Executive Summary

Biotic and Biophysical Underpinning of Ecosystem Services in the Scottish Context: A Review

This review has been undertaken as part of the Ecosystem Services Theme of the Scottish Government Strategic Research Programme: Environmental Change.

The aim of this review is to help deliver the request from Scottish Government for:

> *Increased understanding of the linkages between the primary ecological and evolutionary processes, ecosystem function and ecosystem services, to inform assessment of the consequences of environmental change for the wide range of ecosystem services. (RD 1.1.2).*

By undertaking a review exercise focussed on the underpinning of ecosystem service delivery by the natural environment we are able to:

1. Improve shared understanding across the Work Packages, Themes, and Programmes about ecosystem service delivery and the Ecosystem Approach concepts.

2. Better target future research activity toward identified knowledge gaps.

This is a rapidly-developing research field, and the breadth of topics and information that might be covered by such a review is very large. Consequently, the review is focussed around topics which are relevant to the needs of Scottish Government and which will inform future research activity by the Ecosystem Services Theme of the RESAS Strategic Research Programme.

Our ***Introduction (Chapter 1)*** sets out the wider context for the work. It explains the origin of the Ecosystem Approach and ecosystem service concepts. It looks briefly at the wide range of research being conducted globally on biodiversity-ecosystem service linkages. It explains the approach that we have taken to focus the review to make it more policy-relevant within a Scottish context.

At the heart of this approach is an alignment with 'broad policy goals' – around which chapters 2 through to 5 are structured - as well as the identification of prioritised ecosystem services. The prioritisation of services took place as part of the second Ecosystem Approach Working Group workshop, and was based upon expert judgement and opinion from participating stakeholders. The prioritisation process is explained in more detail in Chapter 1. The broad policy goal chapters consider how biodiversity and biotic/biophysical processes underpin the delivery of prioritised services.

For clarity, Chapter 1 also provides our working definitions for key concepts and terminology which are used throughout.

With respect to a ***Low carbon economy (Chapter 2)*** trees, peat, soil formation and crops were considered by the workshop participants to be the most important ecosystem services. It is the carbon sequestration provided by these that is particularly important, contributing to the final ecosystem service of climate regulation.

- With respect to ***trees***, biophysical conditions influence species growth and carbon storage but may be overridden by management practices such as fertilisation and drainage. Biotic processes both enhance and restrict the ecosystem service of trees, through mycorrhizal associations, pollination, dispersal of seeds/fruits, pest regulation, disease, and browsing by herbivores. Increased tree cover results in more vegetation-stored carbon, but this is balanced against carbon loss from soils in some instances. Abiotic and biotic factors and forestry management influence total carbon storage by trees.

- With respect to ***peat and soil formation***, extraction of peat leads to GHG emissions, in conflict with the 'good' of an equitable climate. Peat formation is underpinned by biotic processes of peat-forming plants and associated litter-decomposing microbial communities. *Sphagnum*-dominated bryophyte communities are the main peat builders in high latitudes. While Sphagnum has been described as an 'ecosystem engineer', reflecting its importance in peatland formation, the impact of associated microbial decomposer biodiversity on peat formation is unclear. Most soil processes, including soil formation, are mediated by the soil microbial community, which in turn is strongly influenced by plant community structure. Although the huge biological diversity found in soils may appear relatively 'inactive', it may be central to system or functional resilience; therefore discounting this diversity may fail to account for a key regulating component of the soil environment and its processes.
- With respect to ***crops***, bioethanol, biodiesel, food and fibre from reduced input farming are the 'goods' of greatest relevance. Crops play a key role in delivering a low carbon economy because land use or crop types might be directly targeted to support renewable energy actions, and changes in crop management also impact on carbon emissions. The impact of biodiversity on crop production is often positive (e.g. pollinators), but biodiversity effects are relatively small compared to management actions as well as geographic and temporal variation in soil conditions.
- ***Overall***, upland habitats generally provide more carbon storage (trees and peat) than lowland habitats, while lowland habitats generally provide more food and fibre, but these broad generalizations hide much local variation. The most common conflicts or trade-offs occur around land use and land management; for example, decisions are required on how best to manage land as a limited resource in providing different crops (food or biofuels) or protected habitats, and ecosystem service mapping is invaluable in this respect. However, there are gaps in our understanding of how biodiversity and biotic/biophysical processes underpin the delivery of ecosystem services relevant to a low carbon economy.

With respect to ***sustaining food production (Chapter 3)***, crops, livestock, soil formation, and pollination were considered by workshop participants to be the most important ecosystem services.

- With respect to ***crops***, Scottish production is highly mechanised, with considerable inputs and high intervention. Consequently, although biophysical conditions are a major determinant, biodiversity currently has a limited underpinning role. However, many studies find positive relationships between biodiversity and relevant functions (e.g. productivity or pest and disease regulation), often thought to result from the characteristics of the species concerned and their impacts on ecosystem function. Declining biodiversity could have consequences for ecosystem functions central to crop production, and ultimately for its productivity and sustainability.
- ***Livestock*** production is the dominant agricultural sector in Scotland, and is particularly important for the uplands. There is a considerable literature on how livestock production affects biodiversity and biophysical processes (both positively and negatively), but rather little information on its underpinning by biodiversity. However, biophysical drivers and processes (e.g. climate, soil and water conditions) clearly can impact livestock directly by influencing grazing quality, and indirectly through regulating disease and pests.
- For ***Pollination*** services, the link between biodiversity and pollination is strong and clear: a reduction in pollinators can be expected to have a deleterious effect on this ecosystem service. However, a relatively small proportion of current Scottish crop production is dependent on pollination (about 13% of total output value). In addition, since wind-

pollinated grasses are the main source of fodder, there is likely to be no impact of pollinator losses on the production of meat and dairy products or on grain production.

- ***Soil formation*** is vital for food production. The links between soil formation, biodiversity and biotic and biophysical processes are complex. Research on the role of soil biodiversity in ecosystem function has lagged behind corresponding research above-ground, but functional trait approaches may be useful in addressing research gaps. Soil biodiversity in many areas is clearly in decline and, as soil biota are a component of healthy soils, the impacts of current farming practice on soil biota may negatively impact on soil formation.
- ***Overall*** it appears that the functional diversity of organisms may be central to sustaining food production. Natural processes, and biodiversity at a range of scales, can help to deliver services directly relevant to sustaining food production, and can do so in a sustainable manner. However, it is clear that we need a better understanding of how to integrate nature conservation with food production, and to balance the negative (e.g. pests and diseases) as well as the positive effects of biotic processes and biodiversity.

With respect to ***halting biodiversity loss (Chapter 4)***, the ecosystem services prioritised by workshop participants for consideration here are wild species diversity (as both a cultural service and provisioning service), disease and pest regulation, and crops.

- ***Wild species diversity (cultural service)*** is more likely to be directly regulated by natural biophysical and biotic processes in upland than in lowland systems. Defining the 'goods' delivered is complex but important: these may differ substantially between stakeholders, and so too might the service's relationship to biodiversity and biophysical processes. Understanding the basis for conservation targets – the "appropriate" level of biodiversity - is also important: this will differ between the lowlands and uplands. All types of biodiversity are likely to play a role in regulating this service
- For ***wild species diversity (provisioning service)***, increased biodiversity is likely to be important for ecological restoration, but this positive relationship is probably weaker for other types of bioprospecting (e.g. the hunt for pharmaceutical products). Increased diversity overall can be beneficial for the provision of harvestable species, with the exception of some particular species groups (epidemic pests and diseases).
- The relationships between biodiversity and biotic/biophysical processes and ***disease and pest regulation*** are complex, not least because either side of the pathogen/pest–host relationship may be affected. We have some knowledge of these relationships from crop and livestock production systems, but our knowledge is poorer for more complex natural and semi-natural systems (although critical with respect to halting biodiversity loss). There is now considerable potential for extending techniques developed in production systems to explore these relationships in natural/semi-natural systems.
- With respect to ***crops***, intensification clearly leads to negative biodiversity impacts. Sustainable farming practices will be beneficial for biodiversity in crop production systems, but the extent to which biodiversity-supported functions can offset the loss for crop production from less intensive farming practice is unclear. Other changes in crop production systems, beyond simply reducing the intensity of management, may have beneficial impacts for farmland biodiversity and can contribute to biodiversity conservation.
- ***Overall***, in all systems it is important to understand which elements of biodiversity are critical for delivering the aims of the broad policy goal, and how these relate to the desires of and management by different stakeholder groups. This level of detail is necessary for developing integrated management practices that promote biodiversity conservation.

Prioritised ecosystem services selected for consideration for ***sustainable water management (Chapter 5)*** are water cycling, water detoxification and purification, and water supply. To deal with the close interconnectedness of these services, Chapter 5 focuses on water quantity and quality: delivery of both involves elements of all three prioritised ecosystem services.

- With respect to ***water quantity***, climate, topography, geology and physical processes play a very substantial role in determining quantity. Perhaps the most critical aspect of biological processes is the occurrence of specific habitats and ecosystems rather than biodiversity *per se*. Within these habitats certain groups of organisms, in particular vascular plants and bryophytes, have the biggest impact on water quantity. However, other groups such as soil fungi may have substantial yet currently-unquantified roles. Native ecosystems (semi-natural habitats) tend to have a greater beneficial impact on water quantity compared to those comprised of or dominated by non-native organisms.
- There is a much greater relative role for biological processes in regulating ***water quality***. Land management can determine the functioning of biophysical processes that regulate water quality, e.g. water penetration. As with water quantity, the physical process of water penetration (prior to detoxification) may be dependent on the occurrence of specific ecosystem types, although biodiversity *per se* may also be important in enabling a wide range of potential pollutants to be detoxified. Although there is less certainty about this biodiversity role, different habitats deliver different components of the water cycle that enhance water quality, and new pollutants indicate the potential for apparently 'redundant' components of biodiversity to be of future use in detoxification processes.
- ***Overall*** the uplands are central to delivering both water quantity and quality. Purification processes – enhancing quality - are also important in lowland ecosystems, but there is much greater dependency of lowland users on upland systems than *vice versa*. The dependency between upland and lowland systems is probably much greater than for other ecosystem services. The scale needed for appropriate planning for the delivery of sustainable water management is likely to be much larger (e.g. across entire catchments) compared to the delivery of services important for other broad policy goals.

In our ***Discussion and conclusions (Chapter 6)*** we assess the approach taken for our review, overarching patterns in the relationships between biophysical/biotic processes and biodiversity and ecosystem service delivery, and knowledge gaps.

In terms of our ***approach*** we conclude that:

- The focus on prioritised ecosystem services for practical reasons has not limited the types of services or levels of biodiversity considered;
- Consistent use of terminology is essential, as is the provision of clear definitions for key concepts (such as those used in Chapter 1);
- This review should be seen as part of a process of on-going dialogue and discussion which is helping to deliver improved and shared understanding.

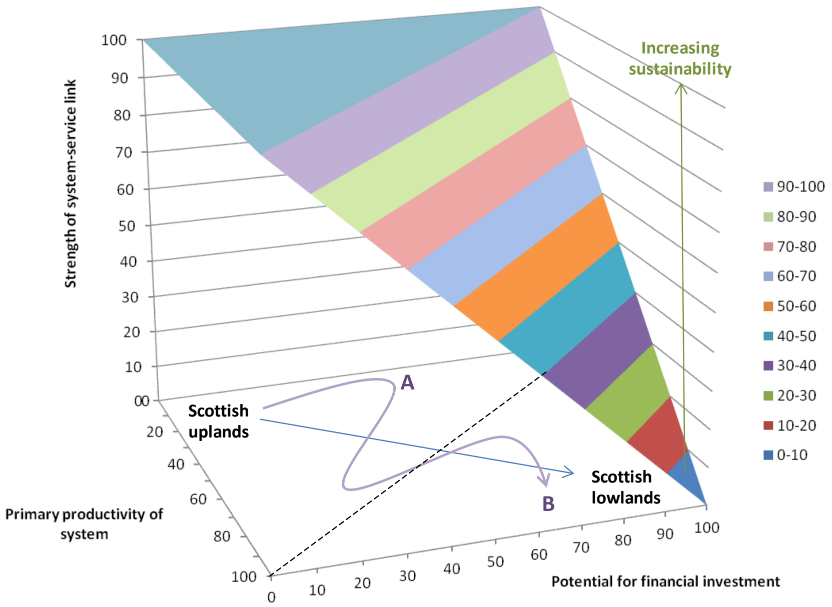
In terms of the ***relationships*** between biodiversity and biotic/biophysical processes and ecosystem services, we conclude that:

- Although biotic and biophysical processes clearly underpin the vast majority of ecosystem services, the role of biodiversity *per se within* an ecosystem is unclear: in many cases it is the occurrence of particular species, functional groups or habitats that seems critical for service delivery, and the diversity of these components *among* locales which is required to sustain Scotland's multifunctional landscape;
- In some cases service delivery is strongly and directly regulated by the physical environment; in others it is mediated by interactions between biotic and physical processes;

- Differences in the physical properties of upland and lowland systems have profound implications for the potential uncoupling of service delivery from any biodiversity/biophysical underpinning. A simple model (below) can be put forward to clarify these relationships. This suggests that indicators that can genuinely monitor the delivery of services will be more effective in monitoring system health in upland rather than in lowland environments in Scotland.

***A simple graphical model** for the extent to which ecosystem service delivery <u>can be</u> detached from underlying biodiversity and biophysical processes.*

The two underlying drivers of this potential detachment are the primary productivity of the system, and the potential for financial investment in land management. These drivers are shown in arbitrary units from 0 (Low) to 100 (High) but are not independent. Low primary (biotic) productivity reduces income and the potential for investment in management. However, there is not always a direct positive correlation: high primary productivity does not necessarily mean high income generation – this is dependent on whether the potential income is realised. Consequently, at low primary productivity investment in management interventions is constrained, and the delivery of services is directly dependent on biodiversity and biophysical processes (there is a strong link between natural systems and service delivery). However, as primary productivity increases, potential income streams increase and consequently the strength of the link between natural systems and service delivery is reduced (shown in the response surface by a reduction in the strength of the system-service link). It is important to recognise, though, that the response surface represents the <u>hypothetical potential maximum decline</u> in the strength of this link: this maximum will only be realised if services are exploited and resulting income used to invest in artificial processes that replace natural ones. Note also that the model does not indicate whether the relationship will be positive or negative, simply whether in general it is likely to be strong or weak. The green arrow shows the hypothetical change needed to re-establish the link between natural systems and service delivery, and increase system sustainability. The purple arrow shows the movement of a service such as water supply across the response surface, with the final dependency on natural systems of that service being the mean value across the length of the path.



Finally, one of our primary aims was to identify ***knowledge gaps***. Each chapter identifies knowledge gaps that are of particular relevance to that broad policy goal, and some of these have been mentioned above.

In addition, some knowledge gaps are common across broad policy goals, specifically:

- Framing cultural service concepts to explore their underpinning by biodiversity and biotic/biophysical processes;
- Understanding the role of genetic diversity in maintaining ecosystem function and service delivery;
- Understanding the role of functional diversity and species redundancy;
- Understanding the importance of the spatial configuration of habitats/ecosystems, including the possible occurrence of scale-dependent thresholds of function;
- Understanding whether the Ecosystem Approach *will or will not* further enable biodiversity conservation.

This list of generic knowledge gaps should in no way be taken as indicating some form of priority order. In addition, although some knowledge gaps might be considered generic across broad policy goals, this does not mean that they are necessarily of greater importance than those related to particular policy goals. In order to genuinely enhance the application of the Ecosystem Approach and uptake of the ecosystem service concept, it will be necessary to address all of these knowledge gaps.

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