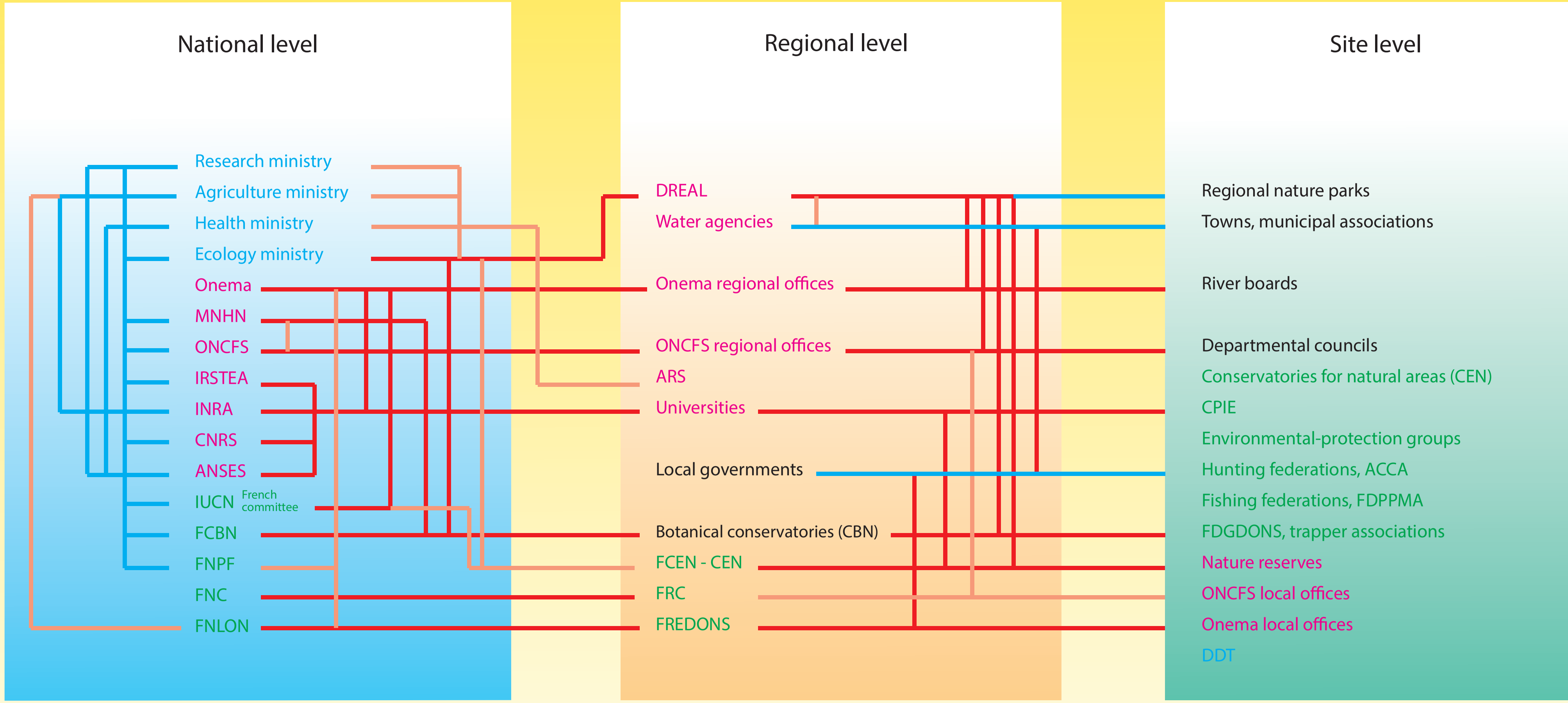
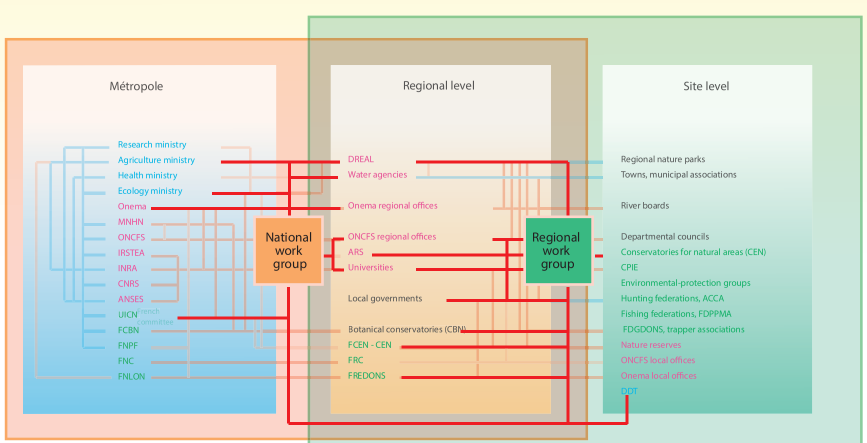


Figure 110



State services
Public institutions and organisations
Non-profit organisations
Local governments and related public organisations

Note that the National botanical conservatories vary significantly in their legal status (non-profits, boards, section of the MNHN). Their status is not indicated in this diagram.

Project funding
Project development
Exchange of knowledge, know-how, opinions and information

The diagram showing the relations between the stakeholders involved in IAS management in aquatic environments (see Figure 109) illustrates this complexity.

Though far from complete and not attempting to provide a total picture, the diagram nonetheless reveals a certain number of points.

■ A wide variety of stakeholders are involved on each level of IAS management. Though the stakeholders differ in type of organisation, resources and objectives, they all participate. Several categories of stakeholders exist:

- the State and State services, active primarily on the national level. In conjunction with public agencies and local State services, they implement environmental policies, including those concerning IASs. The interministerial relations involve above all information exchange,
- public agencies and local State services ensure the links between the national level and the management stakeholders on the site level. In this category, the research community is present on both the national and regional levels and can serve as a link with environmental managers,
- environmental-protection groups/federations and non-profits are well represented on the national level and on the site level. Their more limited presence on the intermediate level reduces the links between the local and national levels, however the public agencies and research organisations can play the same role,
- the local governments (regions, departments, towns) are involved in funding management projects and in disseminating information on IASs. The various forms of municipal cooperation (urban areas, municipal associations, boards), river boards and the regional nature parks play a more direct role in the actual management of IASs.

■ There is a dense web of relations between organisations on the same level. Between levels, relations are not as numerous. Contacts between the site and national levels could be improved by better coordination on the regional level. On the site level, stakeholders are obviously in direct contact, however their roles and degree of involvement vary with each situation.

■ The transmission of information and the development of know-how are often approached in a top-down manner, from the national to the local with little involvement of managers, whereas the formulation of projects and the actual management are organised from the bottom up. The stakeholders on the site level inform the upper level on the disturbances and damage caused by IASs and the needs for management intervention.

■ Funding for projects and interventions is provided by a limited number of clearly identified sources, namely the Ecology ministry and its regional directorates, Onema, ONCFS, the Water agencies and local governments, all of which also bring European funds (ERDF, LEADER, LIFE, etc.) into play.

Greater interaction between these stakeholders and levels is required to improve the implementation and the results of IAS management. Improved knowledge and its dissemination depend to a large degree on collaborative efforts between managers, technicians, researchers and experts active in the various networks. For example, new information on IAS distribution can result for the collaboration between:

■ the managers of natural areas (whether protected or not) who monitor the species and the colonised areas;

■ the coordinating structures on the departmental and regional levels that participate in producing collective distribution maps to inform the upper level and the research organisations;

■ local people and land owners who can inform on the past history of the intervention site, on the introduction and colonisation of species and on the results of management techniques employed previously.

On the basis of this initial diagnosis, what can be done to improve the production, dissemination and sharing of this “hybrid” knowledge, combining science and observations in the field, held by the various stakeholders? How can coordination, a decisive factor in better IAS management, be encouraged and improved, what steps can be taken to optimise the work done and the funds invested?

Coordination groups

■ The emergence of the work groups

Difficulties in managing invasive alien aquatic plants arose in France in the 1970s (Dutartre *et al.*, 2014), primarily in the South-west, but they then spread along most of the Atlantic coast up to Brittany. Limited interventions on a few, heavily colonised sites were carried out as early as the late 1970s. The results demonstrated the full extent of the difficulties that remained to be overcome, notably the need to coordinate the work and the participants.

Starting shortly after the year 2000, work groups were progressively established to improve coordination of the management work against invasive aquatic plants. Their launch was often spontaneous in response to repeated requests on the part of stakeholders involved in managing invasive species and the objective was to provide scientific and technical answers to the problems encountered by environmental managers.

The administrative boundaries of the areas covered by these groups varies considerably. Those boundaries depend on the history of past management work, on the structures in charge of coordinating the work and on the participants. Work groups are active on all levels, e.g. from the national level with the Biological invasions in aquatic environments (IBMA) work group down to the departmental with the Charente observatory on invasive plants (OPE), as well as in large river basins, e.g. the Loire-Bretagne work group on invasive plants, and on the regional level with the Pays-de-la-Loire committee. Their operations are specific to each group and depend on the situation in each area.

These groups offer management stakeholders a chance to participate in generating new knowledge on IASs. A number of them have existed for over ten years and have contributed, in proportion to the areas covered, to producing significant amounts of information on the distribution of invasive plants, to drafting distribution maps, to disseminating information on past management projects and to increasing awareness of the problems involved. They also made possible a number of interventions by finding the necessary funding and ensuring its availability over time, by bringing together a wide range of participants to jointly develop management techniques designed to maintain human activities on the sites while limiting the impacts caused by invasive alien species.

By mobilising many different stakeholders (non-profits, public agencies, State services, local governments, managers of natural areas, local people, etc.), these groups serve as information clearing houses and contribute to disseminating throughout the country data on the species and on the technical and organisational aspects of their management. Building on this experience, the work groups have progressively expanded their scope to include invasive plants outside of aquatic environments and, currently, invasive alien fauna, thus taking advantage of the existing networks and the available know-how, and continuously reaching out to new stakeholders.

Figure 110 shows the position of these regional groups within the web of interactions between the stakeholders involved in IAS management in aquatic environments. The regional and national work groups reinforce the links within each level and between levels. They facilitate the launch of many projects in conjunction with the stakeholders on both the site level and higher levels, e.g. research organisations and public agencies. Finally, they are all interconnected and serve as relays between managers and decision-makers.

Indispensable strategies

That being said and the existence of the work groups notwithstanding, there remain many needs in terms of network building and information sharing, particularly in areas where coordination groups do not yet exist.

■ A national strategy for IAS management

The formulation of a national strategy is an indispensable step in order to:

- reinforce links, both horizontal (between organisations and stakeholders) and vertical (between the national, regional and site levels);
- ensure that IASs are seen as a priority issue for environmental management;
- support local projects and improve information exchanges between organisations.

The upcoming implementation of the European regulation will improve coordination on the national level and information exchanges between the various stakeholders. The regulation requires that the Member States set up a surveillance, monitoring and research system for IASs and it also laid the foundation for information exchange on the species in the Union list in order to coordinate management work on the European level (Le Botlan and Deschamps, 2014).

■ Regional strategies

In the absence of a national strategy, local strategies have been progressively proposed by a number of coordination groups (see Box 28). They are the product of the organisational efforts by these groups (consolidation and sharing of knowledge and information, creation of decision-aid tools, coordination of management work, etc.). They also exist thanks to the collective dynamism shown by many of the stakeholders dealing with IAS management and to the helpful and supportive ambiance that has come into being over time within the work groups. The main objective of these strategies is to provide answers in terms of the necessary knowledge and management of IASs in the geographic and/or administrative area specific to each group, while providing a general framework for the work on these species by the main stakeholders involved. They are intended as a means to coordinate and ensure the consistency of the various projects implemented in the given region.

These strategies are often accompanied by definitions of terms and highlight the national and regional context of IAS management (main species encountered, projects and stakeholders active in the region). They list the general objectives and a number of guidelines. Finally, lines of work are presented and filled out with a detailed programme of prioritised operational projects.

These strategies initially focussed on plants, but they now increasingly include animals. Though they are often established for regions, they can also target other types of geographic areas such as river basins. That is the case of the recently published strategy on IAS management in the Loire-Bretagne basin (Hudin *et al.*, 2014).

Examples of regional strategies for invasive alien species

■ Regional management strategy for invasive alien plants in the Pays-de-la-Loire region (Matrat *et al.*, 2012)
This regional strategy is the product of the discussions held over the past five years in the Pays-de-la-Loire committee for the management of invasive alien species. The strategy is divided into two sections dealing with general policy and with management recommendations. It focusses on aquatic plants and highlights the need for urgent action and for better organisation of public policies.
(http://www.pays-de-la-loire.developpement-durable.gouv.fr/IMG/pdf/STRATEGIE_PAYS_DE_LA_LOIRE_2012.pdf)

■ Strategy against invasive species threatening biodiversity in the Basse-Normandie region (Mercier (coord.), 2013)
The Basse-Normandie regional "Invasive species" committee was set up in 2007 to set priorities for IAS management work. The strategy has resulted in a consistent programme of operational projects for IAS management on the regional level (fauna and flora), according to priorities targeting three components, new knowledge, management and communication.
(http://www.gt-ibma.eu/wp-content/uploads/2014/04/Strat%C3%A9gie-de-lutte-contre-les-EI-mena%C3%A7antla-biodiversit%C3%A9-de-BN.pdf)

■ Regional strategy for invasive alien species in the Languedoc-Roussillon region (CBNMED and CEN-LR, 2010)
The purpose of the strategy against invasive species (fauna and flora) is to establish and coordinate a strategic management framework. The objective is to reduce to a minimum the risks represented by IASs for the environment, the economy and society, and to protect the aquatic and terrestrial ecosystems in the Languedoc-Roussillon region. To reduce ecosystem exposure to those risks, the strategy is divided into three sections, 1) assess the threats, 2) manage species, habitats and landscapes, and 3) exchange information, communicate and coordinate.
(http://www.languedoc-roussillon.developpementdurable.gouv.fr/IMG/pdf/StrategieLR_Document_Final28mr__2__cle5aa554.pdf)

■ 2014-2020 strategy for IAS management in the Loire-Bretagne basin (Hudin *et al.* (coord.), 2014)
This strategy deals with knowledge, prevention and the restoration of ecosystems, in an effort to coordinate the work between the different administrative levels in the Loire-Bretagne basin, in conjunction with other, larger areas (France and Europe). It recommends focussing on the most relevant projects within the framework of a large river basin. Common objectives and major guidelines are set to optimise the human and financial resources required on the different levels (river basin, region, department, sub-basin, river board, etc.). The document is accompanied by an operational set of projects.
(http://www.centrederessourcesloirenature.com/mediatheque/especes_inva/StrategieGestionEEE_BassinLoireBretagne_FCEN.pdf)

The available tools for managers

Lists of species

Before it is possible to set up effective management strategies, it is necessary to obtain more information on IASs and to rank them according to their invasive potential. Many studies on alien species have already been conducted, on different geographic scales, on different taxa and using different methods depending on the objectives of the study (Mandon-Dalger *et al.*, 2014).

■ Lists to raise awareness

IAS lists presented to non-experts in biodiversity are often intended to raise awareness and inform on the adverse impacts of species with which people are occasionally familiar in other circumstances. That is the case for managers of parks and gardens who, in some cases, eliminate certain species after learning that they are invasive in natural and semi-natural environments. In most cases, the official lists for plants are drafted on the regional level by the national botanical conservatories and occasionally approved by the regional scientific council for natural heritage (CSRPN) (see Figure 111).

Figure 111

© CEN BN et CBNB

The list of invasive plants published by the Basse-Normandie region (BN conservatory for natural areas and the botanical conservatory in Brest).

In Belgium, an effort was made to limit the sources introducing IASs. The novel approach consisted of negotiating with plant producers to draw up a list in view of a voluntary agreement not to market the listed species (Halford, 2011). This initiative may be used in France in the near future to limit the sources of IAS introductions.

■ Lists to provide knowledge

These lists are intended by their authors either to provide information in addition to various guides and identification sheets, which present the risks raised by these species, or as recommendations for management work in natural areas. In some cases, these management recommendations suggest limiting the sources of IAS introductions and the authors hope to reach certain professions (horticulturists, growers, merchants). However, the lists do not take into account the economic situation of the professions and do not specifically target them, which explains why the lists rarely achieve their objective.

■ Lists for surveillance, early detection and rapid response

Given that it is often difficult to monitor an entire region and all species, a solution is to draw up lists of priority species. The lists may contain both species already present in the region in view of avoiding their dispersal and species that are not yet present, but for which the risks of introduction are deemed high. Alerts may be issued for species known to be invasive and that require a rapid response following early detection (Mandon and Fried, 2013). The alert documents are sent to the naturalist networks and the plant-protection services, two groups highly competent in taxonomy because that is needed in some cases to distinguish between relatively similar plants. A recent example concerned Japanese knotweed in Corsica, a fairly easy species to identify, but occasionally difficult to distinguish from the hybrid *Reynoutra x bohemica*. Alerts have already been issued by the Agency for food, environmental and occupational health & safety (ANSES) and by the national botanical conservatories.

■ Regulatory lists

The regulation prohibiting trade in IASs or their introduction in the natural environment (article L411-3, see Chapter 2), with the appended lists of invasive alien species drawn up by Muller (2004), was included in the document on Good agro-environmental conditions (BCAE, decree dated 13 July 2010 on the rules for good agro-environmental conditions). The lists prepared by the European plant protection organisation (EPPO) were mentioned in the decree dated 31 July 2000 listing the organisms harmful to plants, plant products and other objects, that are subject to mandatory countermeasures. The decree dated 25 August 2011 (French official bulletin dated 27 August 2011), modifying the decree dated 31 July 2000), lists the organisms harmful to plants, plant products and other objects, that are subject to mandatory countermeasures (see Chapter 2 and Figure 112).

Figure 112

© Emilie Mazaubert

The coypu (Myocastor coypus) is on the list of harmful organisms for plants and subject to mandatory countermeasures.

■ The problems with lists of species

The drafting of lists of species is confronted with an array of difficulties. The lists are produced by numerous stakeholders or groups of stakeholders, they cover different geographic scales and implement methods that vary, to the point that there is no real organisation between them. The result is a large number of species lists, of different types and having different objectives. The work to produce them may result in conflict, particularly when the objective is to set up regulations on the introduction and sale of certain species. The above is particularly true for plants, whereas for animals, to date there is only a small number of lists containing few species or only certain groups of species, mainly vertebrates not including fish, and they rarely cover entire regions.

A second problem with lists of species is that they generally include only the invasive alien species already known in the given area, i.e. they do not mention the new arrivals, the so-called "door knockers" already near the area, but not yet introduced. Finally, there is still no national list, for either plants or animals, because the method of preparing the list and its objectives have not been defined.

A number of recommendations have however been made (Mandon-Dalger *et al.*, 2014). Drawn up using scientific criteria, "general" lists for plants and animals could serve as the starting point for other lists. They could be used as lists for monitoring, comprise multiple criteria and cover the country as a whole. "Operational" lists could then be derived from the general lists, adapted to the specific stakeholders and conditions (objectives, local area). These operational lists would include the regulatory lists or topical lists, adapted to the applicable geographic scale. In addition, by listing entire taxonomic groups (e.g. families and genera) comprising the invasive species, it would be possible to include a larger number of species whose ecology is not well known and thus contribute to prevention. A general requirement is that the lists remain open and easy to update for new species arriving in a given region. Information on how they should be used and on their territorial validity must systematically accompany the disseminated lists in order to avoid incorrect use.

A number of methods for drawing up lists based on an assessment of the invasion risks (EPPO, ISEIA, Weber and Gut, see Box 3, page 31, and Box 13, page 93) already exist and it is necessary to consult them, in order either to select one and use it, thus making possible comparisons with other known lists, or to adapt them in view of producing the various "general" and "operational" lists. When drawing up the future national lists, it will also be necessary to take into account the requirements contained in the European regulation. These lists should be prepared in a very open manner, involving the environmental managers and economic stakeholders (horticulturists, breeders, farmers, etc.), including when the lists are intended for regulatory purposes. Approval by the various stakeholders of the method employed and the results produced is a factor in ensuring the success of regulations.

■ The results for aquatic environments

A double issue of the *Bulletin français de pêche et de pisciculture* (no. 344-345) was published in 1997 following the symposium titled "Species introductions in continental aquatic environments in continental France". It contained an initial list of aquatic plants with almost 50 species (Dutartre *et al.*, 1997).

A national survey by Aboucaya (1999) also proposed a list of alien plants including 61 known invasive species, 65 potential invasive species and 91 species requiring monitoring, of which over 20% were aquatic species. In 2004, Muller coordinated a review on invasive plants and proposed a list of the main invasive alien plants in continental France, among which were a number of species from aquatic environments.

Since that time, the disturbances caused by biological invasions have increased significantly and an array of lists, often focussing on plants, have been drafted for a wide range of geographic areas, but rarely for continental France as a whole. The fact that lists of plants were composed earlier and in greater number than lists of animals is primarily due to the existence of regional stakeholders working essentially on plants.

For example, below are some lists covering Europe and continental France.

■ The Delivering alien invasive species inventories for Europe (DAISIE) programme has drafted lists of species introduced in European countries and a list of the "100 worst invasive alien species in Europe" comprising numerous aquatic species (http://www.europe-aliens.org/).

■ The National list of natural heritage (INPN), composed by the National museum of natural history (MNHN), also proposes a list of 118 invasive species introduced into continental France (plants and animals, all environments) (http://inpn.mnhn.fr/espece/listeEspeces/statut/metropole/J).

■ For vertebrates, a reference list of species introduced into continental France was prepared by the Natural heritage department (SPN) at the MNHN (Thévenot, 2014). One of the criteria for admitting a species to this list is its intentional or accidental introduction by humans. The status of each species (known invasive, potential or requiring monitoring) is not indicated in the report.
(http://spn.mnhn.fr/spn_rapports/archivage_rapports/2014/SPN%202014%20-%2041%20-%20Elaboration_des_listes_vertebres_09.10.14.pdf).

■ Difficulties

It is not easy to draw up a complete list of IASs in aquatic environments in France, given the degree to which the available information is voluminous, scattered around the country, different in nature, organised for different objectives and regions, and originating from an array of sources (Mazaubert *et al.*, 2012). Any conclusions concerning IASs are all the more difficult given that the term "invasive" can be based on any number of often subjective criteria. That being said, an effort was made to draw up a complete list of IASs in aquatic environments in continental France by the Biological invasions in aquatic environments (IBMA) work group (see Box 29).

An "official" list of plants and animals on the national level will also be drafted in the near future in order to comply with the requirements in the recent European regulation.

Box 29

A prospective list of introduced species in aquatic environments in continental France

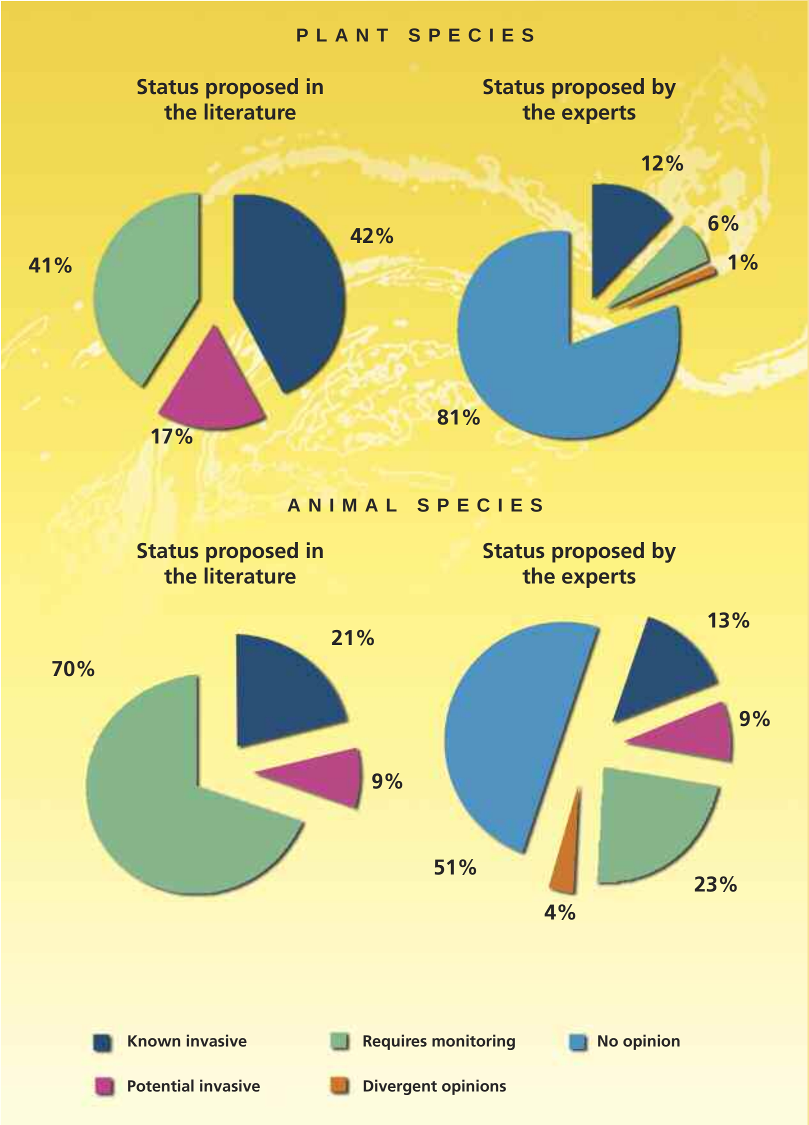
One of the projects launched by the Biological invasions in aquatic environments (IBMA) work group right from its founding was a list of introduced plant and animal species in aquatic environments in continental France. Designed as an open-ended project to assist in reviewing the overall situation in these environments in continental France, the objective of the list was to serve as a knowledge base used in setting up strategies for the management of introduced species.

The available data was first compiled to produce a general list of introduced species. From this first list, a second was drawn up containing only the species seen as invasive by various experts and/or organisations. For each plant and animal species, a proposal concerning its status (degree of invasive potential) was made. The two lists are updated, to the extent possible, in step with the arrival of new information (Mazaubert *et al.*, 2012).

The proposed status for each species is subject to debate because the criteria used by the experts may differ from those of the environmental managers and other stakeholders (see Figures 113 and 114). In addition, the diversity of the available information, of environments and species, the different dynamics of certain species in different parts of continental France and the difficulty in measuring impacts all contribute to the difficulties of drawing up a single list.

Figure 113

Figure 114



Comparison of status conditions (invasive potential) assigned in the literature to plant species (see Figure 113) and animal species (see Figure 114) and of the status conditions validated by the experts. (Dutartre and Mazaubert, 2012).

The proposed list (Dutartre and Mazaubert, 2012) is designed to be upgradeable and should be seen as indicative of current knowledge at a given point in time on the alien species considered invasive. The list and the method used to compile it may be consulted via the link below:
http://www.set-revue.fr/bilan-des-especes-exotiques-envahissantes-en-milieux-aquatiques-sur-le-territoire francais-essai-de/illustrations.

Distribution maps of species

The increasing numbers of invasive species arriving in an area and the limited funds available for management projects often mean that managers and decision-makers must set priorities and fund those management operations promising the best results with respect to the set objectives. Without a precise list of IASs and data on their geographic distribution, it is difficult to set up an effective management strategy. Early detection and a rapid response also require regular monitoring of species distribution over the given area.

Species mapping is a means to obtain precise information on their distribution and by updating the maps over time, it is possible to monitor their colonisation dynamics and to identify any specific local conditions that may facilitate their dispersal (see Figure 115). This information on species distribution and dynamics can also be used to establish an “invasibility scale” and consequently to prioritise species (for example, see the scale proposed by Lavergne[13]).

Figure 115

Distribution of box elder in the Centre region.

© Conservatory for natural areas for the Centre region and the National botanical conservatory for the Paris region

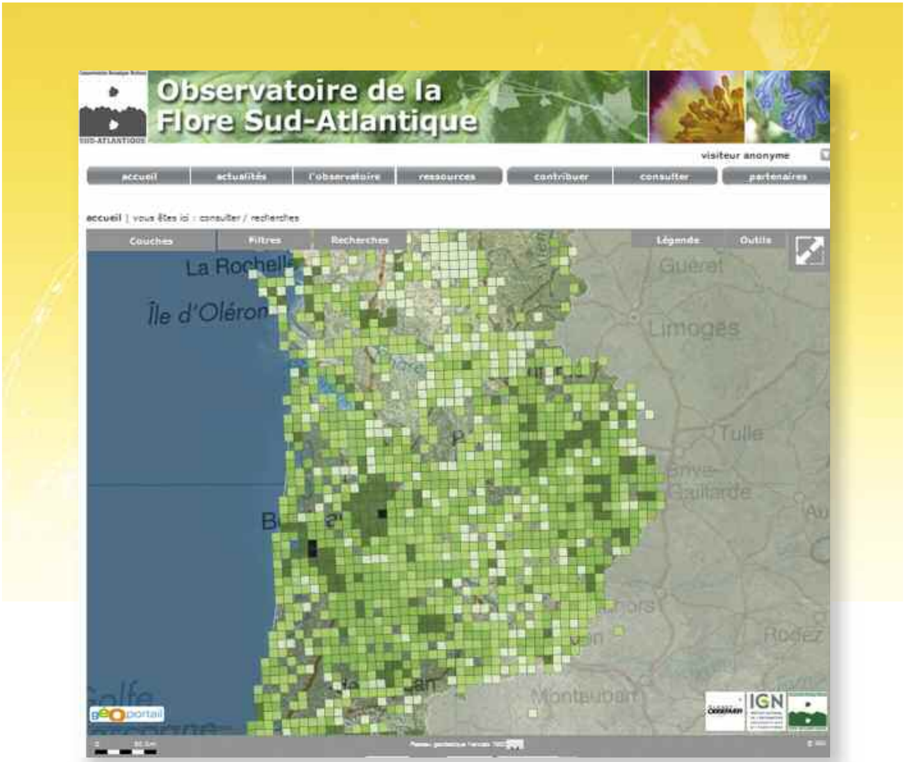
It would be an excellent idea, if only to have on hand the means to convince funding entities of the need to undertake management interventions, to precisely define the data-collection, -storage and -analysis strategy before launching monitoring programmes on the distribution of a species.

For plants, a number of organisations and work groups already coordinate data collection according to strategies adapted to their area (botanical conservatories, conservatories for natural areas, local governments, etc.) and serve as the liaison to national databases. Standardised monitoring protocols (species, colonised environments, priority research areas, types of monitoring points, etc.) have been proposed and training sessions are available to learn to identify and monitor IASs. Maps are then drawn up and made available to stakeholders.

13. Unpublished. Adapted to the index for vascular plants on Reunion Island. (http://flore.cbnm.org/index.php?option=com_florereunion&view=listes&layout=listeinvasif&Itemid=16)

Internet sites for on-line entry of IAS-distribution data have been developed specifically by and for the managers of natural areas (see Figure 116). That is notably the case for the botanical conservatories, the Regional observatory on invasive alien plants in aquatic ecosystems (ORENVA) and the Board for balanced management of the Gardons basin (SMAGE), that all propose sites offering the possibility to input observation data and view distribution maps (see Box 30). These sites are not necessarily open to the general public, contrary to sites for citizen science.

Figure 116



© OFSA

The Plant observatory for South-west France (OFSA), an example of an internet site for data input and access to distribution maps.

Box 30

Internet sites for data input and access to distribution maps

■ **OFSA.** The Plant observatory for South-west France was created by the National botanical conservatory for South-west France (CBNSA) to assist the observation of wild plants (http://www.ofsa.fr). It offers:

- data produced by the naturalist network, inventories managed by the conservatory botanists, resource documents and a herbarium;
- data management and validation services;
- a platform for knowledge analysis and dissemination.

The mapping section on the site provides access to distribution maps for many species present in the area covered by the conservatory.

■ **Orenva.** The Poitou-Charentes regional observatory on invasive alien plants in aquatic ecosystems (ORENVA) was created by the region Poitou-Charentes (http://www.orenva.org/). It consists of a network of local managers drawing up inventories and nine coordinators of departmental or river-basin organisations. Its steering committee in charge of regional coordination includes the region, the regional environmental observatory and the Forum of Atlantic marshes. Following registration on the site, it is possible to directly enter observations (http://sigore. observatoire-environnement.org/orenva/). See also:
http://www.gt-ibma.eu/strategies-ou-en-sont-les-institutions/strategies-infranationales/observatoire-regional-desplantes-exotiques-envahissantes-des-ecosystemes-aquatiques-orenva/

■ **Smage des Gardons.** The Board for balanced management of the Gardons basin (SMAGE) is a public river-basin territorial agency uniting 118 towns in the Gardons river basin and the Departmental council of the Gard department. Management work on a number of invasive plants, including water primrose and knotweed, started in 2009. The work included experiments on several species, interventions to regulate the spread of species and, since 2013, efforts to raise the awareness of elected officials and residents. In 2014, an internet site (http://invasives.les-gardons.com/) was set up to provide access to fact sheets on species and photos, to consult existing observations for approximately 15 species present in the river basin and to enter new observations indicating the location of species, with the possibility of adding photos.
(http://www.gt-ibma.eu/strategies-ou-en-sont-les-institutions/strategies-infranationales/smage-et 114gardons/)

Local monitoring of invasive alien animal species must still be set up in large parts of continental France. On the national level, efforts to monitor vertebrates have been launched by ONCFS, in partnerships with the hunting federations and environmental-protection groups, and by Onema. Surveys on specific taxa, for example those carried out by the League for the protection of birds (LPO) on alien species (Dubois, 2007 and 2013) or by the National museum of natural history (MNHN) on the Asian hornet, fill out the available information.

Geomatic tools (GIS, remote sensing, etc.) are increasingly used to acquire knowledge and to manage the data on IASs. These operational tools serve to store and analyse data on the issues surrounding biodiversity conservation and the pressures weighing on it, using a common reference dataset (Soubeyran, 2010). Remote sensing is also a means to lift the constraints involved in monitoring species distribution over vast territories, e.g. the long distances on rivers, and when access to private property and wetlands is difficult.

Since 2008 in continental France, a technique to monitor and precisely locate water primrose using satellite images has been experimented by Agrocampus-Ouest and the Development agency for the Vilaine River basin (see Box 31).

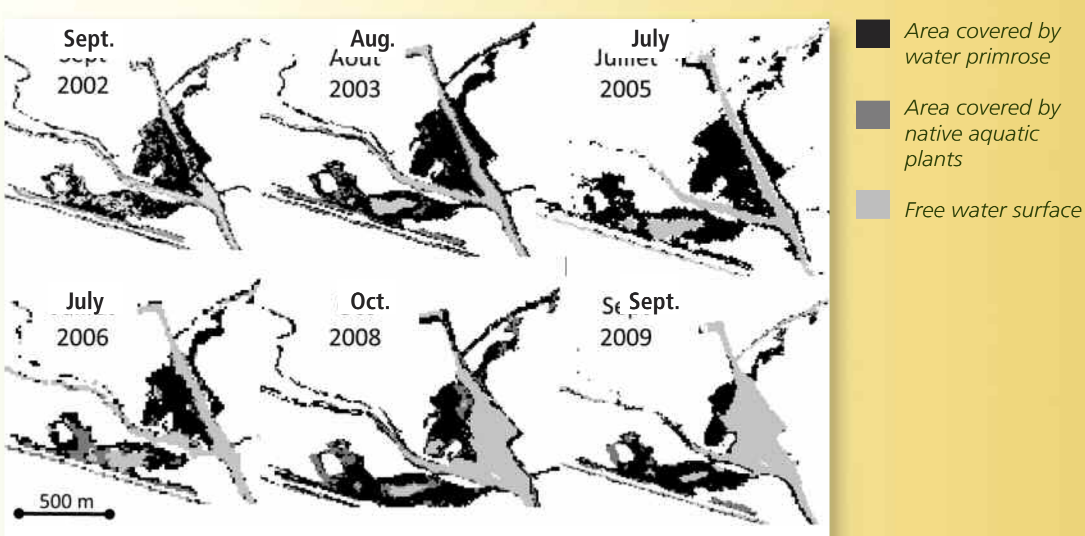
Molecular tools can also be of great help in mapping IAS distributions. For example, the “environmental DNA” technique is based on detecting specific DNA traces left by organisms in water, via their epidermic cells, urine or scat. In the framework of the management work on American bullfrogs in the Centre region, comparisons between the standard survey technique (daytime searches and nighttime listening) and environmental DNA showed that the latter succeeded in detecting the species even when population densities were low and often no visual observations had been made. In addition, the environmental DNA technique turned out to be less expensive (Michelin *et al.*, 2011). The technique is now operational for various taxa (amphibians, fish) and is undergoing development work and tests for other species (crayfish, bivalve molluscs, etc.).

From mapping to management using remote sensing for invasive plants. Water primrose in the Vilaine River basin

The spread of invasive aquatic plants such as large-flower water primrose (*Ludwigia grandiflora*) in many rivers, lakes and ditches in the Vilaine basin and the corresponding need to map the plants led the Vilaine development agency (IAV) to set up a research programme on how to locate the plants using satellite and/or aerial photos. Over a period of six years (2008 to 2013), in a close partnership with Agrocampus Ouest Rennes, the many necessary components were gathered, notably field data (GPS locations, measurements of plant spectral reflectance, botanical inventories, etc.) and satellite/aerial images (using multispectral and hyperspectral sensors across bandwidths ranging from the visible to mid infrared). Following a great amount of work involving statistical processing and image classification, the operational results listed below were obtained:

- proven differentiation of water primrose with respect to other species due to statistical differentiation of the spectra;
- production of basin-wide maps for water primrose with a high degree of precision;
- assistance for field surveys by producing alert maps and identifying the sectors to investigate;
- drafting of maps showing dissemination risks, in conjunction with GIS processing;
- multi-year monitoring of colonisation on control sites (see Figure 117);
- location to the metre on sites using aerial photos to complement the field data.

Figure 117



Monitoring of water primrose, native aquatic plants and free water surface over time in the Mortier de Glénac marshes (Morbihan department). According to Bottner and Noël, 2014.

This approach is promising, but is confronted with the availability and high cost of satellite and aerial images. Improvements are expected in the near future and should facilitate the use of remote sensing for gathering information and managing certain invasive plants.

Benjamin Bottner (Development agency for the Vilaine River basin),
Jacques Haury and Hervé Nicolas (AgroCampus Rennes)

Citizen science and invasive alien species

Over the past few years, citizen science (defined as "programmes to collect information involving the public in the framework of a scientific project" by the French initiative for citizen science, 2012) has made great strides. From newbies to experts, with everyone in between, but always on a voluntary basis, citizen science allows people to participate in research projects on biodiversity and to supply information for scientific databases (see Box 32).

Box 32

Key points in setting up a citizen-science project

When setting up a citizen-science project, a certain number of "ingredients" are required (Gourmand, 2015), but the quantities and proportions vary for each project:

- coordinators, i.e. a research lab, a management structure, local relays, etc.;
- a research topic and educational objectives offering sufficient interest and variation over time to maintain the commitment of the observers;
- a sufficient number of existing or potential observers. They must feel involved and care about the research topic and monitored species. They must also have the impression that their observations are unique, while belonging to a large group. In general, people learn rapidly, but they lose interest just as rapidly if novel aspects are not regularly injected into the project;
- a collaborative spirit and social bonding are central components, with each person providing their experience and know-how, going beyond prejudices and learning to know one another;
- a project protocol with carefully balanced compromises, e.g. required level of competence and number of persons, either few, highly standardised data or a large quantity of more heterogeneous data, activity limited to a precise area or wide open, etc.

Currently, there are over 200 citizen-science projects in France, basing their work on a number of different methods depending on their scientific and educational objectives (IFREE, 2011). Some of these projects aim to set up and maintain a network of observers in order to collect a maximum amount of data without first defining a collection method, followed by ex post exploratory research. The purpose of other projects is to share naturalist information within a network of observers in order to improve their collective knowledge, but without publishing it. Finally, other projects are directly derived from academic research where an ecological question requiring an answer is first raised. A protocol for data collection is then drafted and the educational objectives are built up around the research topic (IFREE, 2011).

Observations of invasive alien species are occasionally included in citizen-science projects, in programmes addressing specific topics or in more general projects monitoring biodiversity. In most cases, the data provided by the observers are of use in monitoring the spread of known populations, in noting the installation of new populations and in detecting the arrival of new invasive alien species. Distribution maps, using the information supplied by the observers, can be drawn up and regularly updated.

For plants in general, the association Tela Botanica was founded in December 1999 in view of creating a network of French-speaking botanists. The site www.tela-botanica.org was launched in July 2000 and its main purpose is to serve as a platform for botanists using French as their main language. There are now over 24 000 registered participants, including over 20 000 French nationals. It serves as the home for and it links over 100 projects and discussion forums addressing different topics, geographic areas, types of plants, etc. The site also publishes a weekly information bulletin.

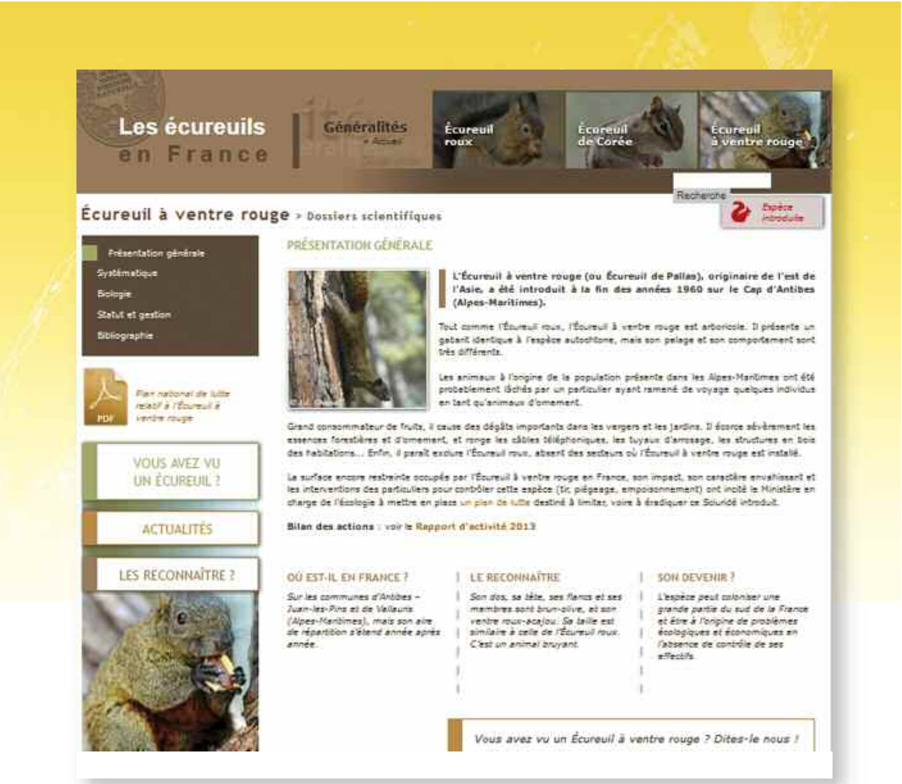
The “Invasive plants” forum deals with naturalised plants that are known to be invasive or are potentially invasive. The objective is to list and map invasive plants, as well as exchange advice on how to manage them. Another project, titled “Invasive plants in LR and PACA”, is for stakeholders working on gathering knowledge and managing invasive plants in the Languedoc-Roussillon and the Provence-Alpes-Côte d'Azur regions (Southern and South-eastern France).

Concerning animals, it is possible to provide information on Asian hornets, squirrels (http://ecureuils.mnhn.fr/) (see Figure 118) and alien flatworms (http://bit.ly/Plathelminthe) via the INPN site or special sites used for programmes coordinated by the National museum of natural history (MNHN).

For plants, a site is available to report common ragweed in the Rhône-Alpes region (www.signalement-ambroisie.fr).

Reports on other species should be made to the more local observation networks (CBN, ONCFS, Onema, local governments and environmental-protection groups) that manage their own database, check the information and transmit it to the national level (see Box 33).

Figure 118



The site for squirrels in France (http://ecureuils.mnhn.fr/) is coordinated by the MNHN. It informs the public on the presence of invasive alien squirrels and can be used to report observations.

Feedback on a participatory survey on invasive alien species in the Auvergne region

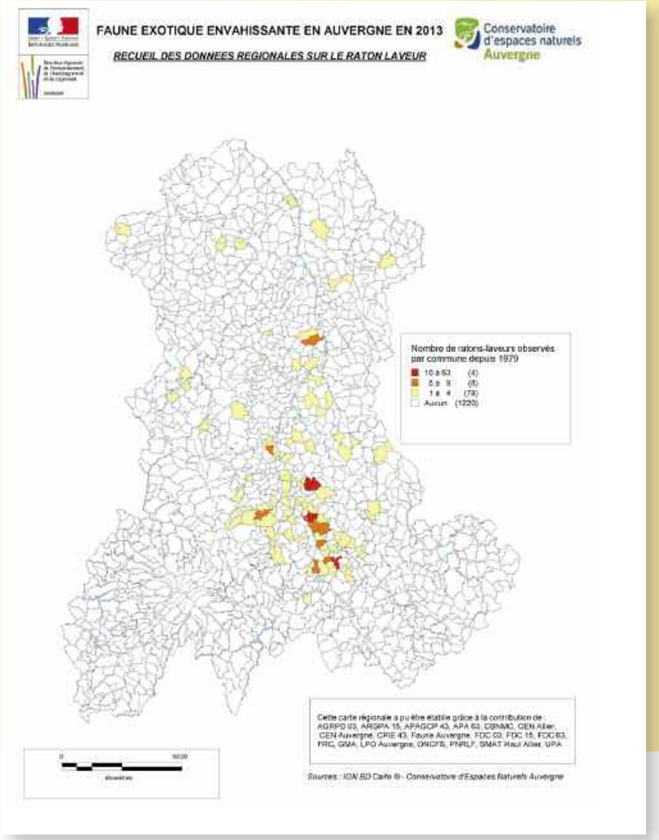
The Auvergne regional environmental directorate became aware of the introduction and spread of many invasive animal species in the region and decided in 2013 to launch two participatory surveys to update the available information on the distribution of several taxa in Auvergne. A year and a half after the start of the surveys, an initial progress report was drafted.

The first survey, addressing red-eared slider turtles and northern raccoons, became operational in the beginning of 2013. Those two species were selected in an effort to attract as many stakeholders as possible (naturalists, hunters, anglers, ONCFS, the general public, etc.) to the project. The survey was managed jointly by the Regional environmental directorate and by the Auvergne conservatory for natural areas. It succeeded in collecting isolated observation data and in consolidating data sets scattered among various stakeholders (e.g. certified trappers for northern raccoons). As a result, the amount of available data increased significantly (see Figure 119). For the northern raccoon, the quantity of observation data tripled and the presence of the species was detected in 90 towns throughout the region, whereas in 2011, only 42 towns had been identified. The survey contributed to identifying a new dispersal locus in France, in addition to the long-standing presence in the Picardie region.

Building on this initial success, in the beginning of 2014 the Regional environmental directorate started a new participatory survey targeting two types of aquatic species, bivalve molluscs and crayfish. Thanks to a major communication effort by the partners (naturalist reviews, sub-basin management plan, fishing federations, etc.), the new survey could call on a regional network of over 110 potential observers of which 70% have gone through a half-day training session. When the survey ended in October 2014, 980 observation data points (90% for crayfish, 10% for bivalve molluscs) had been collected. This regional project looked at both native and invasive species. In addition to providing information on the distribution of the species, it also served to raise the awareness of a large group of stakeholders concerning two relatively unknown species.

David Happe, Auvergne
regional environmental directorate

Figure 119



Map locating observations of northern raccoons in the Auvergne region thanks to a participatory survey launched by the Regional environmental directorate and the Auvergne conservatory for natural areas.
Source: Auvergne regional environmental directorate and the Auvergne conservatory for natural areas.

Other observations may be reported in collaborative naturalist databases that centralise data on biodiversity in general and can include data on certain IASs. These databases are also growing rapidly. In some cases, they are open only to trained observers, in others to the general public. The collected data do not necessarily comply with a set collection method and are often relatively limited in scope (e.g. species observed, date, place, name of observer). For example, the databases managed by the League for the protection of birds (LPO) can be used to report observations of “escaped” animal species, of which some are invasive. The information contained in these databases can be of use in alerting to the presence of IASs and be transmitted to the national and local monitoring networks.

The citizen-science programmes and the collaborative naturalist databases often include the means to input data on-line. A number of smartphone applications to identify and report IASs are now being developed and made available to the general public, including the ones listed below.

■ The *AGIIR* application developed by INRA. This application can be used to report observations on introduced insects and invasive species such as the pine processionary and the Asian hornet. (http://www.inra.fr/Grand-public/Dossiers/Lesagricultures-du-futur/AGIIR-contre-les-insectes-invasifs) ;

■ The *Th@t's invasive* application, developed as part of the Reducing the impacts of non-native species in Europe programme (RINSE - Interreg IV des Deux-Mers). This application uses a library of photos and biological characteristics to identify an IAS, photograph it and geolocate it. (http://www.rinse-europe.eu/smartphone-apps) ;

Pl@ntNet

■ *Pl@ntnet*, an application developed by INRA, CIRAD, INRIA and Tela-Botanica, serves to identify and geolocate over 4 000 species of plants in France, including some invasive alien species.(www.plantnet-project.org) ;

■ *Signalement ambroisie* is an application with an on-line data-input system that can be used to report the presence of common ragweed (ambroisie) and transmit the information to the concerned towns and ragweed manager who will take the necessary action. (www.signalement-ambroisie.fr) ;

iMoustique

■ *iMoustique* is used to photograph and report the presence of the Asian tiger mosquito, a vector for dengue fever and Chikungunya fever. (http://www.eidatlantique.eu/page.php?P=155).

Data supplied by non-experts in species identification should be used with caution in order to reduce error rates when setting up protocols, and during the validation and analysis phases (Gourmand, 2012). It is important to estimate the error rate in species identification and to check observation data when there is any doubt. Error rates can be calculated by checking observation photos and any clearly abnormal data. These rates are useful in determining data quality.

Tools to assist in identification and management

An array of tools to assist in identifying and managing invasive alien species has been developed over the past few years. The tools are intended primarily for the managers of natural areas and consist of identification guides, management manuals, standard protocols on species monitoring and site management, etc. They are often developed and intended for regional applications. Table 13 presents a selection of the available types of tools and provides examples of each.

Table 13 *List of the main internet platforms and the available tools (partial list).*

Type of tool	Objectives	Taxon	Examples (partial list)
Identification guides and species sheets	Identification Species detection	Flora Fauna (vertebrates, fish and a few invertebrates)	- Descriptive sheets prepared by the Federation of national botanical conservatories - Sheets prepared by the Sèvre-Niortaise basin interdepartmental institution (IIBSN) and the Development agency for the Vilaine River basin - Sheets on invasive species in the Lorraine region - Invabio
Management manuals and recommendation sheets	Management advice and recommendations	Mainly flora, a few vertebrates	- Management manual for invasive alien plants in the Loire-Bretagne basin, by the Federation of conservatories for natural areas
Strategies	Proposals, organisation and coordination of projects	Fauna and flora	- Strategy of the Pays-de-la-Loire committee for the management of invasive alien plants, 2012, by the Pays-de-la-Loire environmental directorate - Strategy against invasive species threatening biodiversity in the Basse-Normandie region
Lists of species	Identification and prioritisation of projects	Fauna and flora	- List of invasive alien plant species along the French Mediterranean coast, CBNM - List of invasive alien plants in the Centre region, CBNBP and Centre CEN - List of invasive fauna in the Auvergne region, Auvergne environmental directorate
Methods to prioritise species and projects	Identification and prioritisation of projects	Fauna and flora	- EPPO prioritisation process for invasive alien plants, Lag'Nature
Protocols and sheets for field surveys	Species monitoring, standardisation of protocols and data	Flora	- Field-survey sheet indicating the presence/absence of invasive alien plants for rivers and wetlands, Work group on invasive species in the Loire basin
Protocols and sheets for site management	Standardisation of protocols and data, post-intervention monitoring	Flora	- Protocol for monitoring management sites for invasive alien plants in North-west France, CBNL - Site-monitoring sheets, Pays-de-la-Loire environmental directorate and FCEN
Sheets for waste management	Post-intervention monitoring, regulations	Flora	- Proposal for recycling and agricultural use of water primrose extracted from aquatic environments, Pipet and Dutartre (2011)
Assistance in drafting the special technical specifications for projects	Monitoring of work and compliance with recommendations	Flora	- Guide on drafting the special technical specifications for work on alien plants, Pays-de-la-Loire environmental directorate
Bibliographical reviews	Summary of knowledge and provision of bibliographical references	Fauna and flora	- Invasive alien plants, Lambert E., 2009. Pays-de-la-Loire committee for the management of invasive alien species
Regulatory reviews	Summary and provision of legal references	Fauna and flora	- Summary of regulations on invasive vertebrates, ONCFS, Regulatory aspects of invasive plants, Pays-de-la-Loire environmental directorate
Distribution maps	Information on species distribution, identification of invasion fronts	Fauna and flora	- Distribution maps of the Pays-de-la-Loire work group on invasive plants - Plant observatory for South-west France, SIFLORE, FCBN - Distribution of invasive plants in the Centre region, CBNBP and Centre CEN
Data-collection strategies	Standardisation of data collection and centralisation	Flora	- Data-collection strategy of the Centre region, Centre CEN and CBNBP
Techniques to raise awareness	Information for the general public	Fauna and flora	- Mobile exhibition of the Work group on invasive species in the Loire basin - IIBSN exhibition - Information sheets, posters

Training sessions and informational meetings are regularly organised on the regional level. They serve to improve the knowledge base of stakeholders and consequently IAS management, to create collaborative links between stakeholders and to facilitate the exchange of information and feedback (see Figure 120).

Figure 120

Training sessions and informational meetings facilitate discussions on management topics among stakeholders.

a © Sylvie Varray - b © André Ulmer
c © Alain Dutartre, Irstea

Recently, the training sessions set up by various organisations have encountered difficulties in finding enough trainees. That is particularly the case for sessions lasting more than two consecutive days. For example, the Invasive plants training course organised by the CNFPT in Poitiers in 2014 was originally planned for four days, but had to be reduced to two. The same is true for the Invasive species course organised by the University of Metz in 2014, that was reduced from three to two days. Finally, the session proposed by the University of Strasbourg was cancelled given the lack of interest. To our knowledge, the four-day training course organised by the Technical workshop for natural areas (ATEN) is the only course in 2014 that went as planned.

It is difficult to pinpoint the reasons for this apparent lack on interest in standard training courses, though they probably include the easy access to the growing IAS knowledge base and the difficult financial conditions that reduce the available funds for training in the organisations likely to send people for training. One of the major disadvantages of this virtual disappearance of multi-day sessions is that it reduces or even eliminates any possibility of in-depth discussions between trainers and trainees, turning sessions into strictly one-way informational encounters. That is unfortunate because multi-day courses can easily become an occasion for discussions between all participants, whatever their job sectors, thus capitalising on all the know-how present and contributing to enhancing the overall quality of IAS networks.

On the other hand, short training sessions as well as conferences, symposia and other meetings designed for the rapid transmission of information over a single day have grown sharply in number. Given the large number of people involved, these events can contribute to enhanced awareness of the problems involved in biological invasions and their management, to the formation of stakeholder networks in areas where they do not yet exist and to improving early detection of species.

Platforms for information exchange

The information on IASs is already widely available via various internet sites targeting different geographical levels (see Table 14). The sites propose an array of tools, ranging from documentation to mapping applications. More information is available on specific pages of larger, non-specialised internet sites, such as those of the Ecology ministry, the Conservatories for natural areas (CEN), the regional environmental directorates and various resource centres.

Table 14 *List of the main internet platforms and the available tools (partial list).*

Internet site	Geographic sector	Documentation	Database	Data-input possibility	Regulations	Species-identification sheets	Lists of species	Protocols for site monitoring	Strategies	Maps	Photo library	Management advice	Management feedback	News	Training	Events
GISIN www.gisin.org	International		X	X			X			X						
ISSG www.issg.org	International	X	X			X	X		X		X	X		X	X	X
CABI www.cabi.org	International	X	X			X	X			X	X	X				
EASIN http://easin.jrc.ec.europa.eu/	Europe		X	X		X	X			X						
DAISIE www.europe-aliens.org	Europe	X				X	X			X	X	X				
EPPO https://www.eppo.int/ABOUT_EPPO/about_eppo_fr.htm	Europe	X				X	X					X		X		X
IBMA www.gt-ibma.eu	National	X			X	X	X		X		X	X	X	X	X	X
INVABIO www.invabio.fr	Lorraine region	X		X		X	X			X	X	X		X		
ORENVA www.orenva.org	Poitou-Charentes region	X		X	X	X	X	X		X	X	X	X	X	X	X
IUCN France, overseas IAS initiative http://www.especes-envahissantes-outremer.fr/	Overseas territories	X	X		X		X		X			X		X		
Ecology ministry http://www.developpement-durable.gouv.fr/La-strategie-nationale-du,11793.html	France				X				X							
DREAL	Regional	X				X	X	X		X						
INPN – MNHN http://inpn.mnhn.fr	France		X		X	X	X			X						
FCBN www.fcbn.fr	France					X				X						
Botanical conservatories (CBN)	Regional	X	X			X	X			X					X	X
Loire Nature resource centre http://centrederessources loirenature.com/	Loire basin	X				X	X	X	X			X	X	X		X
Conservatories for natural areas (CEN)	Regional	X				X	X	X		X		X			X	
Biodiversity Bretagne http://www.bretagne-biodiversite.org/	Bretagne region	X	X		X	X	X			X						

Collections of management feedback

The stakeholders in biological invasions in aquatic environments have been virtually unanimous in noting a lack of information sharing and management feedback concerning IASs. There are many projects, conducted independently by different organisations or in partnerships with other groups confronted with the same problems or proposing suitable methods and tools. Each intervention site is managed according to the local context, to the local social issues, the specific characteristics of the site, the targeted objectives and the implemented protocols.

In response to the need for information sharing and to encourage contacts between stakeholders, regional collections of management feedback have been published (see Box 34). These collections illustrate the diversity of projects and stakeholders, and present the main results achieved. The objective is to pool the experience and make it available to other stakeholders confronted with the same problems. These documents can make a major contribution to the collective learning process now under way concerning the management of invasive alien species in aquatic environments.

Box 34

Collections of feedback reports on management of invasive alien species

- Invasive alien species in aquatic environments, Practical knowledge and management insights (Sarat *et al.* (editors), 2015)

The second volume of this book published in the Onema Knowledge for action series is a collection of fact sheets on invasive alien species and management projects carried out in continental France and Europe. A total of 26 fauna and flora species are covered in 52 examples presenting management projects, drafted in conjunction with the managers.
(www.gt-ibma.eu)

- Management of invasive species in the Bretagne region (Quemmerais-Amice and Magnier, 2012)

This document describes management projects for eight invasive species (both plant and animal), of which five are found more or less exclusively in aquatic environments (groundsel bushes, pampa grass, water primrose, Asian knotweed, American mink) and one in coastal marine environments (smooth cordgrass). Following a presentation of each species (origin and distribution, description and ecology, management recommendations), the document reviews a total of 15 management interventions for the six species. The information for each example includes a description of the site, the methods and resources employed, and the results obtained. The contact information for the managers of each intervention is listed at the end of the document.
(http://www.bretagnevivante.org/images/stories/Reserves/Forum_gestionnaires/recueil%20esp%C3%A8ces%20invasives_2012.pdf)

- Management feedback from the Loire basin (Loire Nature resource centre)

A database on the management of natural environments in the Loire basin presents management projects targeting IASs. The database provides detailed information on the projects, habitats, project context, costs involved and the contact information of the managers.
(http://centrederessources-loirenature.com/home.php?num_niv_1=1&num_niv_2=5&num_niv_3=21)

- Invasive alien vertebrates in the Loire basin (not including fish), Knowledge gained and management feedback (Sarat (editor), 2012)

This book, the product of a collective project coordinated by the National agency for hunting and wildlife (ONCFS) in the framework of the Loire Grandeur Nature plan with funding from the Loire-Bretagne environmental directorate and ERDF, describes the invasive alien vertebrate species present in the Loire basin and presents feedback from management projects.
(http://centrederessources-loirenature.com/mediatheque/Faune_inva/Vertebres_exotiques_envahissants.pdf)

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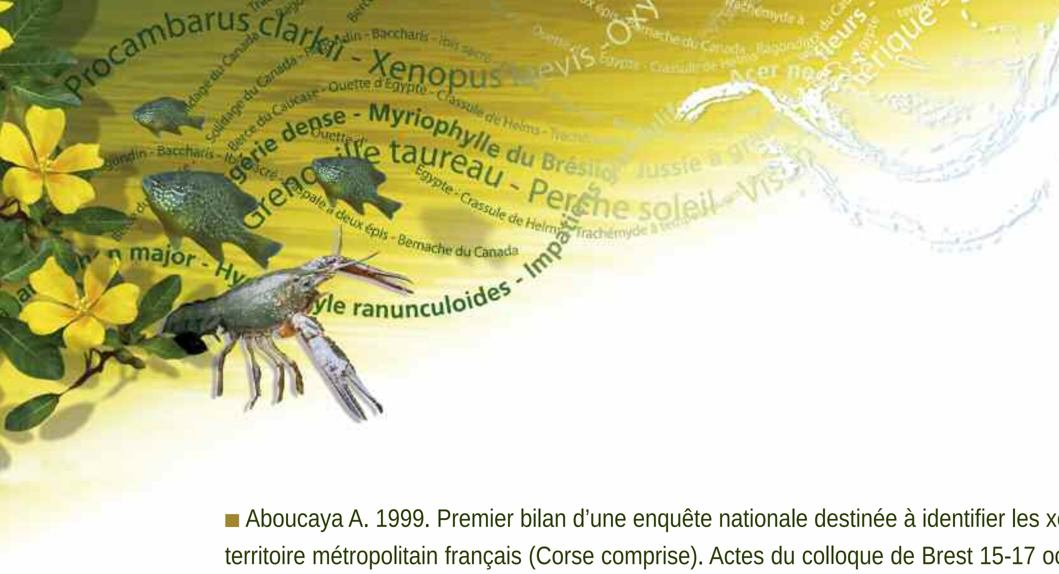

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- Dorine Vial (Conservatory for natural areas in the region Centre)

Editors

- Emmanuelle Sarat (IUCN French committee)
- Emilie Mazaubert (Irstea)
- Alain Dutartre (independent expert, formerly at Irstea)
- Nicolas Poulet (Onema, Research and development department)
- Yohann Soubeyran (IUCN French committee)

Authors

- Emmanuelle Sarat (IUCN French committee)
- Alain Dutartre (independent expert, formerly at Irstea)
- Emilie Mazaubert (Irstea)

Publication

- Véronique Barre (Onema, Research and development department)
veronique.barre@onema.fr

Translation

- Bartsch & Cie (info@bartsch.fr)

Graphic design and layout

- Béatrice Saurel (saurelb@free.fr)

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Contact: veronique.barre@onema.fr
http://www.onema.fr/IMG/EV/cat7a.html

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Invasive alien species (IAS) and their impacts represent a growing concern for the managers of natural areas. That is particularly true for aquatic environments where an array of stakeholders are now taking action. Public policies on the French and European levels are also coming into play.

What is the status of current knowledge on biological invasions? What is the applicable legal framework and what recommendations should be made? In the field, which species are managers attempting to address? Which techniques are used, where and how, and what are the objectives and the results achieved?

For these two volumes of the *Knowledge for action* series, almost 100 experts collected the information required to clearly present the situation and propose a scientifically based approach to assist water managers in setting up management projects.

This first volume, titled *Practical information*, presents the current situation concerning the management of invasive alien species in aquatic environments. Though no "cure alls" currently exist, this volume offers highly useful information while attempting to address the specific aspects of each situation.

The second volume, titled *Management insights,* illustrates the situation discussed in the first volume with feedback from management projects in continental France and Europe.

Emmanuelle Sarat, a scientific officer for invasive alien species at the IUCN French committee, has managed the Biological invasions in aquatic environments (IBMA) work group since 2014.

Emilie Mazaubert, a research engineer at Irstea from 2009 to 2013, participated extensively in the work at IBMA over the period, drafting a large number of research reports and promoting the work, while managing the work group and acting as group secretary.

Alain Dutartre, an independent hydrobiologist (formerly at Irstea), has worked for almost 40 years on aquatic plants (native and alien) and their management. As a founding member of the IBMA work group, he has contributed to research work and efforts to assist water managers in improving the management of invasive alien species.

Nicolas Poulet, a scientific officer at the Onema Research and development department, has worked to establish research and management projects on both invasive and patrimonial species and participated in managing the IBMA work group.

Yohann Soubeyran, a scientific officer for invasive alien species at the IUCN French committee, has managed a special project on IASs in the overseas territories since 2005. In 2014, he joined the management team at the IBMA work group.

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