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Defining an invasive species

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Summary
The definition of an invasive species will depend on the viewpoint of the observer, who in some cases may be responsible for introducing the species. History has taught us that humans are the species that has invaded the largest surface area of the planet. So, before going on to propose a few definitions, this article describes three different examples or types of example in which domestic animal species, wild animal species and microorganisms (for biological pest control) have been transported intentionally. By doing so, this paper uses a variety of situations to support the definitions. A contemporary argument would counter a strictly biogeographical definition with a more ecological definition. The two are probably complementary. In any case, these definitions should remain practical. The consequences of species movements vary. However, their health impacts should not be underestimated.

Keywords
Alien species – Casual species – Invasion process – Invasive species – Naturalised species.

Introduction

The description and analysis of the natural distribution of species on the planet, both in the sea and on land, belong to an ancient discipline of biology known as biogeography. The colonisation of the continents by living organisms and the history of their establishment provide ample evidence of the adaptive and evolutionary capacity of life (6). Each region of the world is inhabited by its own set of characteristic species. Over the course of one or more human lifetimes, such species distributions appear fairly stable. Besides the distribution of animal species, the human species is now present on virtually every land mass on earth today, having fanned out from its native Africa several hundred millennia ago to discover all the earth's different habitats and ecosystems (7). After the first waves of settlement, which spread into virgin lands, human movements continued. Some peoples went on to invade already inhabited neighbouring territories, supplanting their former occupants, and the successive intermingling of populations continued, with varying degrees of discontent or satisfaction. At first, all these movements were on foot. Means of transport were developed with the advent of navigation and its successive improvements right up until the Age of Discovery and a short time afterwards. The domestication of the horse was another major milestone. In much more recent times, the industrial revolution accelerated and intensified these movements significantly, and this has continued ever since. In these early years of the 21st Century, an estimated 2 billion passengers travel by air every year. On a planetary scale, humans are the best example of an invasive species!

It has become increasingly evident that, since the outset, humans have not travelled alone. They have always carried with them their parasites and commensals, their food and ornamental crops and their favourite animals, with the list growing longer and more diverse with each successive millennium. Following the Neolithic Revolution around 11,000 years ago, and the domestication of a few plant and animal species, the phenomenon shifted into a new dimension (35). Gradually certain species came to be labelled universally as 'useful' and began to be developed anywhere the environmental conditions were suitable, whereas others became known as 'harmful', irrespective of their biological reality. This culminated in the 19th Century in the work of zoologists such as Isidore Geoffroy Saint-

Hilaire (16) in France, who developed the notion of acclimatisation, i.e. the introduction of species into new areas in order to add variety to the local flora and fauna. Although doubtless not new, acclimatisation really started to become a large-scale phenomenon during that period.

Some acclimatisation attempts were supported by governments or powerful, well-organised structures. They never prevented other movements which, while much less numerous, have sometimes had an impact disproportional to the volumes or quantities moved. These movements included the transport of extremely diverse species, either intentionally or accidentally, for countless reasons, more often than not personal and with no structured intent or pre-established strategy (9). Some of these species are labelled 'invasive' today. Such movements have been occurring since time immemorial. They may be the action of just a few people, but in some cases they have consequences for entire communities. It is undoubtedly impossible to propose a single coherent typology of all such movements because the reasons behind them have varied so widely in time and space. However, in brief, it is possible to distinguish several types of movement:

– the intentional movement of species for utilitarian purposes, chiefly domestic animals, but also a few cases of wild species for use in biological pest control

– the movement of companion, game and recreational species

– accidental movements.

All we know for certain is that such accompanied travel has been going on for as long as humans themselves have travelled, and it continues today.

Another problem in defining this phenomenon is the very different views people can take, depending on which side they stand. Those responsible for the movement may sincerely believe that they are enhancing the target environment, whereas their neighbour may consider it only as the arrival of an exogenous species that threatens the host ecosystem. The outcome of such an introduction is just as difficult to foresee. It may be that nothing happens or, on the contrary, the newcomer may spread massively in its adoptive environment, either immediately, after a short time, or much later. It may also die out fairly rapidly.

The movement of domestic plant or animal species is rarely considered a potential type of biological invasion, although from a certain standpoint that is just what it is. At the botanical level, examples include the presence on the tropical shores of every continent of the traveller's tree (*Ravenala madagascariensis*) and royal poinciana (*Delonix regia*), both originating from Madagascar; the frangipani (*Plumeria rubra*) and coconut palm (*Cocos nucifera*), probably both from the Americas; the African she-oak (*Casuarina equisetifolia*); the Brazilian rosewood (*Jacaranda mimosifolia*) and the Indian almond (*Terminalia catappa*) (18, 22). Although these species are not necessarily invasive, they are just a little too widespread for botanists, who view this as the standardisation and globalisation of landscapes that were formerly much more characteristic. The natural plant diversity of these lands is sometimes reduced as a result, because the imported plants are often favoured over local species. Moreover, it can be difficult to ascertain the precise geographical origin of certain crop and ornamental plants as there have been many movements over thousands of years.

An ornamental plant species that has become almost universal is the shrub verbena (*Lantana camara*), which originated in tropical America. It is capable of invading huge swathes of cleared land to the detriment of indigenous flora. The plant is potentially toxic to livestock. There are many examples involving ornamental species (both plants and animals), but one of the most striking is the spectacle that greets modern-day visitors to Hong Kong (special administrative region of the People's Republic of China) where yellow-crested cockatoos (*Cacatua sulphurea*) fly free in Victoria Park (Fig. 1). These beautiful parrots, which come from Sulawesi, Indonesia, feed on seeds from the fruit of the Brazilian rosewood (or jacaranda).

If plant and animal colonisations are becoming standardised, so are their accompanying microorganisms. Indeed, potential pathogens are a special category of invasive species, even though their rules of movement are comparable to those of plants and animals. Sometimes a pathogen is transported intentionally. However, more often than not these microorganisms travel with their hosts,

Fig. 1
Yellow-crested cockatoo (*Cacatua sulphurea*) in a Brazilian rosewood (*Jacaranda mimosifolia*), Hong Kong
The parrots, an Indonesian species, escaped from captivity and are now a common sight in Hong Kong
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which are either clinically ill animals/humans or healthy carriers. They are real 'stowaways', which can therefore have health, as well as economic and ecological, impacts.

In all cases, it is easier to define an invasive species retrospectively than in advance. Although many acclimatisation attempts have come to nothing and probably only a minority have succeeded in establishing a line, sometimes they are spectacularly successful. Biological invasions have been an issue of particular concern to ecologists since the middle of the 20th Century. An international programme devoted to the study of biological invasions, entitled SCOPE (Scientific Committee on Problems of the Environment) began in 1982 and lasted for 10 years. Several comprehensive works were published following the SCOPE studies (see the list in 14 and 37). In his conceptual framework, Williamson (37) distinguished a number of phases in the invasion process. First there is the arrival and establishment of an exotic species, then its spread or the invasion proper, the equilibrium and effects, and lastly the implications. Williamson points out that nearly all invasions are linked with human importations, while other authors go so far as to attribute all biological invasions to human movements. In contrast, two *a priori* natural invasions of animals, which were fairly closely monitored, are the arrival from the Balkans of the Eurasian collared dove (*Streptopelia decaocto*) in Western Europe and that of the northern fulmar (*Fulmarus glacialis*) from Iceland, also in Western Europe over the North Atlantic (26, 37). In both cases, ornithologists were taken by surprise. Explanations are not lacking, and so far health officials have had no cause for concern, although the same cannot be said for all biological invasions.

A few rather more recent cases have involved range expansion, they include:

– the cattle egret (*Bubulcus ibis*), which crossed the Atlantic alone from east to west

– the great cormorant (*Phalacrocorax carbo*), which has returned to Europe in force after a severe population decline in the early 20th Century (26)

– the golden jackal (*Canis aureus*), again in Europe, from its historical population nucleus in the Balkans.

The golden jackal is now on the point of reaching Switzerland and Italy (2). It would, of course, be extremely interesting to ascertain the processes underpinning these natural invasions. However, this article is principally concerned with introductions and invasions that are linked to human movement.

Before proposing a few definitions, part one of this article discusses examples of biological invasion. It was considered easier to deduce the definitions afterwards. In the discussion, a distinction is made between biological invasions and other apparently similar phenomena that can be confused with them, such as migration, fluctuation, population cycles and natural expansion.

Examples of biological invasion

The examples can be divided into the three major groups mentioned earlier, namely, domestic species introduced for utilitarian purposes, recreational species, and 'accidental' (often wild) species; some demonstrative and 'universal' situations can then be sought. Although the term invasive species is more often than not reserved for non-domestic species or formerly domesticated species that have returned to the wild (feral populations), it was felt that it would be interesting to include in the discussion domestic animals that are still farmed and that are under control. Indeed, some invasion episodes can be attributed directly to domestic animals, or else to a combination of different situations associating wild and domestic species. Added to this is the fact that the movement of domestic animals is often encouraged, even though the health, economic and ecological consequences of such movements can be much more far-reaching than the consequences of the escape from captivity of a few individuals of an exotic wild species.

The case of cattle (*Bos taurus*), one of the oldest domesticated animals, illustrates the scale and severity of the health impacts that can occur. Another example concerning a domestic mammal is that of the pig, and the wild species from which it descended: the boar (*Sus scrofa*). Lastly, a classic example of the introduction of a domestic animal involves the domestic animal, the rabbit, with its wild form, the European rabbit (*Oryctolagus cuniculus*), and an exotic virus used for the latter's biological control, the myxomatosis virus. These examples are valuable in demonstrating the implications of movements, and the authors trust that they will provide a useful complement to other examples presented in this issue.

Cattle

Domestic cattle and their movements associated with the movements of human populations are a prime example of how a subject can elicit very different reactions depending on a person's standpoint, for instance, that of a herder as opposed to a crop farmer. Cattle were domesticated from their ancestral wild stock, aurochs (*Bos primigenius*), which are now extinct (8, 29). Although the estimated initial range of the aurochs must have extended over part of the Palearctic Region, the species never reached the Americas via Beringia during any glacial period or when the sea level dropped in the Quaternary period (34). At that time Kamchatka and Alaska were joined by a land bridge. The

first humans arrived in the Americas without cattle because they had crossed before cattle were domesticated. Later, cattle were prevented from crossing by the rise in sea level. Aurochs were not present in sub-Saharan Africa either. Cattle are believed to have been domesticated in two different areas, Mesopotamia and the Indus Valley, at approximately the same time, at least 8,000 years ago. In Mesopotamia, in the Near East, this gave rise to non-humped cattle, and in the Middle East, to humped cattle or zebus (20, 21). Later, herders and their cattle travelled and, in particular, invaded Africa in two waves, first with non-humped cattle, then more recently with zebus. The supplanting of local cattle breeds with zebus continues to this day, with a specific health and animal production consequence: the probable imminent loss of certain ancient breeds which were selected empirically *in situ* during the first millennia and which have become relatively resistant to trypanosomiasis, unlike zebus.

More recently, in the late 19th Century, the movement of domestic cattle between Asia and Africa led to the arrival on the African continent of the rinderpest virus (*Morbillivirus*). For a historical study of this phenomenon, refer to Barrett *et al.* (4) and Blancou (5). The introduction of the rinderpest virus as a result of the movement of cattle accompanying an expeditionary force had significant ecological, economic, health and political consequences. It was the spread of a rinderpest epizootic in the early 20th Century, originating from zebus introduced into Europe via the Belgian port of Antwerp, which led to the creation of the World Organisation for Animal Health (OIE) in 1924. Prior to that, in Europe, rinderpest seems to have always spread by invasions, in successive waves from the Eastern Steppes, although it never became endemic (32). In these early years of the 21st Century, however, we seem close to eradicating rinderpest from Africa, and perhaps the entire world (23).

The final example involving domestic cattle is that of the arrival of cattle in New Zealand with Europeans, beginning in the early 1800s. Clearly this explains the concomitant arrival of bovine tuberculosis caused by *Mycobacterium bovis*, at a time when biosecurity did not really exist. Quite independently, Europeans also happened to introduce an Australian species of marsupial into New Zealand, the common brushtail possum (*Trichosurus vulpecula*), for use as a game animal and also to 'enrich' what they considered a poor environment. The only mammals present in the archipelago before the arrival of humans were two species of bat (19). The first possums to be documented arrived in 1868 (19). There is no known information prior to that about any relationship between the possum and the mycobacterium. We now know that the possum is a particularly effective reservoir of the bovine bacterium in a range of environments where it has also established itself very successfully, causing real economic concerns to local cattle farmers.

The history of domestication is complex. The details regarding the start of each attempt, the species selected, the locations and the reasons behind the decisions taken are still unclear. While each successive phase in the improvement of knowledge provides us with a better understanding, it also shows us how complex the matter is. Even just the history of domestic cattle in association with herders and human populations highlights the many paradoxes associated with species invasions. There are intentional introductions and unintentional introductions. Sometimes these introductions are totally independent of each other, but in some instances they can occur in a single area, combining and sometimes causing very severe health consequences, in some cases rapidly and in others many years later. Bovine tuberculosis and rinderpest have travelled around the world with cattle. This can doubtless be termed an invasion. The rinderpest virus is probably the ancestor of the measles virus, and bovine tuberculosis is a zoonosis. The health impacts of domestication are significant.

Pigs and boar

The pig and the boar provide another illustration of the blurred and shifting boundaries of introductions and biological invasions. The study of these animals is a sphere where knowledge is evolving quickly. A recent publication on the ancient history of the pig in the Eastern Mediterranean shifts back the previously known dates of the start of the invasion process (36). The pig is an interesting animal because it can be found in a variety of states: free-roaming, wild and farmed. Moreover, unlike in the case of cattle and aurochs, the original wild stock still exists: the boar (*Sus scrofa*). At the same time, the wild form is bred for a variety of reasons: for game animals, for restocking, and for meat. The associated terminology is far from clear. Terms such as 'domestic boar', 'wild pig', 'pig reverted to the wild', 'feral pig' or 'free-roaming boar' can lead to confusion, whatever the language. The French have even coined the terms *sanglochon* and *cochonglier* to denote a cross between a wild boar (*sanglier*) and a domestic pig (*cochon*)! The boar naturally occupied vast swathes of temperate Eurasia, an area which corresponds to what the biogeographers call the Palearctic Region. Although it has died out fairly recently from the British Isles and from Cyrenaica and the Nile delta, it still exists in the Maghreb countries. Conversely, it is naturally absent from the Mediterranean islands, sub-Saharan Africa, North America and Australia. The 'boars' of the Mediterranean islands provide interesting testimony of the domestication phase when the first humans arrived several thousand years ago. In North America and Australia, however, feral pigs are descendants of animals introduced by the Europeans in the 16th Century and 19th Century, respectively. They most likely arrived with their associated accompanying microorganisms. The situation is even more complex in

Southeast Asia, where several species of the *Sus* genus coexist, having been moved among the Sunda Islands for many years. Certain endemic populations have died out, whilst others have hybridised with other wild boar species or with domestic pigs, which are often free-roaming. So, today, not only because of their history but also in the minds of the inhabitants, mainly crop farmers, animals of the biological species *Sus scrofa*, are considered an integral part of the local biological heritage, either as a valued game species or as an invasive species to be kept in check. Not all these viewpoints are necessarily mutually exclusive.

The ancient boar populations of the Mediterranean islands have gradually been supplanted by populations of continental boars and by selectively bred domestic pigs. Similarly, the boar is currently being reintroduced into the British Isles; it will be interesting to see how this situation develops (17). These reintroductions make it tricky to ascertain the direction in which viruses such as the classical swine fever virus or Aujeszky's disease virus circulate. More is known about the history of the arrival of the African swine fever virus in Europe and the Antilles. The presence of a free-roaming population of wild or feral pigs on the island of Sardinia makes any attempt to control this virus difficult. The recent introduction of the virus into the Caucasus and southern Russia is giving new cause for concern.

While wild boar populations can represent natural reservoirs for certain potential porcine pathogens and even zoonotic agents, populations of feral pigs can be considered introduced reservoirs, the outcome of a successful biological invasion.

Invasive species and biological control

Another well-known case of invasion is the pairing of the European rabbit (*Oryctolagus cuniculus*) with the myxomatosis virus. Their history is really quite extraordinary. In the earliest times, the natural range of the rabbit, which is now so common in many countries, either wild or farmed, or even as a companion animal, was very modest (10). The European rabbit's conquest of many areas of every continent illustrates the acclimatisation concept mentioned earlier. It is also an example of the introduction of an animal for hunting, not only for the purpose of providing protein (as in the case of the boar) but for recreational purposes too. In Australia the rabbit's impact has been spectacular (see F. Fenner's article in this issue). When, in the late 19th Century, a virus that was endemic in South America was discovered to be specific to leporids of the *Sylvilagus* genus, it was seized upon by some as the ideal weapon to vanquish invasive rabbit populations. While *Sylvilagus* is receptive but not susceptible, *Oryctolagus cuniculus* is susceptible and its mortality rate can be very high. In the early 20th Century there were two attempts to use the virus to control rabbit populations: one by the Australian government, beginning in 1937, and the other by a French private concern in 1952. To combat a species classified as invasive, an exotic virus was intentionally spread in the hope that a second biological invasion would eradicate or at least control the first pest (15). The result is well known. The first surprise is that in Australia several attempts were needed to achieve a result, whereas in France a single introduction was sufficient to spread the virus throughout Europe. The epidemiological role of fleas and mosquitoes was discovered during that period. The second surprise is that in neither country did either the virus or the host actually die out. So, in terms of biological invasion, it was a dual success! Since then, genetic studies have revealed the simultaneous presence of several virus strains and susceptibility profiles in the rabbit. In countries where the virus circulates and where rabbits are present, this dual genetic diversity persists.

This example clearly shows that the introduction of exotic species for biological control purposes is not something that should be rushed into in the future.

Discussion

Defining an invasive species

Now the authors attempt to propose a few definitions for this notion of invasive species, as well as for the phases in the invasion process. The SCOPE programme mentioned earlier, which was launched in 1982 (37), sought to answer three questions:

1. What factors determine whether a species will be an invader or not?

2. What are the characteristics of the environment that make it either vulnerable or resistant to invasions?

3. How can the knowledge gained from answering the first two questions be used to develop effective management strategies?

Answering these questions led to a few initial attempts at providing a definition of an invasive species. A simple definition was proposed by the DAISIE project (Delivering Alien Invasive Species Inventories for Europe) (13). Their definition suggests that a species should be classified as invasive when it colonises an ecosystem in which it has never been present before. The timescale considered is ecological, corresponds to the biological cycles and generation times of the species present, and does not evolve. The success of an invasion is increased if no predators or competitors of the introduced species exist or they have been eliminated. Introductions into naturally

or secondarily species-poor ecosystems have bigger impacts than introductions into areas in which natural diversity is high. The introduction of generalist herbivores will probably have a marked impact, especially where predators have been eliminated.

More recently, Pysek *et al.* (24) proposed a series of definitions close to those in the recently published glossary of the DAISIE project (13, see Chapter 14 in particular). More information about the DAISIE project can be found at their website (www.europe-aliens.org).

Alien species

A species which is not native to a region and which was introduced to that region through human activity. In this context, synonyms for 'alien' include: exotic, introduced, non-indigenous, non-native, allochthonous.

Casual species

An alien species whose continued presence in a region relies on its repeated introduction by human agency, for example by planting (and subsequent escapes from cultivation), release into the wild or the regular unintentional introduction of seeds.

Invasion process

A sequence of events and processes during which an introduced species faces, and potentially overcomes, various barriers to its establishment, proliferation and spread in a new region. After overcoming the geographical barrier between the native and target region, the species occurs as a casual alien. Those species that overcome reproductive barriers are considered naturalised. Invasive species are those with the ability to spread widely beyond their point of arrival into natural, semi-natural or man-made environments.

Invasive species

Invasive species are alien species that reach the final stage of the invasion process and have the capacity to spread. They are considered to have a highly detrimental impact in the regions concerned, not only on local biodiversity and on the way ecosystems work, but also on socio-economic parameters, including animal production and hence animal health, and lastly on public health. The Invasive Species Specialist Group (www.issg.org) of the Species Survival Commission of the International Union for Conservation of Nature (IUCN) refers to 'invasive alien species'. (Information about other specialist groups of the IUCN can be found on their website: www.iucn.org/about/work/programmes/species/about_ssc/specialist_groups.) (Additional information on invasive species can be found at www.invasivespeciesinfo.gov/ index.shtml.)

Naturalised species

An alien species is considered naturalised if it forms persisting populations and reproduces in the wild without subsequent human intervention. A naturalised species is not necessarily invasive.

This raft of terms illustrates the difficulty in finding a simple definition for a process that may develop over a certain period of time. This in no way reduces the potential detrimental consequences for the environments involved in such a process. Moreover, it is not always easy to ascertain whether such disruptions are the causes or consequences of species invasions (28).

A recent discussion (31, 39) in the wake of two preliminary articles (30, 38) returns to the issue of whether only species exotic to an invaded territory can be considered as invasive. Both authors use the same example, that of the European starling (*Sturnus vulgaris*), in its native Europe and in North America where it was introduced. While some take a strictly biogeographical view of the phenomenon of biological invasion, others adopt a more ecological approach. The debate is still open. Another question is whether or not there is any natural regulation of the spread of invasive species, and if there is, how does it work. In fact, study is focusing more on the 'how' aspect (33). Biological invasion cannot escape the known rules of biology and ecology.

Other movements of animal species

To help reinforce the concept of invasive species the authors briefly present examples of types of animal movements that cannot be considered biological invasions. They do not seek to be exhaustive or to explain everything but merely to provide a few examples.

The most classic example is that of migration, which is well known among birds (Fig. 2) and a few fish species, although migratory species also exist in other zoological groups. These are regular movements, twice a year for birds, between breeding and wintering grounds. While the outgoing and return migration routes in spring and autumn may not always be identical, the movements continue year after year.

Among birds and other species, we see more or less predictable and regular population fluctuations resulting in temporary range expansions, but without subsequent permanent establishment. This is the case of the waxwing (*Bombycilla garrulus*), a bird from the Russian taiga, which in some winters travels as far as western and south-western Europe. The phenomenon can be very spectacular (26). It is important to distinguish between these types of movement and the accidental and apparently random movements of far-flung species that arrive from time to

Fig. 2
Common wood pigeon (*Columba palumbus*), France
Some populations of this bird species are migratory and others are sedentary
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time as a result of meteorological phenomena or apparently as vagrants. Birds, which can travel fast over long distances and are regularly monitored by professional and amateur ornithologists, are the zoological group for which there are the most frequently available data on movements (26).

Lastly, there are population cycles that result in wide variations in animal density, which can make animals visible in places where they were not seen formerly, but which do not indicate an actual increase in the geographic range. This is fairly typical among certain voles (*Arvicola* spp., *Microtus* spp.) of several temperate regions of the northern hemisphere (2).

It is worth noting that while some authors will consider invasions to include spontaneous range expansions and natural invasions, others will not.

Conclusion

The difficulty in finding a satisfactory definition for invasive species also stems from the fact that the same animal, plant or microorganism will be perceived differently depending on the place, time and person involved. Although in many regions of the world the arrival of domestic species is considered progress, this is not always the case. The circulation of pathogens associated with domestic species has taken and is still taking a very heavy toll. Moreover, the feral populations that result from domestic herds (or cultivated fields) can have a serious impact on still natural or largely unmodified ecosystems. We must also take into account the result of intentional introductions for biological control operations. In the latter case, the ecological, economic and even health consequences can be severe. A classic example in terms of biodiversity, in a less spectacular domain than that of vertebrates, is the use of one terrestrial gastropod mollusc to control another. The herbivorous giant African land snail *Achatina fulica* (Fig. 3), for example, has been widely introduced: into Madagascar prior to 1800, into China in the 1930s and into American Samoa in around 1975 (1), as well as in many other Pacific archipelagos. It was introduced for food purposes or for traditional medical remedies, while some introductions were accidental. Later, a carnivorous American species called *Euglandina rosea* was introduced to combat the giant African snail, because of the damage it was causing to crops. In Polynesia, the end result has been the extinction of a whole range of endemic species of small snails of the *Partula* genus. In Hawaii, it is the species of the *Achatinella* genus that have died out. Both cases have served as models for evolution studies (37). One recent study lists around 400 species of land mollusc that have become extinct on oceanic islands. Of this total, 234 lived on islands where *E. rosea* had been introduced, and this species alone is blamed for the extinction of 134 of these species (25). The story does not stop there because the giant African snail is also an intermediate host in the life cycle of *Angiostrongylus cantonensis*, a parasitic helminth of rats (*Rattus* spp.) and sometimes humans. On numerous islands where *A. fulica* has been introduced, rats have also been introduced, into the Pacific as well as into the Indian Ocean islands (1, 11). A real health problem is therefore also associated with this introduction (1, 3).

The recent acceleration in the volume, speed and intensity of global trade and communication has been accompanied by an unprecedented increase in the frequency of species movements. The most recent DAISIE (13) handbook lists around 11,000 species that have been introduced onto the

Fig. 3
Giant African land snail (*Achatina fulica*), Zanzibar, Tanzania
The species was widely introduced into the islands of the Indian and Pacific oceans
© V. Besnard & F. Moutou

European continent alone. Their degree of aggressiveness varies, but some pose real problems.

Around 30 years ago, the international scientific community began to be concerned about the impact of species classified as invasive. Ecologists were probably among the first to rally to action, along with biogeographers. Nature and species conservation specialists came hot on their heels. An organisation as important as the IUCN makes no secret of its serious concern about this phenomenon, because the impact of certain invasive species on weakened ecosystems (particularly those of many islands and archipelagos) can accelerate biodiversity degradation. It would appear that the more the biodiversity of invaded ecosystems has been preserved, the greater is their resilience. This diversity is important in coping with the effects that biological invasions can have on human health, which should not be underestimated. The consequences may be immediate or deferred, but in all cases they can be very serious. Ecosystem biodiversity can guarantee resistance to the invasion of a microorganism. This certainly appears to be the case in the Americas if one looks at the wealth of avifauna and the incidence of human infection with the West Nile virus (27). Similarly, fluctuations in the population density of a game species were associated with increased risks of epizootics and of microorganism transmission to a domestic species farmed in the same area (12).

In addition to providing definitions, other articles in this issue examine a wide range of striking examples of biological invasion and the scale of their associated impacts.

■

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