5.1.2 Biological Invasions and Soil Biodiversity

What are biological invasions?

Biological invasions are introduced exotic species which become a problem in the invaded areas because they develop excessive abundance. An overview of invasive species in Europe can be found on DAISIE European Invasive Alien Species Gateway (http://www.europealiens. org) where the current estimate is that approximately 11,000 species are invasive in Europe.

Classical examples of invasive species are the black rat and Giant Hogweed (Fig. 5.13), a plant species originating from the Caucasus that causes severe blisters when it comes into contact with the skin.

Fig. 5.13: Giant Hogweed (*Heracleum mantegazzianum*). (MBe)

However, there are relatively few known examples of invasive soil organisms. These include the New Zealand Flatworm (Fig. 5.15) which is currently causing a large reduction in earthworm diversity in some areas in the UK, as well as some invasive soil pathogens. It is likely that the number of invasive soil organisms is much greater than assumed, but most of these species, as with all soil dwelling organisms, are difficult to be sampled and identified.

The problems caused by invasive species can be ecological and/or economic. Examples of economic costs are species that prevent or reduce ongoing economic activities, and that require much effort to be controlled. For example, water hyacinths block ship traffic, tigernut sedge is a problem weed in root stock fields, and Eucalyptus trees in southern Europe enhance the incidence of forest fires, because their leaves decompose slowly and act as fuel for the fires.

Ecological costs become obvious when exotic species replace native species. For example, as with the replacement of native red squirrels in the UK by invasive gray squirrels from the US or exotic plants that suppress symbiotic soil dwelling fungi which are essential for tree seedling establishment. Another ecological cost occurs when exotic species alter ecosystem functioning, for example when invasion occurs by fast growing plants which produce easily decomposed litter, thereby enhancing nutrient cycling between soil and vegetation. This can lead to overall changes in plant community composition in affected areas with concurrent changes in below ground biodiversity.

Human activities are the major causes of biological invasions, as it is usually humans that enable exotic species to cross natural boundaries in the landscape such as oceans or mountain ridges. Colonisation of North America, Australia and New Zealand by European settlers is the main reason why there are so many invasive exotic species in the New World; they were introduced and released by the colonists. While many introductions were not intentional, quite a few have been deliberate. For example, the introduction of Black Cherry (Fig. 5.18) to Europe was aimed at enhancing soil fertility, as this cherry species produces large amounts of leaves. It was thought that the fallen leaves would enhance the fertility of poor sandy soils by increasing the soil organic matter when the leaves were decomposed. However, the Black Cherry became a plague that is now controlled by pulling up of saplings by hand and other expensive and time consuming activities.

Introductions of invasive species are often the result of transport or tourism. For example, the Western Corn rootworm in Europe is frequently found initially around airports and from there the insects spread out across the country. Other such examples of introductions include biological control organisms, being organisms that have been introduced to control another pest species (e.g. Black Ladybird), fungal diseases or vector insects (insects which are capable of transmitting disease) in potting soils of tropical plants (e.g. Asian Tiger mosquito), Chinese mitten crabs were introduced into many areas via ballast water in ships, and many weed seeds that are dispersed by both cars and trains.

Fig. 5.15: New Zealand Flatworm (*Arthurdendyus triangulatus*). (KRB)

Introduction alone is not sufficient for an exotic species to become invasive. In fact, only one out of a couple of hundred of introduced species becomes really invasive. This percentage is so small because there are many prerequisites necessary for a species to become invasive in a new location. For example, the circumstances for establishment have to match the requirements, both from a biotic (relating to living organisms) and an abiotic (not referring to living organisms, so usually physical or chemical) perspective. Invasiveness requires, among other things, that introduced exotic species have to not be in contact with the various factors which controlled their abundance in their native ecosystems, and that the right growth conditions regarding both soil and climate are present.

With the ongoing climate change, new areas are becoming suitable for species that, until now, have been living at the edge of their climate preference. For example, since 1889 narrow-leaved ragwort from South Africa has been introduced at three places in southern and northern Europe (Fig. 5.17). Currently, this species is spreading rapidly towards the north and east, suggesting that it may be making good use of the current relatively milder climate conditions in that part of Europe.

Climate warming is also causing range shifts of plant and animal species (see Section 5.1.3). Recently, it has been shown that some range expanding plants, for example, Austrian yellowcress (Fig. 5.14) have moved northward while their natural enemies have not yet moved, or have failed to become established in the more northern areas meaning reduced control for the expanding plant species.

It is also possible for plague organisms to switch host plants when expanding their range. In these cases, successful range expanding species may show invasive properties, especially when they are released from control by natural enemies. Enemies of plants can be present above ground (insect, pathogens, large grazers), as well as in the soil (insects, nematodes, pathogens). Much of the theory developed for invasive exotic species can also be used to study the possible consequences of climate warming induced range expansions: will these species perform as invasive exotic species, or as normal natives do? Much of this is still a big mystery, but it is already clear that the soil and its biodiversity play a crucial role in these responses of ecosystems to climate change and invasive species.

Fig. 5.14: Austrian yellowcress (*Rorippa austriaca*). (TE)

Effects of biological invasions on soil biodiversity and ecosystem functioning

Considering the immense biodiversity of organisms which are present in one gram of soil, it is irrelevant to simply describe how invasive species influence the total numbers of soil organism species. It is more insightful to consider what sort of species exotic invaders influence and what the functions of those species are. Here, the effects of invasive plants, animals and soil organisms on soil biodiversity are discussed.

European earthworms, for example, while very beneficial for European soils, are often considered to be invasive species in the USA as they have been shown to be capable of changing the structure of plant communities.

One particularly successful invasive soil organisms is the earthworm *Pontoscolex corethrurus*. This organism originally comes from the Guayana plateau, but has now invaded almost all anthropogenically impacted tropical soils world-wide and has even been found in Finnish greenhouses!

Fig. 5.16: Eucalyptus (*Eucalyptus globulus*). (LB)

Plant invasions

Plants influence soil organisms directly by being a host for pathogens, food for herbivores, and partners for symbiotic mutualists (that is two organisms that exist in a relationship where both gain benefits). Other soil organisms, such as microbes and soil fauna which are involved in the decomposition of organic matter, are influenced by plants in a more indirect way, through their feeding on dead organic matter, mainly leaf litter and root exudates. Exotic plants have the highest chance of becoming invasive when they are not attacked by the local soil pathogens and root herbivores and when they can still use, or do not need, mutualistic symbionts in their new range. This provides the exotic species with an advantage in competition when compared to the native flora and contributes to their disproportionate abundance. When the exotic plants are poor hosts for symbiotic soil organisms, the exotic plants can indirectly reduce the growth possibilities of native plant species that depend on symbiotic relationships due to the reduction in the soil biota capable of supporting the growth of the native plants.

Exotic plants that grow fast and produce high quality litter will enhance the abundance and possibly the diversity of decomposer soil organisms, which in turn enhances the nutrient supply to the plants. When the chemicals present in the litter of invasive plants are very different from the native community, this can cause a huge shift in soil community composition and functioning as the soil decomposer communities have not evolved in the presence of the new chemicals and so generally won't have the ability to break them down or may even find them toxic.

Often, exotic plants increase their invasive abundance via the aforementioned acceleration of nutrient cycling. A famous example of an invasive plant that completely changes nutrient availability concerns the invasion of Hawaii by the shrub *Myrica faya*. Because this shrub is capable of converting aerial nitrogen (not available for use to plants) into mineral nitrogen (available for use to plants) via a process called nitrogen fixation, it strongly increased pools and fluxes of nitrogen on Hawaii. Before Myrica started to invade Hawaii, no indigenous plant was capable of fixing nitrogen, and so this invasive species has completely changed the ecosystem in much of Hawaii. However, there are also many examples where exotic plants do not influence nutrient cycling differently to native plant species. In other ecosystems the effect of exotic species seems limited to shifts in specific groups of organisms: the invasive smooth cordgrass has been found to lower diversity of nematodes in marshes, whereas Japanese knotweed has been found to decrease snail and isopod abundance and diversity, but to increase predators.

In conclusion, some invasive exotic plants can reduce, and others increase, the diversity and abundance of soil organisms, as well as the nutrient fluxes processed by the soil community in the new range. Possibly, the reason why so many exotic plant species do not turn into invaders is in part because these plants are controlled by local soil pathogens which are already present in the soils or ecosystems at large in the new range. The usefulness of local soil pathogens for controlling invasive plants therefore has potential, but needs further research to test effectiveness and ensure safety.

Current and future issues

Effects of biological invasions on ecosystem functioning in Europe

Ecological studies over the past two decades have raised awareness regarding the effects of biodiversity loss of biodiversity on ecosystem functioning. In the case of biological invasions, their effects on ecosystem functioning are evident. Besides a potential loss of biodiversity (which has not yet been shown that often), the invasive dominance of ecosystems by few species can have an enormous impact on nutrient cycling, water-holding capacity of soils, fire incidence (for example due to introduced Eucalyptus trees in southern Europe – Fig. 5.16), and also on the resistance of ecosystems to drought, erosion and other large-scale disturbances. Moreover, the invasive species can outcompete highly valuable, from an ecological viewpoint, indigenous species and thereby indirectly reduce the provisioning of ecosystem goods and services. Until relatively recently, the generally accepted view was that the New World was far more susceptible to invasions, but in reality, Europe too has become flooded by exotic species, some of which have developed into notorious invaders.

Fig. 5.17: Narrow-leaved Ragwort (*Senecio inaequidens*). (TE)

Does soil biodiversity offer protection against biological invasions?

Ecological theory predicts that resources will be optimally used in biologically diverse communities. Therefore, in species-rich communities most available niches are expected to be occupied. Consequently, loss of biodiversity is likely to enhance the chance that exotic species can become invasive owing to the availability of niches within a reduced biodiversity ecosystem. Currently, there is little evidence either supporting or rejecting this hypothesis, but it would be worthwhile to consider soil biodiversity as an insurance against biological invasions. This "insurance effect" of soil biodiversity may also function in other ways. For example, soil biodiversity may increase the chance that pathogens and root herbivores are present that can potentially control the abundance of exotic plants. Such control may be immediate, in the case of soil pathogens which are preadapted to break through the resistance of exotic plants at the start of an invasion. It may also be that the soil pathogens can become adapted through natural selection, which may enable the pathogens to circumvent the resistance genes of the invasive plants. As a result, these adapted soil pathogens may suppress the invasion over time. Decline of invasive potential of exotic plants over time has been reported, but the role of adaptation of soil pathogens has not yet been investigated.

Is recovery from invasions possible?

Exotic invaders that change the structure, chemistry, or biodiversity of the soil may cause changes in the invaded ecosystems that are difficult to be reversed. For example, exotic plants that cause loss of symbiotic mycorrhizal fungi (fungi which interact with the roots of plants and increase nutrient uptake from the soil) can have strong negative effects on the re-establishment of native mycorrhizal-dependent plant species such as orchids and tree seedlings. Often, management of exotic invaders is planned with the aim of eradicating the invader. However, this in itself, may not be sufficient in order to restore the original ecosystem and its functioning. Current awareness is growing that soil biodiversity needs to be restored in order to promote the restoration of former vegetation, ecosystem properties and therefore the associated ecosystem services. The ecological interactions in soil can be extremely complicated and as such much more research is needed in order to develop effective management options. For example, in coastal fore dunes of north-western Europe, the native marram grass is protected against root-feeding nematodes by a highly complex, multi-factor interaction web. If this balance were to be disturbed by an exotic invader, the original interaction web might not easily be rebuilt. It is possible that the invaders may change the ecosystem properties so profoundly that recovery of the original state is simply impossible.

Fig. 5.18: Black Cherry (*Prunus serotina*). (SW)