Upland biodiversity, ecosystem processes and services: how strongly coupled are they?

Philip A. Wookey & Iain Hartley

University of Stirling, School of Biological and Environmental Sciences, Stirling FK9 4LA

Background

There is a vigorous debate in the international research community, and amongst policy-makers and planners, concerning the functional role of biodiversity (Chapin 2000; Loreau *et al.* 2001; Hooper *et al.* 2005). Attaching a value (e.g. economic, aesthetic or cultural) to biodiversity is seen as a pragmatic way of reinforcing conservation programmes and land management practices that foster the maintenance or enhancement of biodiversity. Making the link between biodiversity and the provision of ecosystem 'services' (defined by the FAO (2005) as "The conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfil human life") is not, however, always as straightforward as it might at first appear, and our fundamental understanding of ecosystem structure and function is often insufficient to underpin 'evidence-based' ecosystem management. When multiple drivers of environmental change (e.g. climate change, pollutant deposition, land-use change) are also considered the position becomes extremely complex.

Biodiversity, Ecosystem Processes and Services

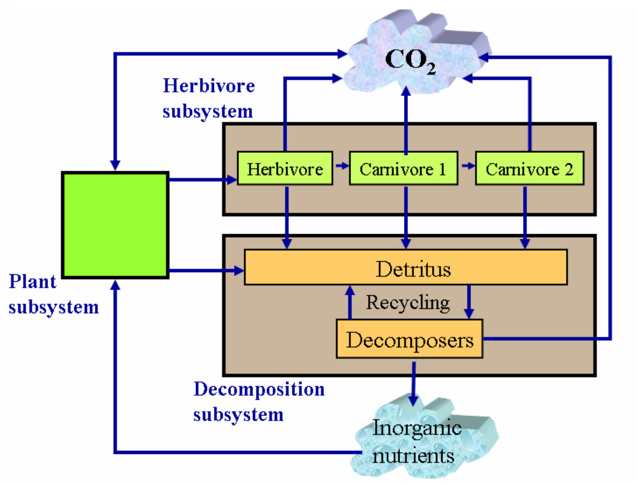
The science of biodiversity has rapidly gathered momentum since the term was first used in print nearly 20 years ago. The threat of biodiversity loss has led ecologists to try to understand the consequences for ecosystem processes and services, and to understand the 'functional role' of organisms in these terms. Key questions posed in the literature include: Are some species 'redundant' in an ecosystem? Does it matter if organisms become extinct locally (or indeed globally), and what are the consequences? What do we mean by ecosystem processes and services? What are the functional roles (traits) of organisms, and can we classify organisms into functional types?

To some extent answers are being found to some of these questions through the establishment of field and laboratory experiments manipulating biodiversity and recording the consequences (see, for example, Tilman 1996; Naeem 2002). The broad-scale application of these results to questions of practical ecosystem management remains, however, an elusive goal.

Biodiversity, Ecosystems and the Scottish Context

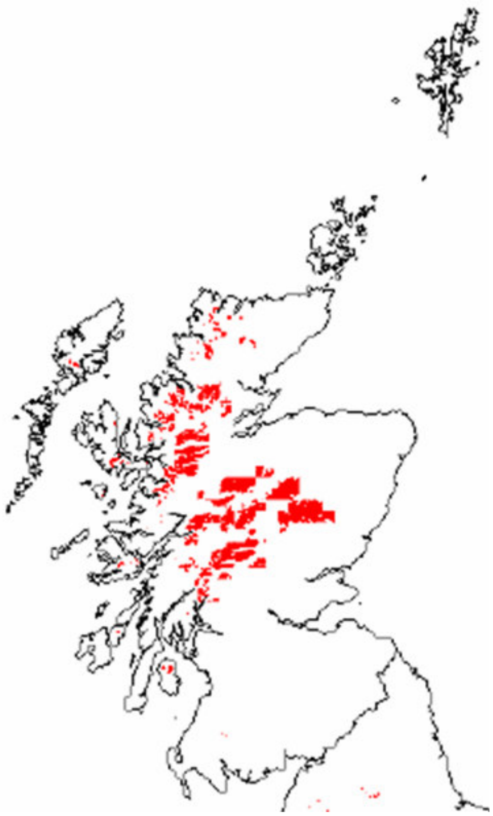
There are obvious connections between biological resources and ecological services in Scotland. It has been estimated that the annual 'ecosystem service' value is approximately £17 billion (Williams *et al.* 2003), and wildlife tourism, for example, employs 30,000 people. Charismatic/iconic species (e.g. red deer, red grouse or white-tailed eagles) have a direct economic value (e.g. from tourism), underpinned by an aesthetic, cultural, and even spiritual value. These are the obvious links between explicit components of biodiversity and, for example, ecosystem services. But there are remarkably few integrated ecosystem studies (this is true both in Scotland, and internationally) which address the importance of several trophic groups or ecosystem components. Figure 1 shows the basic components of a terrestrial ecosystem, with its three subsystems (the Plant, Herbivore (including carnivore), and Decomposition subsystems). Significantly, specific avian and mammalian taxa are often used to evoke biodiversity in the uplands. We hear talk of biodiversity, which is then illustrated by, for example, the hen harrier (*Circus cyaneus*) or the black grouse (*Tetrao tetrix*)! In fact the vast capital of genetic diversity in most terrestrial ecosystems resides in the soil (decomposition subsystem) yet we know, or hear, very little about this (although see, for example, Bardgett & Chan 1999; Dennis 2003). In terms of the maintenance of stability and integrity of bulk ecosystem <u>processes</u> (e.g. photosynthesis, transpiration, decomposition and nutrient recycling) the organisms responsible are frequently overlooked or taken for granted. Dennis (2003) has noted, for example, that "arthropods contribute the most species of any taxa in the uplands and are critical in upland food chains".

Figure 1. A simplified model of a terrestrial ecosystem (redrawn from Swift, Heal and Anderson, 1979) showing the three subsystems (plant, herbivore and decomposition) which are functionally integrated by flows of energy and recycling of materials. Note that the herbivore subsystem also includes carnivores. In many terrestrial ecosystems (and certainly in the Scottish uplands) the major reservoir of biological diversity resides in the decomposition subsystem (i.e. in the soil).



An argument that has been applied in favour of an emphasis on charismatic or iconic species, however, is that their management or conservation should ensure, by default, the protection of all the ecosystem components, processes and services which underpin them. There is some merit to this argument, but it needs to be applied intelligently. The Scottish Biodiversity Forum (SBF, 2003) identifies 'biodiversity resources' which can be categorised according to their implicit or explicit connection with the ecosystems or communities of which they are a part. In the uplands/montane in Scotland 'keystone species' would include, for example, heather (*Calluna vulgaris*) and red deer (*Cervus elaphus*). Indeed SBF states of the latter that it is "a classic keystone species, strongly associated with Scotland, whose grazing and browsing affect forest regeneration and the development of tall herb communities over wide areas". 'Umbrella species' might include bearberry (*Arctostaphylos uva-ursi*) heath, whose conservation would support the survival of intermediate wintergreen (*Pyrola media*), which is currently on the SNH 'Species for Conservation Action' list. A further category recognized by SBF is the 'flagship species' which comprises "charismatic species serving as symbols and rallying points to stimulate conservation awareness and action". In Scottish montane communities a good example of this could, for example, be the dotterel (*Chardrius morinellus*) or ptarmigan (*Lagopus mutus*). This 'biodiversity resources' approach is a pragmatic one, particularly for conservation purposes, and it has some value in guiding the development of research questions, but the risk inherent in the approach is that important organisms (in terms of ecosystem processes and services) can be eclipsed by the charismatic ones, and the linkages between ecosystem structure and function may remain untested.

Figure 2. The distribution of montane habitats in Scotland.



The Scottish Montane

In a Scottish uplands context the 'montane' environment (Figure 2) provides a good illustration of some of the key issues. Montane habitats in Scotland are some of the least affected by direct human activity in the UK, yet the prognoses for a doubling of atmospheric CO_2 concentrations are for a 200-960 m upwards shift in vegetation zones and a 93% reduction in arctic-alpine habitat (SBF 2003). In spite of their wild character these habitats are also exposed to heavy grazing pressure (there has been a 32% increase in sheep density between 1950-1990, and the red deer population has also increased substantially due to under-culling in recent decades). Furthermore, the deposition of airborne acidifying pollutants remains high (and well in excess of critical loads in many areas, particularly south of the Great Glen).

Although they comprise, arguably, some of the most vulnerable habitats in the UK, montane systems have only been added to the list of UKBAP 'Priority Habitats' very recently. In terms of the provision of ecosystem services, it is not only as rough grazing land that these systems are important: They have a disproportionate aesthetic value, and they are part of the cultural identity of Scotland as well as home for the UK's arctic-alpine animal and plant species. Apart from these obvious aspects the role of montane habitats in, for example, carbon cycling and the hydrological cycle merits consideration.

Although it is relatively straightforward to identify 'flagship' species for Scottish montane habitats (e.g. the dotterel or ptarmigan; see previous section), from a whole-ecosystem perspective one species which might appropriately be considered a 'keystone' or 'umbrella' species is the woolly fringe moss (*Racomitrium lanuginosum*: Figure 3). This moss is often found in association with arctic-alpine species such as stiff sedge (*Carex bigelowii*), trailing azalea (*Loiseleuria procumbens*), crowberry (*Empetrum nigrum* ssp. *hermaphroditum*) and dwarf willow (*Salix herbacea*), and *Racomitrium* heaths are important feeding and breeding grounds for dotterel, and the invertebrates upon which they depend.

Montane communities containing woolly fringe moss provide a classic example of the way in which two or more environmental change drivers can reinforce one another and result in a profound change in community properties. In an experimental study van der Wal *et al.* (2003) illustrated that the deposition of airborne nitrogen-containing pollutants in the eastern Grampians (Glas Maol), in combination with heavy grazing pressure, can result in the replacement of valuable *Racomitrium lanuginosum*-dominated habitat by grasses and sedges (Figure 4). Essentially this is a feedback loop whereby nitrogen deposition both encourages the growth of grasses and sedges, but is directly toxic to the *Racomitrium*. The improved growth of grasses

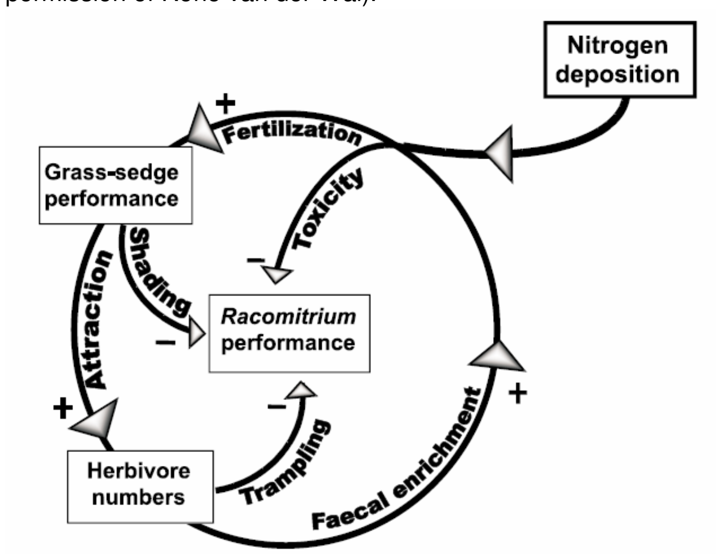
Figure 3. *Racomitrium lanuginosum* / *Carex bigelowii* (degraded) at Meall na Samhna SAC (Stirlingshire).

and sedges both attracts herbivores and also shades the *Racomitrium*. The increased grazing pressure causes damage to the *Racomitrium* both via trampling (a physical process) and also by exacerbating the nitrogen 'fertilization' (a chemical stressor) through the addition of urine and faeces. The overall result is dieback of the *Racomitrium*, and the replacement of heath by a grass-sedge sward. Although there is scope for substantially more research on the knock-on implications of these changes in vegetation for other primary producers and trophic levels it is clear that the value of the habitat for specialist montane organisms is reduced substantially. There may also be implications in terms of ecosystem carbon sequestration, water balance or erosion resistance, but these remain to be systematically studied.

On a broader basis, the Joint Nature Conservation Committee (JNCC) notes currently that "32% of alpine grass and heath features reported are in favourable condition. This is below the average for terrestrial habitats, all habitats or all features combined". Clearly, although montane habitats in the UK are some of those least affected directly by human activity, they are under considerable pressure nonetheless. If climate change impacts are superimposed upon pollutant deposition and grazing pressure then the prognosis for these habitats, and the organisms that depend on them, is not encouraging.

Identifying threats to biodiversity (e.g. from changes in land-management regimes, climate change, or pollution) is relatively straightforward, but identifying the implications of changes in biodiversity for ecosystem processes and services is not. This situation is not unique to the Scottish uplands. Essentially the argument

Figure 4. Conceptual model (from van der Wal *et al.*, 2003) integrating impacts of nitrogen deposition and grazing. This multi-step positive feedback loop shows how atmospheric nitrogen deposition leads to the replacement of the woolly fringe moss (*Racomitrium lanuginosum*) by sedges and grasses of lesser conservation value (diagram reproduced by kind permission of René van der Wal).



that biodiversity is important for ecosystem processes and services is often rolled-out to justify conservation and mitigation programmes: The paradox is that, except with a few fairly obvious examples, this is often much harder to demonstrate scientifically.

Whilst it is pragmatic to argue that biodiversity is important for ecosystem processes and services, and whilst we know (instinctively) this to be true in many ecosystems, there is still a valid social, cultural and ethical argument. Sir Martin Holdgate summed this up perfectly in the Scottish context by stating "We must always recognise that conservation is a social activity, expressing social values. Biodiversity is valuable in its own right, but it is also part of our heritage… The biodiversity of Scotland is a part of Scotland's Scottishness. Conserving it is a cultural priority". This argument should underpin all others in which a cruder economic prerogative is invoked.

References

Bardgett, R.D. & Chan, K.F. (1999) Experimental evidence that soil fauna enhance nutrient mineralization and plant nutrient uptake in montane grassland ecosystems. *Soil Biology and Biochemistry*, **31**, 1007-1014.

Chapin, F.S. III (2000) Consequences of changing biodiversity. *Nature*, **405**, 234-242.

Hooper, D.U., Chapin, F.S., Ewel, J.J., Hector, A., Inchausti, P., Lavorel, S., Lawton, J.H., Lodge, D.M., Loreau, M., Naeem, S., Schmid, B., Setala, H., Symstad, A.J., Vandermeer, J. & Wardle, D.A. (2005) Effects of biodiversity on ecosystem functioning: a consensus of current knowledge. *Ecological Monographs*, **75**, 3-35.

Loreau, M., Naeem, S., Inchausti, P., Bengtsson, J., Grime, J.P., Hector, A., Hooper, D.U., Huston, M.A., Raffaelli, D., Schmid, B., Tilman, D., Wardle, D.A. (2001) Biodiversity and ecosystem functioning: current knowledge and future challenges. *Science*, **294**, 804-808.

Naeem, S. (2002) Disentangling the impacts of diversity on ecosystem functioning in combinatorial experiments. *Ecology*, **83**, 2925-2935.

Tilman, D. (1996) Biodiversity: Population versus ecosystem stability. *Ecology*, **77**, 350-363.

van der Wal, R., Pearce, I., Brooker, R., Scott, D., Welch, D. & Woodin, S. (2003) Interplay between nitrogen deposition and grazing causes habitat degradation. *Ecology Letters*, **6**, 141-146.

Scottish Biodiversity Forum (ed. M.B. Usher) (2003) Towards a strategy for Scotland's biodiversity – Scotland's Biodiversity resource and Trends. ISBN 0755923200.