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Briefing **34**

Invasive alien species

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Summary

- *Globalisation of trade has led to an exponential increase in invasive alien species, which pose a threat to biodiversity, health and the functioning of ecosystems.*
- *In France, the economic losses have been estimated at between €1.2 and €10.6 billion over 25 years, ranking in third place among European countries.*
- *The national strategy to combat the spread of invasive species must be based on early detection methods, improved controls and raising public awareness. It must also be accompanied by relocalisation of the economy.*

Mr Hendrik Davi, Member of the National Assembly

Introductions by humans of non-native species into new habitats date back thousands of years. They have increased exponentially with the globalisation of trade, however, and this has exacerbated the damage to biodiversity, human health and agriculture. Not all alien species are invasive, but the current explosion increases the likelihood of some of them causing damage to vernacular ecosystems.

The concept of invasive alien species

Introducing species into the environment

Humans have always introduced new species into the environments where they live. [1] Nowadays, introductions are linked to horticulture, fish-keeping or agriculture, or are unintentional, as is the case with insects transported along with plants or manufactured objects, or algae caught on a ship's hull.

Factors in the presence of alien species in France

In Metropolitan France, about 2,400 alien species have been identified. Our country is open to the world with its seaports and airports. France is also the world's top tourist destination. In addition, Metropolitan France has a close relationship with the country's overseas territories, with their wide variety of different climates. All of this increases the risk of introducing alien species. Finally, France is lagging behind other countries in the fight against invasive alien species, which was only enshrined in law in 2016.

The role of globalised trade

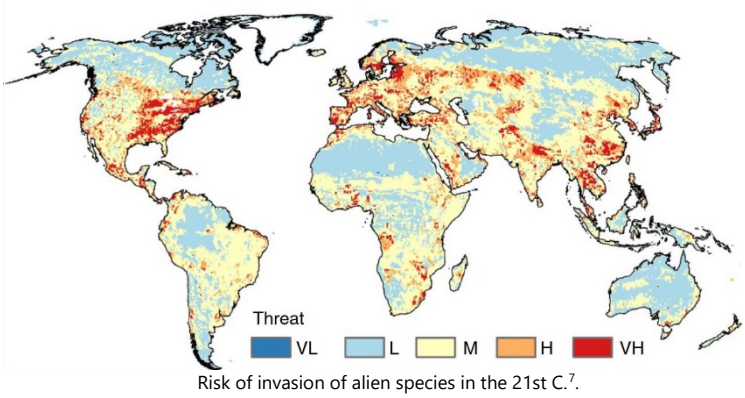
The transport of goods and people is the main vector in the introduction of species. Globalisation has been accompanied by an explosion in such exchanges and therefore in introductions.

It has opened up new routes between different biogeographical regions, while reduced transport times have enabled short-lived organisms to survive the journey.

The increase in introductions began in the Middle Ages[2] with the great explorations, and has gathered steam since 1950. The process has acquired a worrying exponential momentum around the world,[3] although it does vary between groups of species: it is levelling out or declining for mammals and fish, but still growing exponentially for crustaceans, algae and invertebrates.[4] In France, since the 1980s, each Department has seen an average of 12 new species arrive every 10 years.[5]

The alien nature of a species is not necessarily a problem. A species is considered invasive when its introduction, establishment or spread have negative consequences on the environment, biodiversity,

human health, agriculture or other economic sectors.[6]



Risk of invasion of alien species in the 21st C.[7].
VL: very low, L: low, M: medium, H: high, VH: very high

Intrinsic factors affecting the success of invasive species

Some species have biological traits that enable them to establish themselves and reproduce in new environments. For instance, the desiccation resistance of tiger mosquito eggs gives this species a high capacity for dispersal, for example in tyres, which are the subject of sustained international trade.

However, there is no standard profile for an invasive alien species. The success of an invasion depends on a combination between the traits of the invasive species, the communities of species present in the invaded environment, and its environmental conditions.

Extrinsic factors

The composition of the communities and the environmental conditions of the ecosystems into which invasive species are introduced determine how they are naturalised and spread. The absence of predators or parasites to regulate populations of alien species gives them an advantage.

Anthropic pressures on environments, such as changes in land use and pollution, can damage ecosystem functioning, making ecosystems more susceptible to invasions. Although climate change only plays a minor role in the risk of introduction, it does create conditions that are more conducive to the development of new species[8] and can amplify the harmfulness of the alien species. In the case of the tiger mosquito, climate warming extends the season when it is active and therefore the period when it can cause harm.

Alien species and invasive species: two partly subjective notions

The invasive nature of a species is subjective. Conservation ecology initially considered any naturalised alien species as an invasive one[9]. The definition has since been restricted to naturalised alien species that have a negative economic, health or environmental impact.[10]

There is also a subjective element in the alien nature of a species. Indigenisation takes less than a century when the introduced species enters the cultural heritage, as has been the case with the flame tree (*Delonix regia*) on Reunion Island.[11] In Australia or New Zealand, where the adverse effects of biological invasions have been observed for a long time, the population is aware of the risk and continues to see these species as alien.

■ Damage caused by biological invasions

Loss of biodiversity

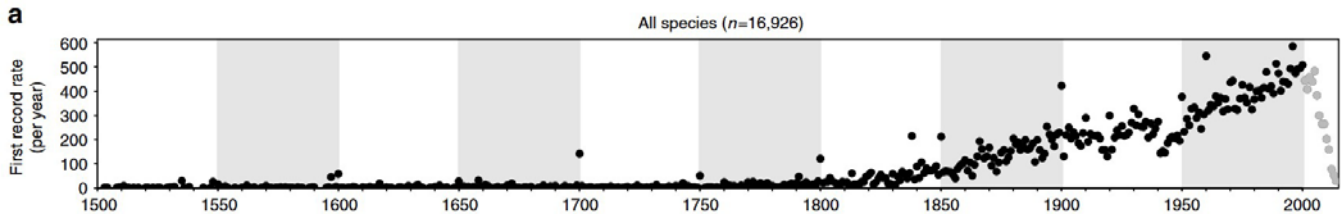
The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) ranks invasive alien species as the fifth-largest threat to biodiversity. They have contributed to the extinction of 25% of plants and 33% of animals (and even 42% of reptiles and 47% of mammals) since the end of the Middle Ages,[12] and these percentages could well increase due to the recent acceleration in introductions and shortening of the time lag between introduction and extinction.

Islands are more susceptible to such invasions, as they offer no "fallback solution" to autochthonous species.

Disruption of human activities

The environmental damage caused by invasive alien species can have significant economic consequences. This is the case with water primrose, for example, which clogs up waterways and prevents navigation. The spread of the Asian hornet across France poses a threat to bee populations as it feeds on bees and attacks hives.

Overall, invasive alien species are involved in the loss of 5% of global agricultural production.

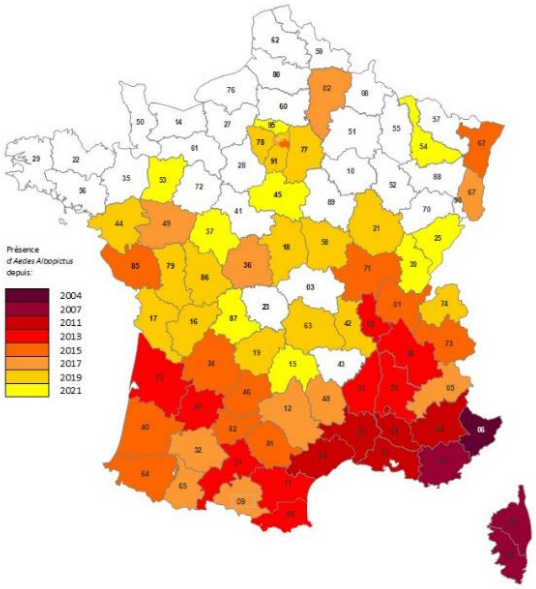


Global temporal trends in first record rates for all species. The data shown in grey at the far right of the graph is not included in the analysis because it has not been consolidated; https://doi.org/10.1038/ncomms14435

Health consequences

Common ragweed pollen is a strong allergen[13] and as such has an effect on the health of millions of French people.

The tiger mosquito has colonised Metropolitan France over the last twenty years. It is a vector of several infectious diseases: Zika, chikungunya and dengue fever. The latter is expected to become endemic in Metropolitan France in the next few years.[14]



Distribution of the tiger mosquito in Metropolitan France, between 2004 and 2021[15]

Economic cost of the damage

The economic cost associated with invasive alien species in France is estimated to have been between €1.2 and €10.6 billion over the period 1993-2018.[16] France is the third-most impacted country in Europe financially.[17] The most affected sectors are healthcare (€288m) and agriculture (€229m).

The plants responsible for the highest cumulative costs are common ragweed (€553m), water primrose (€31m) and Japanese knotweed (€1.8m); among invertebrates, it is the tiger mosquito (€410m), followed by the Asian hornet (€2.3m). Vertebrates – the rusa deer, the rat, the American bullfrog and the domestic cat – induce lower costs.

Many costs are difficult to assess: these estimates therefore only account for a part of the real economic burden of biological invasions.[18]

The French regulatory framework

The Biodiversity Act(1) has provided a framework for the fight against invasive alien species, by transposing European Regulation no. 1143/2014 of 22 October 2014 into French law.

Invasive alien species are subject to two prohibitions: on introducing them into the natural environment(2) and on possessing, trading, transporting and using them.(3)

The list of species concerned includes those that are of concern to the EU, in application of the European Regulation; there are 88 species on the list.(4)

The Veterinary and Phytosanitary Border Inspection Office (SIVEP) is in charge of checking that imported animals and plants are not on the list of invasive alien species. The environmental inspectors of the French Biodiversity Agency (*Office français de la biodiversité*, OFB) are in charge of making checks within the country, especially in garden centres and pet stores.

The overseas territories also have two levels of regulation. The first restricts the introduction into the natural environment to native species. The second is similar to the regulations in force in Metropolitan France.

(1) Law no. 2016-1087 of 8 August 2016 for the restoration of biodiversity, nature and landscapes.
(2) Article L. 411-5 of the Environment Code
(3) Article L. 411-6 of the Environment Code
(4) http://data.europa.eu/eli/reg_impl/2016/1141/2022-08-02/fra

■ Better control of biological invasions

Prevention and awareness-raising

Eradicating an established invasive alien species is always costly and often impossible. It is therefore preferable to prevent its introduction or intervene early.[19]

As introductions are linked to globalisation, it is necessary to reduce trade globally, when the overall environmental footprint is high. It is also essential to inform the economic actors involved and the general public in the areas affected, such as ports and airports.

Raising awareness among the population generally is another way of limiting introductions.[20] We must promote responsible uses of the alien species available in garden centres and pet shops, for example by means of specific labelling, which will require the participation of professionals.[21]

Control of pathways of introduction

Imports of invasive alien species are controlled by the veterinary and phytosanitary inspection service, which checks that animals and plants imports do not include species whose trade and transport are prohibited and

that the appropriate permits have been sought.[22]

There are limits to these controls. In particular, they are not carried out on items purchased online and the list of prohibited species only has 88 species on it out of an estimated 4,000 invasive alien species in Europe. Many species actually considered as invasive by the scientific community therefore continue to be traded and transported legally. We probably need to think about the lists of prohibited species [23] and control garden centres and pet stores more effectively.

Concerning the routes of unintentional introduction, controls are virtually non-existent. Countries that actively guard against invasions opt for border control methods involving quarantines and biocidal products.

Early detection of new alien species

To take early action, surveillance of the introduction and spread of naturalised alien species is necessary. This may involve innovative techniques, such as metabarcoding,[24] or more prosaic ones, such as insect traps, which when placed around exchanges zones can detect an invasion at the earliest stage.[25] Another idea put forward by researchers is to plant "sentinel forests" on other continents.[26]

However, these initiatives are not sufficiently coordinated within a national surveillance system, even though this is required by the European regulations.[27] Although the Invasive Alien Species Resource Centre (*Centre de ressources Espèces exotiques envahissantes*[28]) advises managers on good practices, the management of alerts remains inadequate. An inter-ministerial unit could be set up to coordinate early detection as part of a wider objective of biosecurity.

On the ground, detection of invasive alien species is not a priority due to a lack of human resources and funding. The French Biodiversity Agency (OFB),[29] which checks that there are no prohibited species among those on sale, is understaffed. Decentralised state departments such as the DREAL (environment local agency) should ensure that the control objectives are properly applied and have genuine powers of intervention.

Management of invasive alien species

Once invasive species have become established, we must aim to eradicate them [30] or control their population.

Biological control uses biological agents introduced as predators or parasites of a species to be regulated or eradicated. In Italy, a particular species of beetle which eats ragweed leaves was introduced to combat the plant.[31] Chemical biocides are often used in the fight against mosquitoes that carry infectious diseases, such as the tiger mosquito.[32]

Innovative technologies have been developed to fight the vectors of disease, but a regulatory vacuum[33] makes it difficult to carry out large-scale experiments.[34]

- the **sterile insect technique**, which consists of releasing males sterilised by X-ray;[35]

- the **incompatible insect** technique, which achieves the same aim by releasing mosquitoes infected with a bacterium, Wolbachia,[36] into the natural environment;

- the **gene drive** [37] process, which consists of transmitting a genetic modification introduced into laboratory mosquitoes into the wild population.

In addition to direct control, **preserving ecosystems** can increase their resilience to invasions. Mixed forests are hosts to more generalist natural enemies of exotic pests[38] and protected areas provide refuges for species threatened by invasive alien species.

Conclusions and recommendations

- To limit the introduction of invasive alien species, it is necessary to consider ways of limiting exchanges **by relocalising our economy**.
- It is essential to develop **an effective natural surveillance strategy in coordination with scientists,** and to provide the decentralised state departments with adequate resources. This strategy will necessarily be an inter-ministerial one.
- The fight against invasive alien species must be the subject of **international coordination**.
- Once the IPBES report on invasive alien species is published and depending on the commitments made at the COP15 Biodiversity Conference, **a re-assessment of the national invasive alien species strategy** of 2017[39] will be necessary.

OPECST website:
http://www.assemblee-nationale.fr/commissions/opecst-index.asp
http://www.senat.fr/opecst

Persons consulted

- Mr Franck Courchamp, CNRS research director, head of the Biodiversity Dynamics and Macro-Ecology team at the Ecology, Systematics & Evolution laboratory at Paris-Saclay University, in charge of the Invacost research project;
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- Mr Gilles Escarguel, lecturer-researcher at the Laboratory of the Ecology of Natural and Anthropised Hydrosystems at Claude Bernard University Lyon 1;
- Mr Fabrice Chandre, IRD research director on the Strategies for combating vector-borne diseases team at the Infectious and Diseases and Vectors: Ecology, Genetics, Evolution and Control Laboratory;
- Mr Frédéric Simard, IRD research director and head of the Infectious and Diseases and Vectors: Ecology, Genetics, Evolution and Control Laboratory;
- Mr Cyril Cottaz, invasive alien species lead at the National Mediterranean Botanical Conservatory of Porquerolles and coordinator of the ten-year ecological restoration programme at the *Réserve Intégrale de Bagaud* (scientific reserve) (Port-Cros) ;
- Ms Sylvie Varray, invasive alien species lead at the Federation of Conservatories of Natural Areas (*Fédération des conservatoires d'espaces naturels*), Ms Clara Erard, invasive alien species lead for the Loire drainage basin and Mr Alan Meheust, lead for the Rhône drainage basin;
- Ms Anne Atlan, CNRS research director at the Spaces and Societies unit at the University of Rennes 2;
- Mr Yohann Soubeyran, invasive alien species lead at the French Committee of the IUCN;
- Mr Hervé Jactel, INRAE research director on the Diversity of Biotic Interactions and Functioning of Forest Ecosystems team at the Genes & Communities Laboratory at the University of Bordeaux, corresponding member of the Academy of Agriculture;
- Mr Alain Roques, INRAE emeritus research director in the Forest Zoology Unit at the Orléans INRAE Centre.
- Mr David Renault, professor at the Ecosystems, Biodiversity, Evolution Unit at the University of Rennes 1, coordinator of the InvaBio Research Consortium;
- Mr Olivier Chabrerie, lecturer-researcher at the Ecology and Dynamic of Anthropised Systems Laboratory at the University of Picardy, coordinator of the InvaBio Research Consortium;
- Mr Denis Couvet, professor at the *Muséum national d'Histoire naturelle*, member of the Academy of Agriculture and President of the Foundation for Biodiversity Research;
- Ms Hélène Soubelet, general manager of the Foundation for Biodiversity Research;
- Mr Eric Marois, CNRS research director on the Immune Responses in the Malaria Vector Anopheles gambiae team at the Institute of Molecular and Cell Biology in Strasbourg;
- Mr Jean-Luc Imler, professor of cell biology at the University of Strasbourg and member of the Scientific Council of the OPECST;
- Ms Virginie Courtier-Orgogozo, research director at the CNRS, head of the Genetics and Evolution team at the Institut Jacques Monod and member of the Scientific Council of the OPECST.

Written contribution from the French Biodiversity Agency (OFB).

Références

[1] In particular for food production purposes: wheat, potato, maize, etc.

[2] Ecologists generally consider that the 1500s marked a turning point: it was then that inter-continental trade began to develop, bringing species introductions with it. The landmark event being the first voyages of the great explorers, including Christopher Columbus's first voyage to America in 1492. Palaeontology and archaeology do not allow us to document the dynamics of the introduction of alien species before the current historical period. The techniques they use do not provide a sufficiently precise temporal resolution: the distinction between invasion and geographical expansion – which is of the order of a kilometre a year for mammals, on average – is difficult to make. On islands, which are incomplete ecosystems, these techniques coupled with modern biological analysis techniques sometimes make it possible to distinguish between these phenomena. The oldest described trace of an introduction by human action of is that of the cuscus, a marsupial, introduced into an island in Papua New Guinea, 20,000 years ago; Hofman, Courtney A., and Torben C. Rick. "Ancient Biological Invasions and Island Ecosystems: Tracking Translocations of Wild Plants and Animals". *Journal of Archaeological Research* 26, no. 1 (1 March 2018): 65-115. https://doi.org/10.1007/s10814-017-9105-3.

[3] What appears to have been an exponential increase overall has in fact involved surges and lulls: increased momentum with the expansionist imperialism of the 16th century, the industrial revolution and the beginning of globalisation. This new era, often linked to the Anthropocene geological epoch, began after the Second World War with the implementation of the Marshall Plan. The 1973 oil crisis may have had an impact on this rise, which was then further boosted by China's entry into the globalised economy. Hulme, Philip E. "Trade, Transport and Trouble: Managing Invasive Species Pathways in an Era of Globalization". *Journal of Applied Ecology* 46, no. 1 (2009): 10-18. https://doi.org/10.1111/j.1365-2664.2008.01600.x.

[4] Seebens, Hanno, Tim M. Blackburn, Ellie E. Dyer, Piero Genovesi, Philip E. Hulme, Jonathan M. Jeschke, Shyama Pagad, et al. "No Saturation in the Accumulation of Alien Species Worldwide". *Nature Communications* 8, no. 1 (April 2017): 14435. https://doi.org/10.1038/ncomms14435.

[5] Touroult, J., Witté, I. & Thévenot, J. 2016. *Construction d'un indicateur d'évolution de la distribution des espèces exotiques envahissantes en France métropolitaine. SPN report 2016-90*, Paris. https://inpn.mnhn.fr/docs/EspecesExotiqueEnvahissanteEEE/SPN-2016-90-Rapport_Indicateur_EEE-ONB.pdf. Updated data: https://naturefrance.fr/indicateurs/evolution-du-nombre-moyen-despeces-exotiques-envahissantes-par-departement.

[6] On average, 10% of introduced alien species are naturalised, and 10% of them, i.e. 1% of all introduced species, become invasive.

[7] Early, Regan, Bethany A. Bradley, Jeffrey S. Dukes, Joshua J. Lawler, Julian D. Olden, Dana M. Blumenthal, Patrick Gonzalez, et al. "Global Threats from Invasive Alien Species in the Twenty-First Century and National Response Capacities". *Nature Communications* 7, no. 1 (23 August 2016): 12485. https://doi.org/10.1038/ncomms12485.

[8] Pörtner, Hans-Otto, Debra Cynthia Roberts, Melinda M. B. Tignor, Elvira S. Poloczanska, Katja Mintenbeck, Andrès Alegría, Marlies Craig, et al., ed. Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, 2022. https://report.ipcc.ch/ar6/wg2/IPCC_AR6_WGII_FullReport.pdf.

[9] To define a biological invasion, some ecologists even prefer to focus more on the behaviour of an invasive species within an ecosystem than on its origin or its repercussions on human activities. Valéry, Loïc, Hervé Fritz, Jean-Claude Lefeuvre, & Daniel Simberloff. "In Search of a Real Definition of the Biological Invasion Phenomenon Itself". *Biological Invasions* 10, no. 8 (1 December 2008): 1345-51. https://doi.org/10.1007/s10530-007-9209-7.

[10] The IPBES stipulates more precisely that a species is invasive if it impairs ecosystem functions and services, which may include the impossibility of humans enjoying recreational use of the impacted ecosystems; IPBES (2019): *Summary for policy-makers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services*. Díaz, S. et al. IPBES secretariat, Bonn, Germany. 56 pages. https://doi.org/10.5281/zenodo.3553579.

[11] Humair, Franziska, Christoph Kueffer, and Michael Siegrist. "Are Non-Native Plants Perceived to Be More Risky? Factors Influencing Horticulturists' Risk Perceptions of Ornamental Plant Species". *PloS One* 9, no. 7 (2014): e102121. https://doi.org/10.1371/journal.pone.0102121.

[12] Bellard, Céline, Phillip Cassey and Tim M. Blackburn. "Alien species as a driver of recent extinctions". *Biology Letters* 12, no. 2 (29 February 2016): 20150623. https://doi.org/10.1098/rsbl.2015.0623.

[13] ANSES. "Impacts sanitaires et coûts associés à l'ambroisie à feuilles d'armoise en France - Rapport d'expertise collective", October 2020. https://www.anses.fr/fr/system/files/AIR2018SA0088Ra.pdf.

[14] Dengue fever, which causes serious epidemics in the French overseas territories is usually only present in Metropolitan France through imported cases. However, in 2022, as a result of the establishment of its vector mosquitoes, 65 autochthonous cases of dengue fever were recorded in the country. Now that the environment has become favourable to the transmission of the disease in Metropolitan France, it is likely to gradually become endemic in the years to come; "Chikungunya, dengue et zika - Chikungunya, dengue et zika - Données de la surveillance renforcée en France métropolitaine en 2022". Consulted on 18 November 2022. https://www.santepubliquefrance.fr/maladies-and-traumatismes/maladies-a-transmission-vectorielle/chikungunya/articles/donnees-en-france-metropolitaine/chikungunya-dengue-et-zika-donnees-de-la-surveillance-renforcee-en-france-metropolitaine-en-2022.

[15] Map based on data supplied by the Directorate General for Health (*Direction générale de la santé*); https://solidarites-sante.gouv.fr/IMG/pdf/extension_moustique_departements_annee_2004_a_2021.pdf.

[16] Estimates based on the most reliable data concerning 98 species (27 vertebrates, 14 invertebrates and 55 plants). Only reported costs are analysed. They concern 27 species of vertebrates out of the 140 alien species listed in the GISD and GRIIS databases, 14 species of invertebrates out 1002 and 55 species of plants out of 1552; Manfrini Eléna, Leroy Boris, Diagne Christophe, Soubeyran Yohann, Sarat Emmanuelle, Courchamp Franck. 2021. *Les coûts économiques des invasions biologiques en France. Synthèse à l'intention des décideurs.* Paris, France; https://invacost.fr/wp-content/uploads/2021/08/RapportCoutsFrance.pdf.

[17] Almost 80% of the costs generated relate to the damage and loss caused, whereas in Spain, 80% of costs relate to the efforts to manage these species.

[18] In addition, as the time lapse between the observation of the damage and the introduction causing can be long, the estimated costs will increase, because the pace of introductions has not slowed. As the cost of managing a species when it is introduced is marginal compared to that of managing it once it has become well established, the cost of inaction must be taken into account when calculating the financial trade-offs. The quantification of the damage caused by invasive alien species to ecosystem services in monetary terms is an oversimplification insofar as not all types of damage can be measured in terms of costs, but it is a metric that allows comparisons to be made and the scale of the damage to be conceptualised.

[19] See the second figure in the annexes.

[20] It can also be a means of control. In the case of the tiger mosquito, efforts by local people to limit stagnant water help to control mosquito populations and limit the nuisance; Report of the Committee of Inquiry in charge of assessing the research, prevention measures and public policies required to combat the spread of the Aedes mosquito and vector-borne diseases, presented by Ms Ramlati Ali, Member of the National Assembly, July 2020; https://www.assemblee-nationale.fr/dyn/15/rapports/ceaedes/l15b3280-ti_rapport-enquete.

[21] An attempt by the Ministry for the Ecological transition to set up such a labelling system came to nothing. The initiative deserves to be taken up again.

[22] Information report of the fact finding mission on the proliferation of invasive plants and the means of addressing this situation on behalf of the Regional Development and Planning Committee, by Ms Nadia Essayan and Mr Patrice Perrot, Members of the National Assembly, July 2021; https://www.assemblee-nationale.fr/dyn/15/rapports/cion-dvp/l15b4391_rapport-information.

[23] Certain regions, and in particular the overseas territories for the first level of regulation, use "white lists" ("everything is prohibited, except the indigenous species"). This solution would no doubt be difficult to apply in Metropolitan France given the volume of trade and the consequent inadequacy of the control services. It is, however, possible to draw up a national list of species complementary to the European list, as the European Regulation allows, an exhaustive national list of invasive alien species for scientific purposes or lists of priority species for management purposes.

[24] Metabarcoding, mainly practised in aquatic environments, is used to identify the species present in an environment: the gene sequences found in a sample taken from the environment are sequenced to identify the species using genome databases.

[25] Such experiments are being conducted by researchers, in collaboration with operators, decentralised state departments and the Directorate General for Food (*Direction générale de l'alimentation*); https://draaf.nouvelle-aquitaine.agriculture.gouv.fr/IMG/pdf/Pour_diffusion_Denux_etal_2017_INRA_resultats_Portrap_et_ports_Aquitaine_cle0dfc13.pdf

[26] These plantations allow the identification of alien species which could become invasive in ecosystems similar to ours. They are made up of species of trees present in Metropolitan France; Roques, Alain, Jian-Ting Fan, Béatrice Courtial, Yan-Zhuo Zhang, Annie Yart, Marie-Anne Auger-Rozenberg, Olivier Denux, Marc Kenis, Richard Baker and Jiang-Hua Sun. "Planting Sentinel European Trees in Eastern Asia as a Novel Method to Identify Potential Insect Pest Invaders". *PloS One* 10, no. 5 (2015): e0120864. https://doi.org/10.1371/journal.pone.0120864.

[27] Article 14 of Regulation (EU) no. 1143/2014: "Within 18 months of the adoption of the Union list, Member States shall establish a surveillance system of invasive alien species of Union concern, or include it in their existing system, which collects and records data on the occurrence in the environment of invasive alien species by survey, monitoring or other procedures to prevent the spread of invasive alien species into or within the Union."

[28] The Invasive Alien Species Resource Centre (*Centre de ressources Espèces exotiques envahissantes*) was set up by the French Biodiversity Agency (OFB) and the French Committee of the IUCN to support the actors confronted with the problem of invasive alien species. The Centre provides technical support based on accumulated experience and feedback. It is a federation of the actors involved in the management and control of invasive alien species. The network is supported by a network of scientific and technical experts; http://especes-exotiques-envahissantes.fr/centre-de-ressources-especes-exotiques-envahissantes/.

[29] There are 1700 environmental officers who carry out these checks, raise awareness and record offences. Their actions to prevent the introduction of invasive alien species leads them, in particular, to check pet stores and garden centres; https://www.ofb.gouv.fr/police-de-lenvironment.

[30] Total eradication is rarely achieved. Eliminating enough individuals, beyond the species' natural renewal threshold, will be enough for a species to go into decline.

[31] Revised opinion and ANSES Report on the effectiveness of the *Ophraella communa* beetle used as a biological control agent against common ragweed and assessment of any associated risks, French Agency for Food, Environmental and Occupational Health & Safety (ANSES), June 2019; https://www.anses.fr/fr/system/files/SANTVEG2015SA0078Ra.pdf.

[32] An insecticide targeting the larvae (*Bacillus thurigensis israelensis* (Bt) toxin) is used during the dengue fever inter-epidemic period, while, during the epidemic period, it is an insecticide targeting the adults that is used. This is the case in Metropolitan France, in particular, in the area around dengue fever cases, whether they are imported or autochthonous, to prevent virus-carrying adults spreading it to other people.

[33] For example, a question remains about the status of mosquitoes modified to be carriers of certain strains of Wolbachia: although the bacteria strain is considered as a biocide, the modified mosquito carrying the strain is not.

[34] And yet experimentation is necessary to evaluate these techniques, which often raise ethical issues. Trials are taking place, though, in Reunion, New Caledonia and French Polynesia.

[35] Male mosquitoes are raised in a laboratory, irradiated to sterilise them and released into the environment in order to enter into competition with fertile males and reduce the species' reproductive capacity. This is not a viable technique for Metropolitan France insofar as it requires large quantities of laboratory-bred mosquitoes and therefore excessive human resources. Furthermore, the technique works in restricted environments, but its success in open environments is uncertain.

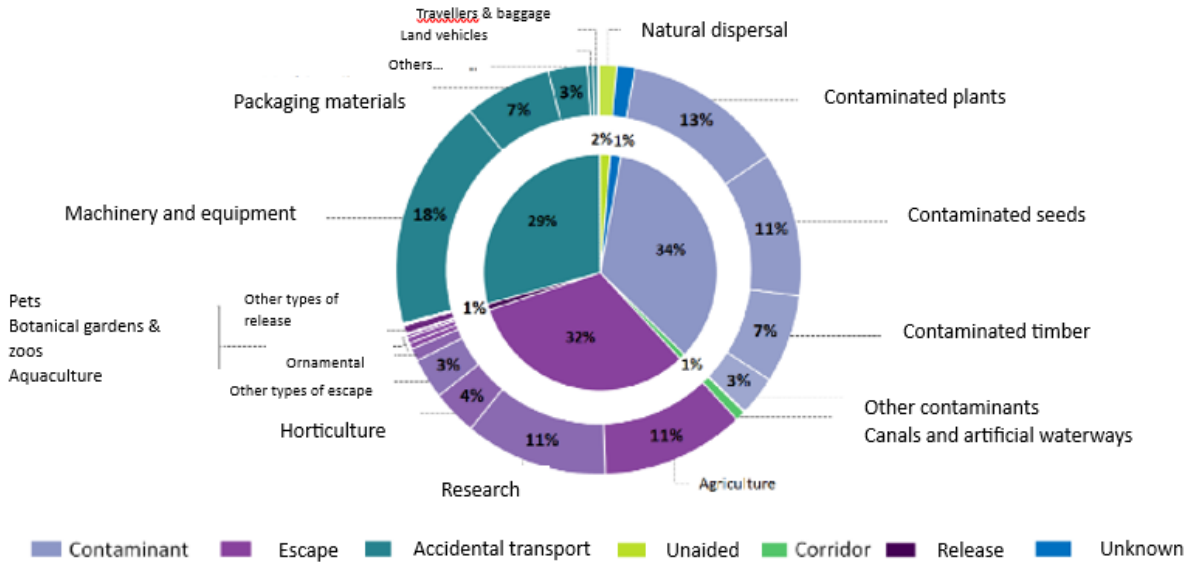
[36] Wolbachia is a bacterium that colonises many insects – infection not being lethal. The incompatible insect technique consists of introducing males carrying a certain strain of Wolbachia into a population not infected, or infected by a different strain. By a mechanism of cytoplasmic incompatibility, the embryos produced when these individuals mate do not develop. Infection by certain strains of Wolbachia can also lead to less effective transmission of a virus, meaning it can be used to combat disease vectors by replacing one population of vector mosquitoes by another with a lower transmission capacity.

[37] A gene drive is a genetic engineering technique that propagates a genetic modification in a target population, through the generations. The genetic modification may be aimed at eradicating the population or preventing it from transmitting a virus. Genetic engineering can override the laws of genetics to ensure the propagation of the modification to the target population. *Report of the Parliamentary Office for Scientific and Technological Assessment (OPESCT) on the economic, environmental, health and ethical issues relating to biotechnologies in light of new research avenues,* presented by Mr Jean-Yves Le Déaut, Member of the National Assembly, and Ms Catherine Procaccia, Senator, April 2017; https://www2.assemblee-nationale.fr/documents/notice/14/rap-off/i4618-tI/(index)/rapports.

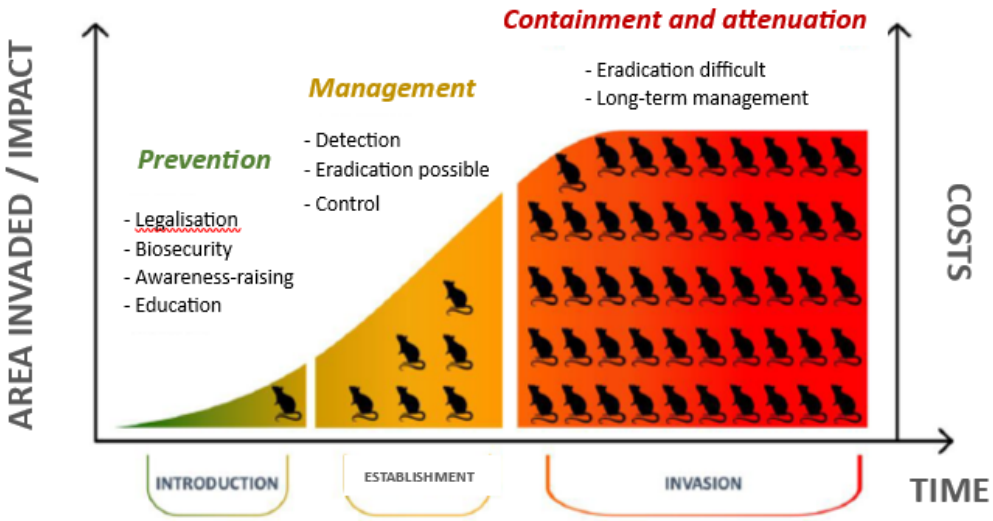
[38] Jactel, Hervé, Xoaquín Moreira & Bastien Castagneyrol. "Tree Diversity and Forest Resistance to Insect Pests: Patterns, Mechanisms, and Prospects". *Annual Review of Entomology* 66, no. 1 (2021): 277-96. https://doi.org/10.1146/annurev-ento-041720-075234.

[39] National strategy on invasive alien species (*Stratégie nationale relative aux espèces exotiques envahissantes*), 2017; https://www.ecologie.gouv.fr/sites/default/files/17039_Strategie-nationale-especes-exotiques-invahissantes.pdf

Annex: figures from Manfrini, et al. 2021. *Les coûts économiques des invasions biologiques en France. Synthèse à l'intention des décideurs.* Paris, France; https://invacost.fr/wp-content/uploads/2021/08/RapportCoutsFrance.pdf.



Proportion of the cumulative costs according to the main pathways of introduction into France between 1998 and 2018. The inner circle represents the proportion of the cumulative costs of the 7 main pathways of introduction while the external circle represents the 44 subcategories of these 7 main pathways. Subcategories representing less than 1% of the proportion do not show the percentage.



Invasion curve illustrating that the area invaded by invasive alien species, but also their impacts, follow a logistical curve: slow at the beginning, then accelerating exponentially before reaching a plateau. The initial phase, associated with the introduction, has negligible impacts, over a negligible area, and is conductive to preventive management actions. The next phase, establishment and spread, requires increasing reactive efforts. Finally, once the invasion is firmly established, the only management actions possible are costly and relatively ineffective, while the impacts are at their highest. Consequently, the economic costs of both management and impacts follow the same progression, demonstrating the need to react as soon as possible after an invasion.