FORUM

INDIGENOUS INVERTEBRATE COMPONENTS IN ECOLOGICAL RESTORATION IN AGRICULTURAL LANDSCAPES

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The challenge of community restoration is to understand and exploit the principles of ecological succession at all seral stages, by complementing and accelerating the processes of colonisation and regeneration. The main aim is to construct self-sustaining, appropriate communities, connected in the landscape, that meet conservation, landscape and crop production goals.

Research, to date, has been biased towards the plant and soil components with little consideration for the animal element. We discuss the importance of this missing component, put forward our belief that it is essential for enhancing landscape biodiversity, given that invertebrates provide the bulk of the biodiversity in New Zealand, and ensure that many ecological functions are performed. We suggest that restoration is an ideal model system for testing succession theory.

Introduction

There is a spectrum of goals in restoration ecology (Hobbs and Norton, 1996), but it usually aims to re-establish, or improve, the ecological status of damaged or lost plant and animal communities (Jordan, Gilpin and Aber, 1987). The emphasis is often stated to be the re-establishment of a functioning community, although too often the target is limited to a particular plant, insect, or bird species (e.g., Mitchell, 1985).

We see the challenge of ecological restoration as the use of knowledge of ecological processes in the reconstruction of entire and appropriate communities. It should therefore be at the level of the community that success be judged (Keesing and Wratten, 1997), rather than that of one or more independent plant populations. The animals, specifically the invertebrates, are often a secondary consideration.

The success of most programmes which aim to restore ecological communities is ultimately connected with the animals that colonise these areas. The community's soil structure, rates of litter decomposition, nutrient turnover, plant growth and competitiveness, as well as plant species composition, reproductive success (seed set and dispersal) and the direction and speed of succession of the system are all moulded by the activities of animals, especially invertebrate herbivores, detritivores, pollinators, and predators.

Most work to date that includes animals in re-colonisation research has been done in connection with mine sites (Hutson, 1980a,b; and see Majer, 1989 for an excellent review), with less contribution from work on 'island' re-colonisation after disturbance (Simberloff and Wilson, 1969; Robinson, Quinn and Stanton, 1995). There is little work that deals specifically with restoration/ recolonisation in agricultural landscapes. The work that does exist in this area points to the value of non-cropped, little-managed habitats on farmland as potentially important sources of species diversity and as refuges for beneficial arthropods. In fact, part of the response of the United Kingdom Government to the Rio de Janeiro 'Biodiversity summit' has been to identify field boundaries as an area in need of more ecological research. Recent work in this area has begun to quantify the role of these areas as sources of, and impediments to the movement of beneficial invertebrates in the cropped landscape (Burel and Baudry, 1995; Wratten and van Emden, 1995). In New Zealand however, and in other depauperate 'colonial' agricultural landscapes (Keesing and Wratten, 1997), little attention has been given to the prospects for restoring indigenous

plant and animal communities in farmland. Restoration on farmland can have a number of aims. These include: (1) purely visual appeal (aesthetics); (2) the maintenance of indigenous flora and fauna by increasing habitat area (biodiversity); (3) improvement of ecological processes within agricultural landscapes (a) where management practices have removed elements and (b) to reduce adverse 'off-site' effects (e.g., nutrient run-off). The animals in the restoration of agricultural landscapes need not be indigenous, as long as they provide ecosystem functions suitable to their environment.

The concept of restoring ecological communities has eluded many restoration programmes. Many have appeared to assume that the re-creation of a plant seral stage will automatically result in colonisation by the appropriate animal assemblage, as is evident by the paucity of literature involving animals/invertebrates in restoration in New Zealand (Figure 1). For sites near, or surrounded by, the same community types as those aimed for in the restoration program, this may be true (Williams, 1993). In most agricultural landscapes, however, this is unlikely, as natural refuges (the sources of colonists) are often remote from the site being restored.

It seems logical, although this logic is not always apparent (Hussey, Hobbs and Saunders, 1991) that restoration sites should be designed with some connectivity of similar habitats to create a set of 'islands' containing meta-populations (Ebenhard, 1991) in the landscape. The extreme isolation of 'natural' habitats, with large differences between the ecological diversity in the early stages of a restoring site from that of the existing land is very pronounced in the Canterbury Plains in the South Island of New Zealand. Any 'indigenous' restoration site created there, in total isolation, cannot possibly gain a significant proportion of its usual complement of invertebrate species. At best, a few very mobile indigenous invertebrate groups, such as some Lepidoptera, Acari (mites), and some Arachnida (spiders) may arrive. In the early stages of succession, the colonisers will probably come from the nearby agro-ecosystem, and are, in New Zealand, likely to be mostly exotic, e.g., Collembola (Davidson et al., in press), Acari, Staphylinidae (Sivasubramaniam, Wratten and Klimaszewski, 1997), Lathridiidae, and Araneae (A. Mc Lachlan pers. comm.). Other, less mobile, fauna will already be there; for example, earthworms in New Zealand pasture are all European species but there are more than 120-170 indigenous species (Lee, 1959, 1961), which are forest dwellers. The likelihood of their colonising, unaided, an isolated restored site will be minimal. A similar case exists with springtails

(Collembola). There were around nine species in one study of a New Zealand lowland pasture (Davidson et al., in press). Of those nine, eight were exotic. This compares with around 230 species in indigenous habitats (Wise, 1977).

As successional change takes place at a restoration site, separating the new ecosystem from its surroundings, 'vacant niches' will appear, the number of which increases as resource complexity grows, and as early, exotic, colonists fail (Majer, 1989). In 'colonial' landscapes, i.e., New Zealand and Australia, where agricultural systems comprise primarily exotic species (Sivasubramaniam, et al., 1997), the phenomenon is compounded, with restoration sites likely to remain almost devoid of indigenous fauna, not even approaching the diversity or complexity of natural habitats.

The influence of animals on terrestrial community composition, productivity, and nutrient turnover

Often invasions of animals into disturbed areas are considered as passive and dependent on the availability of specific vegetation (Murdoch, Evans and Peterson, 1972). As modifiers of vegetation change, their potential effect (especially that of invertebrates) is frequently ignored, but their role is by no means passive (Crawley, 1983). The presence or absence of a particular animal species can cause a rapid decline or a rapid increase in the population of one or more plant species, and through this, affect plant community structure and thus the speed and trajectory of succession.

Recently it has been pointed out that seldom are the potential 'negative' (defoliating, damaging) effects of herbivorous insects and pathogens considered in restoration projects (Louda, 1994). Rather, the emphasis is often on single, rare, plant species, or plant assemblages, ignoring the potentially moderating effects of community processes on a herbivore's impact. If a plant species in a restoration program suffers from severe insect infestations, one reason for this may be that the community in which the plant is placed is 'incorrect', or incomplete i.e., some of the herbivore's predators and parasitoids may not be present.

Animals, especially insects, are crucial components of most terrestrial communities, being potentially directly damaging to vegetation, reducing plant growth and fecundity (Verkaar, 1988) or affecting plant competitiveness (Bently and Whittaker, 1979). It can also be that partial defoliation can promote plant growth and

productivity and (on a community scale) balance competitive interactions, allowing the existence of a greater diversity of vegetation (Owen, 1980). The outcomes of insect feeding impacts are still debated (Belsky 1986; Crawley, 1989; Karban and Myers 1989), but clearly without pollination, nutrient recycling and seed dispersal, all of which are largely carried out by insects (excluding wind-pollinated plants), restoration of communities through regeneration would not be possible.

The role of invertebrates in nutrient turnover cannot be understated (Edwards and Heath, 1963; Anderson and Ineson, 1984; Visser, 1985; Hutson, 1989). The decomposers in the community are vital to the growth and health of any ecosystem, and in turn are reliant on the inputs from the higher trophic levels of that community. Some research has focused on succession and community interactions in the decomposer system, and there is better information available than on the communities above ground. Much work has focused on earthworms, mites (Cryptostigmata) and Collembola (Elkins *et al.*, 1984; Curry and Cotton, 1983) as these are the primary arthropod recyclers of dead biomass. However, as mentioned above, in New Zealand farmland, these species are predominantly exotic, so knowledge of indigenous species' habitat requirements and dispersal capacity is required. Also required is knowledge of the dynamics of the 'interface' species, those that carry out the initial comminution of the dead material, e.g., ants (Formicidae), Diptera larvae, molluscs, millipedes, many Coleoptera, termites (Isoptera), and the unusually large array of detritivorous lepidopteran larvae (J. Dugdale *pers. comm.*).

Impediments to colonisation, and how to minimise them

The 'hurdles' to successful invertebrate colonisation of newly created habitat patches are many. Of primary concern are five factors: isolation, size, shape, resource quality/quantity, and competitive interactions. Isolation of a site from similar habitat governs the sources from which plant and animal propagules will come. The size (area and amount of vegetation) of the site affects its location by colonising invertebrates (Stanton, 1983), the resource abundance (ability to sustain populations) and whether it can resist agricultural/human disturbance (Simberloff and Abele, 1982; Hobbs and Saunders 1994). The shape of the restoration site also determines the amount of buffer, or transition, zone (Reide and Miller, 1989) and thus of undisturbed habitat. Resource quality and quantity

are governed by time, the condition of the system and the surrounding landscape and the effort and understanding of the restorers. Competitive interactions following the arrival of colonists may restrict further colonisation success, depending on the assembly order.

The solution to isolation is to choose the location of the site to maximise the probability of natural colonisation. However this is not always possible. Instead the provision of corridors between the site and field margins, e.g., 'stepping stones' of sawn wood, to connect the site to existing linear features that connect to other potential communities in the landscape is an option. Similarly, raised banks with perennial grasses ('beetle banks'; Thomas, Wratten and Sotherton, 1992) can act as refuges or possibly as corridors. Current work on such banks in New Zealand in what was believed to be a farmland depauperate in such groups as predatory Carabidae, for instance, has revealed much higher densities of carabids, spiders, centipedes and staphylinids (900 ind. m^{-2}; N. Berry *pers comm.*), than in other linear landscape features (e.g., post and wire fences).

The introduction of invertebrates through translocation is the other obvious approach. When the vegetation (or other relevant resources) has established, other elements of a fauna typical of the community which is to be restored can be caught and introduced to the restoration site (e.g., Carabidae). Mark and release methods can be used to monitor dispersal or containment within the site (implying site suitability), and when and whether the introduced species breed. Further, manipulation of animal introductions could involve which 'guild' (Southwood, Moran and Kennedy 1982) to introduce (i.e. a predator, or a herbivore) first, etc. These sorts of experiments may lead to greater insights into community development.

Prior to introductions, the resource base of the site needs to be suitable for the species in mind. Correct genetic sourcing is an issue with restoration ecologists, but it may not be important for the functional development of a community (Bullock and Hodder, 1997). What is important is the number of plant species used, the number of individuals, and which successional stage to start with. Spacing and design of planting are also important in that they affect the movement of invertebrates within the site, and the provision of shelter.

The use of imported resources that mimic those in established systems can be useful. For some forest-floor invertebrates, coarse woody debris (Chandler and Stewart, 1992), exotic or indigenous, is critical. Further, logs removed from existing communities can bring with them useful species, and simulate a developed 'litter layer' that moderates

water loss and temperature fluctuations, and may become a refuge for ground dwelling invertebrates, such as the New Zealand carabid *Megadromus antarcticus* (Chaudoir), which is usually restricted to undisturbed areas of farmland. Alternatively, discs or blocks of untreated exotic wood will create habitat for organisms which depend on coarse woody debris. At Lincoln, we have been using discs of untreated pine, with rough-cut grooves, in a restoration program in pasture, and these are becoming invertebrate aggregation points. Further, the provision of nectar and pollen sources within the site will provide pollinators (even exotic ones) with a reason to remain in the restoration site (Holl, 1995).

Work on the above 'hurdles' to colonisation is sparse and scattered in its aims and in its relation to restoration of formerly-existing communities. Very little restoration work has taken place at the community level, with most studies following the successional progress of one or two taxa only. For example, Majer *et al*. (1984) and Andersen (1993) both studied ants, Meijer (1989) studied carabids and Holl (1995) studied butterflies. Nevertheless, such research has shown interesting successional patterns, involving species replacement correlated with vegetation and abiotic factors (such as salinity changes), distance effects (Andersen, 1993), dispersal capacity (Meijer, 1989), common *vs*. rare species dispersing from existing sources (Majer,

Kabay and Perriman, 1984) and fragment size influences (Harris, 1984). However, despite the extensive bibliography in Majer (1989), animal and plant community research is still under-represented in restoration ecology, especially in New Zealand (Figure 1).

Measuring success

Measuring success obviously depends on the initial goal. However, we consider the following important measures of a developing restoration system as signs of success.
1. Species colonisation (the arrival of new species)
2. The persistence of species arriving
3. Survival and reproduction of colonising species
4. Specific resource colonisation (niche occupation, e.g., coarse woody debris guilds)
5. Enhancement of existing or absent processes - herbivory, decomposition of new material, pollination
6. Balance in processes (i.e., no continued high rate of a process e.g., continued high level of defoliation)
7. Increased indigenous species richness, and abundance
8. An indigenous/exotic ratio that moves to favour indigenous species
9. A reduction in pest species invasions.

Success may be the enhancement of the landscape's biodiversity, however little, or the maintenance of a population of beneficial arthropods (e.g., carabid beetles), or the production of a self-sustaining, comparatively representative, indigenous system. The nine measures above will help determine how far the project is from completion, and will help identify any problems restricting its progress.

Conclusions

Though much of what has been mentioned seems to be common sense, it appears from discussion and the literature that it is not. Further, documentation, publication, and "scientific" method are lacking, and though we know of many restoration projects in progress, many of these results will reach only the "grey" press. It is our aim here to point out the importance of this topic and to encourage the initiation and publication of research which involves a community approach to restoration. Perhaps restoration ecologists see no relevance in researching animals (invertebrates) in production landscapes, or perhaps they believe that, given time, the higher trophic levels appear naturally.
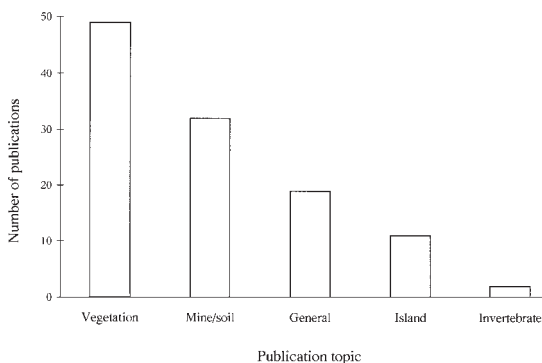

Figure 1: *Subject distribution of literature on ecological restoration in New Zealand. The literature on islands often includes bird and reptile infomation. 'General' means discussion/comment papers. Data come from a manual search using citations, library data bases, the CAB Abstracts database, and S. Reay's in-depth thesis reference search, posted on the N.Z. Restoration Bulletin Board.*

Acknowledgments

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