PTES Internship Final Report

The legacy of environmental engineering on soil nitrogen heterogeneity as a result of water vole burrowing in the Highlands of Scotland

How water vole populations improve their habitat through engineering

Deon Roos

Animals engineering their environments

A beaver is the best known ecosystem engineer with their dam building

Ecosystem engineers are species which physically disturb their environment, and in doing so change the availability of resources available for other species. The classic example of this is the beaver (*Castor spp.*). When beavers construct a dam, they physically disturb their environment. As a result, the surrounding area normally becomes flooded, changing the availability of resources for other species. This ecological process is not only carried out by beavers, but also by a myriad of other species. Scientific literature has tended to focus on burrowing species in arid areas, particularly those that physically shift soil to the surface when they burrow. This specific form of engineering demonstrates a nice clean cause and effect relationship (i.e. the movement of soil from below to above ground leads to more nutrient rich soil above ground), and, as a result, has been well documented. However, the effect of this engineering is not limited to moving nutrient rich soil to the surface. Surely other mechanisms of engineering could exist? This was, in part, the aim of my study.

Another aspect of ecosystem engineering in need of consideration is the timescale over which this process operates. Because some engineering effects occur over a long period of time, potentially decades after the original disturbance event, characterising the dynamics of these effects can be challenging. As a result, understanding how engineering effects builds up and change over time is a time consuming and often costly affair. This has led to the literature giving the impression of a binary effect of engineering; if a beaver builds a dam, the effects are seen instantaneously and at a constant baseline. We know this is not the case, but the experimental limitations faced by ecosystem engineering studies results in this interpretation.

Water voles: the unsung heroes of engineers

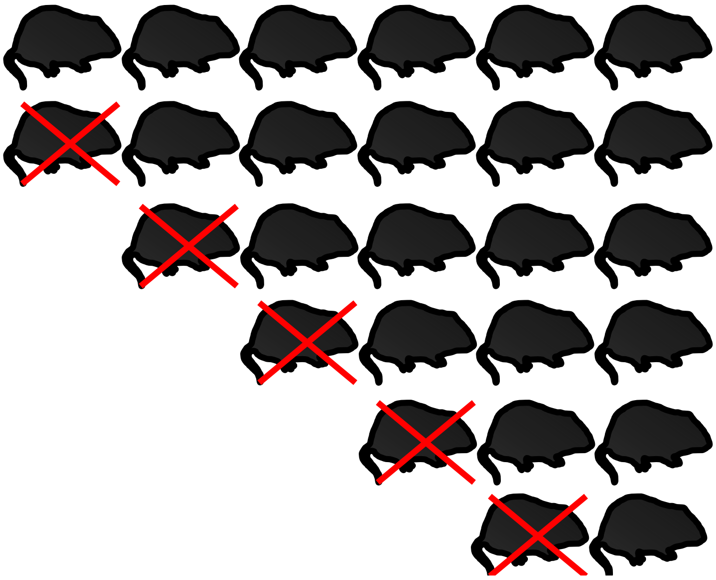
My internship for the People's Trust for Endangered Species (PTES) aimed, in part, to address these knowledge gaps. To best comprehend this process, I used water voles as my study animal. Water voles (*Arvicola amphibius*) were once common throughout the United Kingdom. Indeed, they still are on continental Europe. However, with the release of the American mink (*Neovison vison*) from the fur trade in the 1970s, predation saw water vole populations crash across the UK, to roughly 10% of their pre-mink population size. Currently one of the last strongholds of water voles is in the North West Coast of Scotland around Loch Assynt. This population of water voles also has an interesting characteristic, as they display a so-called metapopulation dynamic. In essence, this dynamic means that the population at large is broken down into smaller, individual populations, each of which has their own independent risk of extinction or probability of survival. These populations are mostly independent of each other, apart from the fact that they interact through the dispersal of young voles. This metapopulation dynamic results in patches of habitat, each with their own history consisting of sequences of either occupation or extinction. The water vole metapopulation study led by Prof Xavier Lambin of the University of Aberdeen in Assynt celebrated its 20th year this year, and over the years has provided fantastic data on metapopulation dynamics. It is also a valuable baseline for projects that seek to restore water voles and their function in UK ecosystems. The occupation histories of water vole patches were of particular interest to me when I set out to study this species.

American mink is the primary reason for water vole extinctions across the United Kingdom

Building on sustained efforts

Using the wealth of historic data available, I was able to construct occupation histories of different water vole patches across the entire study site. I could tell, for instance, that a particular patch had been occupied continuously for four years, following recolonization, since its last local patch extinction. Building up such histories for the entire region allowed me to choose patches that matched certain criteria that I was interested in. I knew I would not have the time to conduct a six year study (nor the resources, despite PTES's generous funding), but by using my newly constructed history of patch occupation I could overcome this. Because I could tell that a given patch had been occupied for six years, I could use that patch as a substitute for a six year-long study. I then used this selection process to determine which patches had been occupied continuously for between one to six years. This allowed me to sample selected patches in the study area rather than attempting time travel. By using all my patches in combination I had the same opportunity to learn as if I had a "six year-long experiment". As a result, I now had the beginnings of an ecosystem engineering study which could potentially identify how the environment changed each year over a six-year time frame. Ultimately, this allowed me to track how engineering effects change over time, something that was previously unheard of.

In the end, this study was only possible thanks to the long term monitoring of the water vole in this region. Amongst other achievements detailed below, this study highlighted the value of long-term, well-designed monitoring in allowing insightful and ground-breaking research to be carried out.



Patch A: occupied for 6 years continuously

Patch B: occupied for 5 years continuously

Patch C: occupied for 4 years continuously

Patch D: occupied for 3 years continuously

Patch E: occupied for 2 years continuously

Patch F: occupied for 1 year continuously

Illustrative demonstration of how patches were characterised based on their occupation histories

Clear as mud? Extracting key variables from soils

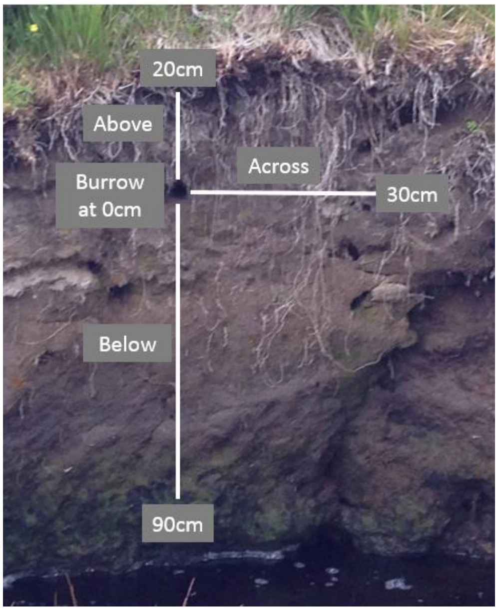
Prior to this study, there has been previous research which looked into the effects that water voles have on their immediate environment. This research strongly suggested that soil microbial activity increased around water vole burrows. Soil microbes are responsible for producing nitrogen (in the forms of NH_4^+ ammonium, and $NO_{2/3}^-$ nitrates) which is used by plants for growth. The nitrogen I aimed to retrieve were both products within the nitrogen cycle. The nitrogen cycle loops various forms of nitrogen (including ammonium and nitrates) in a constant state of production and use. Ammonium is produced from organic nitrogen (often in the form of manure), and is subsequently converted to nitrates that can be used by plants for growth. By measuring both ammonium and nitrates provides an insight into the rate of production from ammonium to nitrates and can be used to determine the nitrogen "health" of an ecosystem. The next logical step was to investigate whether both forms of nitrogen concentrations were greater around water vole burrows.

Illustration of the relevant part of the nitrogen cycle. Water voles act as fertilisers, which prompts microbial activity to convert nitrogen into a useable form for plant use.

Retrieving samples from the bog

Once I had identified what to measure in which patches, I used a spatial mapping programme (QGIS) to focus on specific areas where I should sample. Retrieving the samples involved digging a narrow pit in the peat bog (roughly 30 cm x 10 cm) and taking soil at a range of distances and different directions from the burrow (above, below, and perpendicular). Taking samples from different depths and directions allowed me to get a two dimensional idea of how nitrogen was concentrated around the burrow. The work was done under licence from SNH as water vole burrows are protected in law in Scotland.

All in all, 16 patches were sampled, resulting in over 350 soil samples which required further work.



A collapsed bank, which exposed a burrow network, with illustration of sampling design

Juggling work loads

This work was only possible due to the extensive database available for the Assynt water vole populations. As such, while carrying out my own work for the internship, I also helped collect data to further expand the database. Collecting data involved surveying large (130 km^2) swathes of Assynt with hikes of up to 15km through bog and swamp. Upon reaching a patch, surveying would be carried out along its length (with some patches reaching up to 2km long). Water voles are a particularly shy and cryptic species which means simply spotting the animal is very rare. As such, much of the surveying relies on signs of water vole activity, which include latrines and grass clippings. Doing these surveys allowed patches that were occupied that same year to be targeted for live-mammal trapping. Once captured, water voles were handled and certain characteristics noted. This included gender, weight, number of parasites, among various other attributes. The water vole would then be "marked" by trimming a section of fur that would allow that same vole to be identified in future. By helping with surveying and trapping voles during the summer 2016 field season, I was able to take part in a variety of work alongside gathering my own data.

While doing the internship I was able to help with associated water vole work in various locations

Back in the lab

Following the completion of the field work, the samples were taken back to the University of Aberdeen for analysis in the lab. Analysing soil for nitrogen involves a few steps. The first is to sieve the soil, in order to remove all plant debris, stones, and thoroughly break up the soil. Next, 2.5 g of soil was weighed out for each sample. This was then mixed with a solution of potassium chloride. This mixture can then be passed through a machine which can detect various forms of nitrogen, as well as measure how much of the nitrogen of a particular form (NH_4^+ ammonium, and $NO_{2/3}^-$ nitrates) is contained in the mixture. Using this method, I was able to get a break down of the quantity of ammonium and nitrates present in the soil surrounding water vole burrows

The equipment used for nitrogen extraction

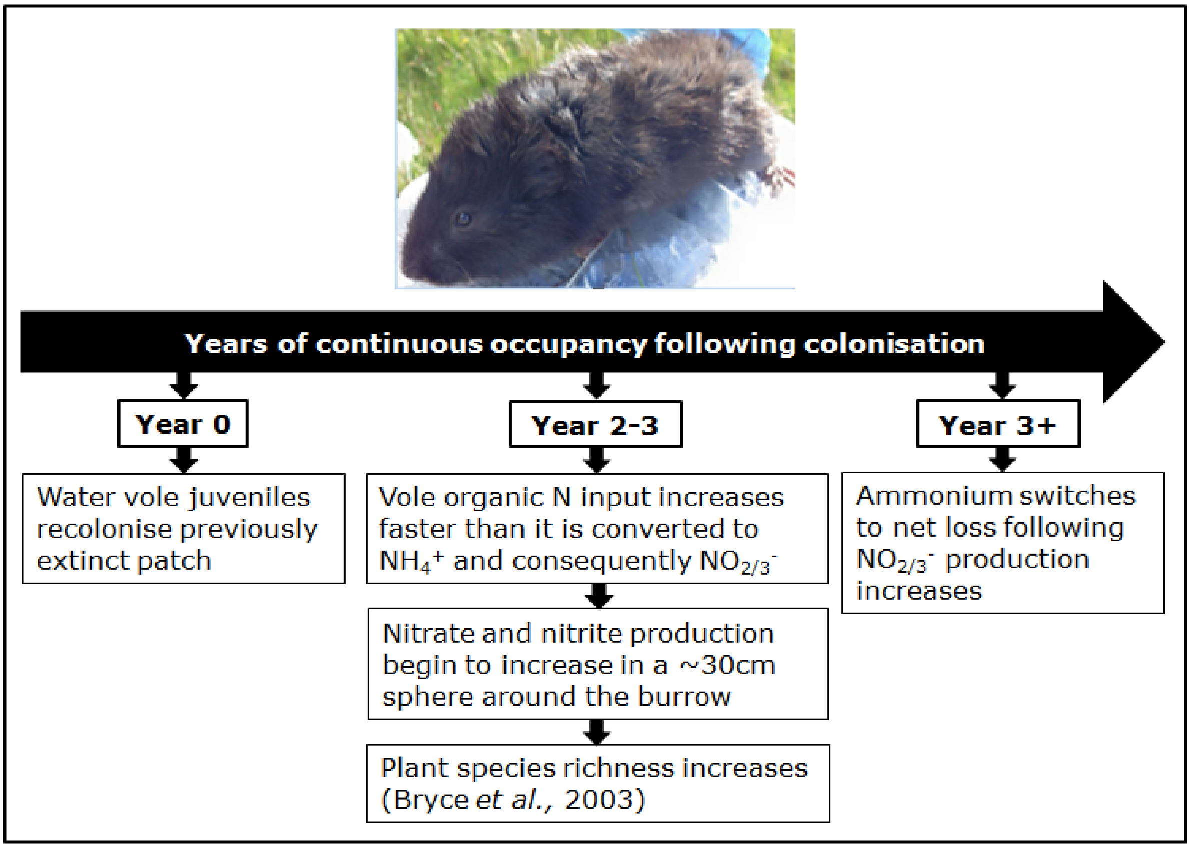
Finally, data!

Collecting my data certainly proved a challenge, particularly due to terrible weather conditions in the field and long waits in the lab, but in the end it was well worth it. I could now begin the lengthy process of statistically analysing my data. In order to do this, I used a statistical method known as General Linear Modelling (GLM). A GLM allowed me to state that the amount of nitrogen present in the samples would be a result of various factors presented in different combinations (for instance, nitrogen levels could vary depending on how long a patch had been occupied, as well as how many burrow entrances were present). Using some statistical wizardry, I identified which statistical model best explained the nitrogen levels while retaining a certain level of simplicity, also known as the most parsimonious model.

In the end, I produced 20 models that could potentially explain the ammonium that I retrieved from the soil. A lengthy process, which I had to reproduce when I then programmed a further 20 for nitrates, another chemical form of nitrogen. From these I selected the best explanation of the data.

What do the models say?

The results showed something quite remarkable. The longer the patches had been occupied, the less ammonium the patches had. This was initially somewhat counterintuitive, as it went against what I had originally been expecting. Surely the longer the water voles had lived in a patch, the more ammonium would build up over time as a result of their engineering effects? It was only once nitrates were also considered that these results added up. Nitrates did not decrease, but in fact increased the longer a patch had been occupied. This allowed the rest of the results to fall into place. Soil microbes transform ammonium into nitrates in a process of conversion. Furthermore, with the exception of a few plant species, nitrate is the form of nitrogen that is used for plant growth. What my models suggest was that the longer voles lived in a patch for a continuous amount of time, the greater the amount of microbial activity in the soil, leading to the transformation of ammonium into nitrates. In this way water voles indirectly and gradually fertilise plants, from below, right near the juicy roots they feed upon. It looks as if, through their burrow digging activities, water voles are farming their fields of roots.



A Schematic of the model outputs shows the crucial time required for engineering effects is for a patch to be occupied for at least 2 years.

What else can the data show?

Some other interesting conclusions could also be drawn from my analysis. When studying the samples which were dug perpendicularly to the burrow I was unable to find a drop off where nitrogen levels became less concentrated. My results suggest that within a burrow complex there is an interacting effect with neighbouring burrows. It seems that each burrow has an "area of influence", and when in close proximity to each other the influence of individual burrows overlaps. This overlap means that patches of water vole habitat may well provide a "neighbour to neighbour" effect (termed the "Roos" effect by my supervisor). This means that water vole patches may be incredibly valuable areas of nitrogen production. Further research will be required to reach a stronger conclusion, but these results are nevertheless very exciting.

Why does this matter?

Water voles often currently inhabit areas that can be described as homogenous; that is environments with low species diversity (but never-the-less spectacular). These can be typified to areas that have low baseline nitrogen production, such as the Highlands of Scotland, the Yorkshire dales and Dorset moors. However, when you get close to a patch of habitat occupied by water voles it's a different story altogether. Suddenly, a plant species which are rare elsewhere become more common, a stark contrast to the otherwise uniform landscape. My models now suggested that this change is partially a result of these areas having more nitrates, providing plants with an important source of nutrients and allowing them to thrive. This does not mean, however, that this effect is limited to low production areas, only that it is here where it is most obvious. Unfortunately for many ecosystems that lost water voles in the past (such as Yorkshire and Dorset), this type of engineering is becoming increasingly rare. In many regions of the United Kingdom water voles have become extinct, and as a consequence this ecosystem engineering effect is no longer present, and indeed the influence of the "ghost of past water vole presence" is diminishing to ever smaller amounts with each passing year. Naturally, this occurs at a cost, and has led to increasingly homogenous habitats where water voles are extinct.

Hopefully this research has highlighted the value of organisations such as PTES. Through protecting and promoting research on current water vole populations, PTES is also providing protection for a broader environment. Furthermore, by planning the reintroduction of water voles to areas where they are no longer present, this ecosystem engineering effect may be similarly reintroduced. I believe that my research has also shown the importance of protecting endangered species which may have a value above and beyond their own existence. The loss of an elusive animal such as the water vole, with little apparent value, may ultimately lead to consequences which are much greater than what was originally expected. Worryingly such losses of ecosystem engineering may well take years to become apparent, leading to complacency when species face extinction. Hopefully, this reinforces the view that even the most unlikely species may have value, and that it is best to be precautious when deciding whether or not a species requires protection.

A valuable experience

I would like to thank the People's Trust for Endangered Species for providing funding for this internship. While working on this project I was offered a PhD focusing on common voles in Spain and the conflicts with farmers, which I have since accepted. During this uncertain period, PTES were incredibly accommodating and understandable, allowing me to cut my internship short in order that I could begin my PhD on time. For this I am incredibly grateful.

Furthermore, I would like to thank PTES for allowing me to take on this opportunity and develop a great many skills, which I am sure will be invaluable as I progress in my PhD. From field skills to sampling and statistical modelling, I have been able to expand upon previous knowledge and become more confident in my work. This was made possible by PTES and I cannot thank them enough.

I would also like to thank Professor Xavier Lambin for his help and support throughout the internship (and hopefully for the next four years as he is now my PhD supervisor).

Reference

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