Reintroduction of ecosystem engineers (e.g. beavers) can have major impacts on the environment. What species would you reintroduce (or introduce) to the British Isles and why has this not been done already?

An ecosystem engineer was first defined by Jones *et al.* in their groundbreaking 1997 paper as 'any organism which modifies, maintains, or creates a habitat'[1]. Ecosystem engineers include many species, from the Eurasian beaver, *Castor fiber*[2], and their masterful manipulation of waterways, to soft corals such as *Alcyonacea*[3] which create habitats 'simply by growing'[4]. The impacts of actions by ecosystem engineers have the potential to be global. Ecosystem engineers can cause a variety of major environmental events, from mass extinctions to conservation of endangered habitats[5], by altering the equilibria of delicate ecosystems. The British Isles may seem antithetical to the concept of an endangered habitat, yet 80% of peatlands[6] and 97% of meadowlands in the UK have been lost since 1930[7]. As a result, between 1994 and 2021, the abundance of terrestrial and freshwater species declined by on average 15%[8]. Britain should provide the optimum conditions for multitudes of species to thrive as a temperate, seasonal, and relatively low-lying[9] region. Yet a disastrous combination of global warming, development of chemical agricultural practices and urban expansion have led the marshes, rivers, and woodlands that native species depend upon to decline at exponential rates[8]. For this reason, species reintroduction must focus on those that will prosper in a reduced habitat, provide a defence against climate change, and be inconspicuous enough to minimize impacts on metropolitan life. To alleviate potential economic losses, it would be beneficial for the reintroduced organism to have a short reproductive time to instigate a rapid reintroduction scheme. Using the beaver as an example, this essay considers the merits of two potential ecosystem engineers that could be reintroduced to Britain, concluding that the lichen *Tornabea scutellifera*[10] would have greater ecological benefit than the apple bumblebee, *Bombus pomorum*[11].

Ecosystem engineers: their roles and effects

Jones *et al.* identified two classifications of ecosystem engineers. Autogenic engineers use 'their own physical structure' to engender environmental change. Allogenic engineers are organisms which incite environmental diversity through the 'transformation' of biotic or abiotic components from 'one physical state to another via mechanical means'[1]. Both classes of ecosystem engineers control resources in their habitat via direct or indirect activities. This may result in 'conspicuous damage' to the biogeochemical cycle of the habitat they are introduced to[12], especially if they are of an invasive species. Native or not, these animate organisms have the potential to cause stress upon resources other species depend on[5]. Evidently, the introduction of a foreign species must be clearly justified to minimize negative concatenation of events upon the overall ecosystem and climate.

The Eurasian beaver: an important case study to understand future species reintroduction.

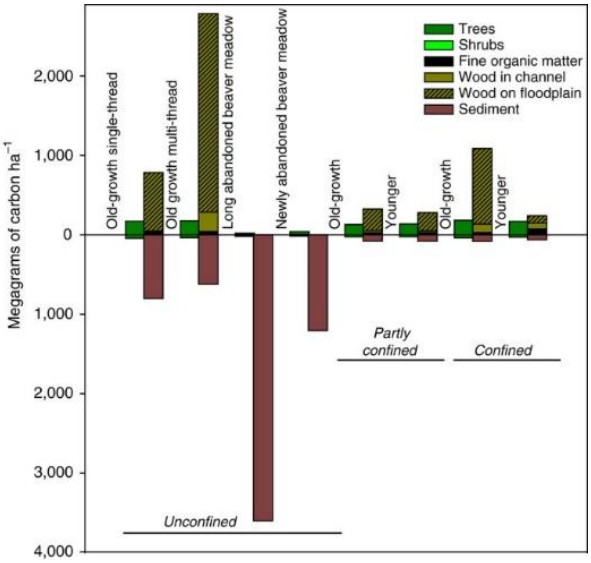
Castor fiber is best categorised as an allogenic engineer. Beavers use their sharp frontal incisors and digited, dexterous front paws to hew down trees and shrubbery to augment their dams with the debris. In short, *Castor fiber* manipulate the biotic flora of their environment using the mechanical means of their teeth. Beavers were declared extinct in Britain by the start of the 16th century, but by the beginning of the 20th century 1200 animals remained in continental Europe[13]. By 2019 extensive reintroduction efforts begun in 2002 had allowed this number to rise to 1,222,000 individuals[14]. But why was reintroduction funded? What benefit to wildlife and human populations could these seemingly 'destructive vermin'[15] provide?

Studies focusing on the ecological impacts of beavers began to answer these questions in the late 1980s[16]. A decade later, mass extinctions of disparate ecological engineers loomed on the horizon and research projects[1,17] began to concentrate on the economic defences and ecological advantages presented by these creatures to justify the cost of reintroduction schemes.

There are many ecological benefits of beaver endeavours. For example, England's commercially important but critically endangered fish species, like the Atlantic salmon[18], may be conserved as a consequence. Stilled pondwaters 'increase the heterogeneity of

watercourses'[15]; felled trees provide sheltered harbours for the laying and maturation of fish eggs and fry[19]; and aquatic invertebrates and fish are protected as the dams 'enhance base-flows during drier conditions'[15] which aids 'drought resilience'[16]. Finally, 'beaver meadows' (marshy wetlands generated by beavers' constructional activities) act as carbon sinks. With this capacity to sequester carbon compounds, beavers reduce the prevalence of the greenhouse gas carbon dioxide in the atmosphere. Naiman *et al*. in 1991[20] proved that beaver meadows impound 1.9% of the total carbon within a wetland environment, more than that of all the shrubs and trees combined (figure 1). In a Britain where vegetated areas are becoming scarce, these meadows could be responsible for the mitigation of climate change[21].

Figure 1: Relative carbon storage in a wetland habitat (Wohl *et al*.[22])



Post-reintroduction studies have demonstrated that basins formed by the stemming of water flow function as flood water retention sites. Along the River Otter in Devon, the local Wildlife Trust reintroduction program recorded beaver dams to reduce flood peaks by 60%. Annually, taxpayer funded flood defences cost £2.6 billion[15] while a beaver reintroduction program in Scotland cost just £195,000[23]. Soft engineering schemes are therefore cheaper and more efficient in preventing river-side settlements from flooding.

Unfortunately, reintroduction schemes like that of the beaver may generate conservation conflict, which occurs whenever 'an action by humans or wildlife has an adverse effect on the other'[12]. For example, localised flooding around beaver-dammed areas was reported to impact economically important grazing land[23].

Bombus pomorum

The last documented member of the British *Bombus pomorum* was recorded in 1864 in Kent[11]. Since then, the remaining 25 species of bumblebee have drastically declined due to two key factors:

1. The loss of 90% of their natural habitat, wildflower meadows.
2. The increased use of the thiamethoxam compound in pesticides[24] which is lethal to bees[25].

Bees have a large ecosystem role as both autogenic and allogenic engineers[17] due to their mechanical role and nesting practices[26]. The loss of bumblebee species will thus cause devastation to British agriculture and wild flora.

Pollination is a bumblebees primary autogenic ecosystem role. Pollination is the transfer of the male plant gamete pollen from one vegetative organism to the ovule of another member of the same species[27]. This process is essential for plants to grow and thus photosynthesise, the mechanism by which carbon dioxide, (the main greenhouse gas), is removed from the atmosphere[28]. Pollination consequently slows climate change and the ensuing loss of biodiversity[29]. Bees are the main vector for this process, responsible for the pollination of 95% of crops and wildflowers in the British Isles[30].

All bumblebees evolved for pollination with anatomical adaptations, such as their furry bodies, which use electrostatic force to adhere to the pollen grains as they feed on them. *Bombus pomorum* have a unique behavioural adaptation for this process which is arguably the crucial factor in their benefit as an ecosystem engineer. This adaptation makes *Bombus pomorum* less vulnerable to food chain disruptions compared to the rest of the genus. Most bee species[31] only feed on (and so only pollinate) one species of plant[32]. However, a distinct physiological adaptation provoked *Bombus pomorum* to adopt a 'generalist foraging strategy'[33]. *Bombus pomorum* individuals contain multiple proteases within their guts enabling them to digest the pollen of a variety of plant species[34].

As ground-nesting organisms, bumblebees live and die in the soil. Detritivores decay their bodies releasing nutrients which enrich soil fertility and provide a habitat for more organisms to thrive. However, these nests are exposed to predation and are unlikely to flourish, dissimilar to the protected enclave of a beaver dam.

The species is well protected against the primary cause of bumblebee species loss[32] because the woodland verges and open grasses that *Bombus pomorum* inhabit are populous within the UK. This is a distinct contrast to the drastic decline of the beaver wetlands and bumblebee meadows. However, as for beavers, there may be conflict between rural settlements bees. Many humans are uncomfortable with ground-nesting bees' intrusion into public spaces.

Regrettably, the successful lobby by British farmers in January 2024 caused a revocation by the Government on the harmful neonicotinoid (chemicals which damage the nerve cells of bees[35]) ban. This was to protect agricultural crops from aphids but has the unintended, but predictable, consequence of killing bees. The shortsightedness of this policy will exacerbate decline of bees and make it difficult for the *Bombus pomorum* re-colonise British habitats[30].

Tornabea scutellifera

Lichens are the unification of two mutually symbiotic organisms, a fungus, and an alga. The alga provides photosynthetic sugars which the fungi feed off; in turn, the fungi provide nutrients from their detritivore activities and impart prime living conditions which allow the algae to thrive[36].

Now recognized as an essential feature of a healthy ecosystem, lichens are renowned for their soil-enriching properties, habitat provision, and availability as a food source[37]. Despite this, it was only in 2019 that lichens were proved to be biological soil crust (BSC) organisms due to promoting stability, enzyme activity, and moisture retention within soils. As BSCs, lichens can be categorized as allogenic ecosystem engineers[38]. Additionally, their algal components' photosynthetic ability absorbs carbon dioxide from the atmosphere and releases oxygen[36] similar to a beaver meadow, thereby mitigating the repercussions of global warming.

These small organisms are unobtrusive to human populations and have no harmful side effects upon agricultural or urbane life. *Tornabea scutellifera* will benefit the agricultural sector by enriching the infertile soils damaged from centuries of intensive farming. UK soils have lost 40-60% of their carbon content in the last 80 years[39]. Crops rely on carbon compounds for growth, so such a loss is detrimental to the food security and biodiversity of the UK. The enzymes released by *Tornabea scutellifera*, and the decomposition of its algal section, will replenish these soils for continuing farming and wild vegetative growth.

Tornabea scutellifera reproduce by the asexual method of blastidia reproduction[40]. This occurs when a projection from the tip of a tendril grows and embeds elsewhere, then detaching from the mother lichen[41]. Unlike the sexual reproduction of beavers, blastidial reproduction is fast and efficient allowing a hasty reintroduction of the species to the UK.

Pre-extinction in the UK, *Tornabea scutellifera* thrived in diverse bedding grounds such as sea-cliffs and timber and was indigenous to the Sussex coastline. A hardy species, their extinction was a result of previous toxic air-pollution by sulphate gases and coastal erosion which severely damaged their habitat[10].

However, the reddish-grey, shrub-like tendrils (figure 2) of *Tornabea scutellifera* remain populous throughout the northwestern Europe and the Mediterranean, North African and southern African Atlantic coasts[10] demonstrating that *Tornabea scutellifera* are protean and could have a strong chance at persisting in the UK. This versatility also provokes the concern that lichen may cuckoo native species out of the essential required resources[41]. Despite this, a mammoth challenge currently facing many lichen species, and one which could affect *Tornabea scutellifera,* is a lethargic evolutionary ability towards adapting to climate change. This could result in their global extinction[42]. While there is a risk that the species would not survive reintroduction, the risk is lower than for *Bombus pomorum.*

Figure 2: *Tornabea scutellifera* (Parsa S. *et al*.[43])

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Conclusions

British habitats have the potential to be saved from decline by ecosystem engineers. These species alter the ecology of their habitats by different mechanisms (like pollination) and processes (like photosynthesis). It is, however, *Tornabea scutellifera* which exhibit the characteristics required for an ecosystem engineer reintroduction scheme in the United Kingdom. With their robustness, possibility of rapid reproduction with minimal impact on urbane life and high ecological benefits, they outweigh *Bombus pomorum* in terms of ease and capability of reintroduction. Both species would ameliorate the damage to biodiversity wrought by industrialisation and have similar barriers to their reintroduction, yet *Tornabea scutellifera* provoke less inconvenience for more practical advantages. Like the beaver, the purely allogenic properties of the species mean that reintroduction would be simpler and more successful.

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