Integrating ecosystem services into land-use planning for sustainable landscapes

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KEY MESSAGES

1. No single land cover provides a full spectrum of ecosystem services. Therefore, land-cover and land-use decisions need to weigh up the ecosystem services being supplied and any subsequent trade-offs in the supply of other ecosystem services.

2. Maximizing the flow of multiple ecosystem services requires a mix of land covers that complement each other in terms of the services they offer. Promoting resilience in the flow of these services requires some redundancy in the types of services offered by different land covers. A balance between diversity and redundancy of land covers should be used to inform decisions on how to manage the desired suite of ecosystem services in different landscapes.

3. Land covers will provide similar services depending on whether they are under intensive, extensive or no production. A mix of intensive and less intensive production land covers can supply a more comprehensive and diverse set of ecosystem services.

4. At large/broad scales, land cover and biodiversity appear to convey similar information about spatial changes in the supply of ecosystem services. Therefore, in many instances land cover information can be a cost-effective surrogate for assessing the effect of biodiversity on ecosystem service provision. For a few services, however, biodiversity adds information that is not conveyed by land cover and biodiversity should be measured directly.

BACKGROUND

Ecosystem services are the benefits provided to humans by nature.[1,2] They are typically described as the products obtained from ecosystems (provisioning services), the benefits from regulating ecosystem processes (regulating services), the non-material benefits obtained from ecosystems (cultural services) and the services necessary for the production of all other ecosystem services (supporting services). Examples of ecosystem services include the provision of timber and freshwater, the regulation of extreme weather events and natural hazards, the existence of natural spaces for recreation and of natural elements to which humans bestow aesthetic or spiritual values.

Land use decisions often maximize the provision of one or a few ecosystem services (e.g. provision of timber or food) that can bring immediate economic reward. However, this is frequently done at the expense of other services that, while not considered explicitly in those decisions, still play a vital role in sustaining ecosystems, economies and human wellbeing.[3,4,5] Understanding how land-use decisions can shape the supply of multiple ecosystem services is therefore critical to leverage long-term sustainability.[6]

In this policy brief we provide some insights and findings to questions raised by natural resource managers around how the supply of ecosystem services is linked to different land covers (as a surrogate for land uses) in New Zealand. These questions include:

1. How does the supply of ecosystem services differ across land covers?
2. How can we maximize supply and resilience of ecosystem services at large (e.g. catchment) scales?
3. Do broader characteristics of land covers determine how well they supply different services? (e.g. do land covers with a similar level of production intensity provide a high supply of similar services?)
4. Does biodiversity tell us anything about the supply of ecosystem services that land cover doesn't?

These insights come from a comprehensive analysis of New Zealand literature that enabled a comparison in the supply of ecosystem services between different land covers (see Box 1 for details on the methodology used).

1. HOW DOES THE SUPPLY OF ECOSYSTEM SERVICES DIFFER ACROSS LAND COVERS?

The supply of multiple ecosystem services is best achieved through a combination of land covers.
Data on how land covers differ in the provisioning of 17 ecosystem services in New Zealand are summarized in Figure 1. The numeric values indicate the relative effect that different land covers have on the supply of each ecosystem service. Many provisioning ecosystem services that arise only from a single land cover (e.g. timber from exotic forests) are not included here as the analysis focused on a comparison between land covers.

In Figure 1, values are relative to the high producing exotic grassland and is the reference against which all other land covers are compared. From Figure 1, no single land cover performs consistently well across all services. For example, indigenous forest, is important for supplying several services (including habitat provision, water purification and erosion control,), but does not perform as well as the high producing grassland at supplying other services (including primary production). This is true for all land covers in Figure 1 and suggests that no single land cover is an optimal provider of all ecosystem services (a *jack-of-all-trades*). Instead, multiple land covers are needed to provide multiple services.

Trade-offs between services are likely unavoidable if land covers change. Therefore, decisions on land cover (and land use) should consider which ecosystem services are being supplied and how that supply will change when land cover changes (i.e. the trade-offs). For example, services where indigenous forests perform better are largely services where short-rotation cropland and orchard, vineyard & other perennial crops perform poorly and vice versa. Therefore, a combination of indigenous forest and either short-rotation cropland or orchards, vineyard & other perennial crops is likely to yield a more diverse suite of services than those offered by these individual land covers.

A few caveats: Ecosystem services that provide material benefits from a single land cover (e.g. meat, dairy, wool, crops) or benefits that are not related to land cover (e.g. location benefits) have not been addressed here since we focused on services that could be compared across land covers. Each value in Figure 1 was calculated from a different number of studies. Since fewer studies were used in the cells with darker shading, we are less confident about their values.

2. HOW CAN WE MAXIMIZE FLOWS AND RESILIENCE OF ALL ECOSYSTEM SERVICES AT LARGE SCALES?

Resilience can be achieved through a diverse and complementary combination of land covers.

From Figure 1 we see that multiple land covers are needed to provide multiple services across any given landscape. The exact combination of land covers to maximize the flow of all ecosystem services (or those we desire) will depend on local conditions. Ideally the mosaic of land covers across the landscape should supply the full range of ecosystem services needed and/or desired and this supply will be maintained even during periods of disruption to one or more land covers. To achieve this, multiple land covers are needed to provide redundancy and, therefore, resilience.

Figure 2 illustrates this point for three hypothetical New Zealand landscapes and seven ecosystem services (freshwater provision, habitat provision, primary production, soil formation, nutrient cycling, water purification and regulation of water timing & flows). For each case, the points indicate the position different land covers would occupy in an "ecosystem services space". Land covers positioned close together supply similar ecosystem service levels and therefore provide redundancy should one land cover be perturbed in a way that reduced its capacity to provide those services. Land covers that lie further away from each other supply different sets of services. The larger the area covered by all points, the greater the diversity of services supplied although, in practice, it is not possible to cover the entire plot area.

Case 1, with few land covers, delivers few ecosystem services. In contrast Case 3, with many land covers, provides multiple services spread over a larger area of the possible "ecosystem services space". However, some of the land covers (e.g., tall tussock grassland, orchard, vineyard & other perennial crops) occupy quite isolated corners of the space. The services uniquely provided by these land covers would be at risk if these land covers where to disappear or have their functioning impaired.

In contrast, the four land covers in Case 2 are clustered around a smaller area of the "ecosystem services space" which indicates that, overall, they are likely to provide a less diverse suite of services than in Case 3, but with greater redundancy between the services offered between the different land covers. Should ecosystem service supply be compromised at one of these land covers, the flow of services within the landscape would likely still be sustained by the remainder land covers.

Exploring how the land covers within a landscape map onto "ecosystem services space" in this way can indicate the diversity of ecosystem services provided by that landscape and the resilience in how each is provided.

A caveat:
This analysis is illustrative covering ten land covers and seven ecosystem services. As more research is undertaken and more information becomes available this analysis could be extended to include more land covers and services.

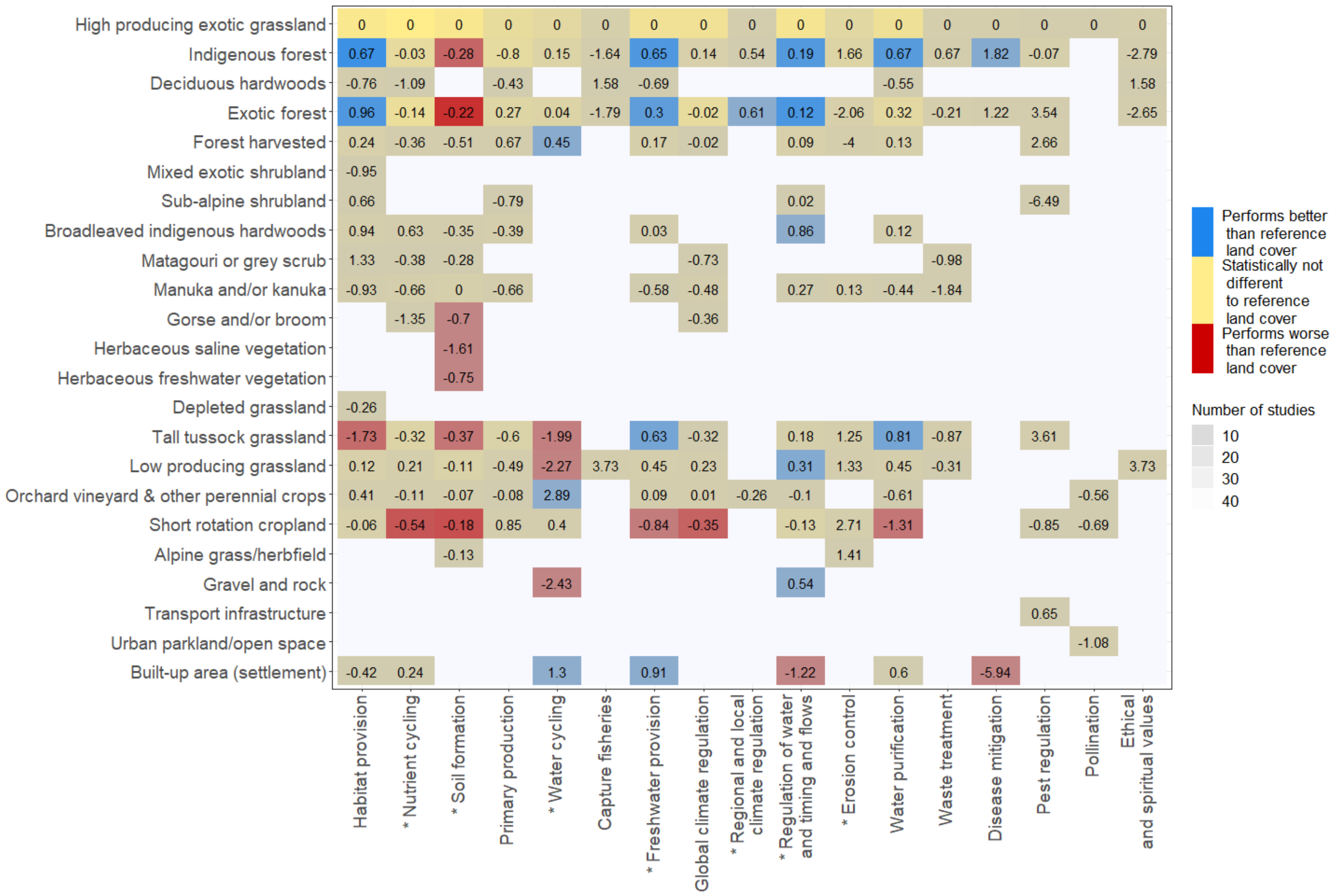

Figure 1. Comparison of the supply of 17 ecosystem services across 23 different land covers in New Zealand. Values indicate how well a land cover supplies the corresponding ecosystem service relative to high producing exotic grassland (the reference, has a value of 0 for all services). Yellow highlights cases where there is no statistical difference between how well a land cover supplies a service and the reference land cover. In contrast, red indicates that a land cover does significantly better than the reference in supplying a service and blue that it does significantly worse. The darker the grey shading over a cell, the fewer the number of studies contributing evidence on that land cover – ecosystem service combination and the less confidence we have in the value for that cell. Blank cells indicate data gaps. For services marked with an asterisk (*) the effect of some land covers can be masked by biophysical factors that have not been included in the analysis. For example: precipitation patterns will affect the provisioning of services related to water flow (water cycling, freshwater provision), soil type will affect nutrient cycling, primary productivity and soil formation while precipitation intensity and slope (which also determines the location of some land covers) will affect erosion control. Figure taken from the review by Gómez-Creutzberg et al. (2021).[7]

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4. DO BROADER CHARACTERISTICS OF LAND COVERS DETERMINE HOW WELL THEY SUPPLY DIFFERENT SERVICES?

Land covers with different levels of production intensity provide different sets of ecosystem services.

Managing land cover to enhance ecosystem service supply can be assisted by knowing which land covers supply similar levels of ecosystem services. In Figure 3, the same branch colour and a small number of "branch-off" points between land covers (e.g. indigenous forest and low producing grassland) indicates greater similarity in supply of the eight ecosystem services assessed than those separated by a greater number of "branch-off" points (e.g. exotic forest and tall tussock grassland). The ecosystem services assessed include freshwater provision, habitat provision, soil formation, nutrient cycling, primary production, global climate regulation, water purification and regulation of water timing & flows.

Land covers with similar levels of management for production tend to provide similar suites of services. In Figure 3, land covers with very intensive production (short-rotation cropland, orchard, vineyard & other perennial crops, high-producing exotic grassland, exotic forest and harvested forest) are separated from groups formed by land covers with no or extensive production (native forest, tall tussock grassland, manuka and/or kanuka, and low producing grassland). This highlights the importance of keeping a combination of land covers with contrasting production levels in the landscape to ensure the flow of multiple ecosystem services from that landscape.

In figure 3, low producing grasslands fall in the same group as native forests. These grasslands are characterized by a mix of native and exotic vegetation cover and usually support livestock grazing at extensive levels. In a landscape dominated by high production land covers, allowing for more extensive production systems such as low-producing grasslands could be an opportunity to introduce different ecosystem services to the suite provided by that landscape.

Some caveats: Figure 3 suggests that different types of land covers have different services associated with them. We use this as evidence to suggest that changes in land covers can introduce changes to the ecosystem services provided within a landscape. However, we cannot use this information to predict the actual changes in ecosystem service supply that may take place at any specific location. When land cover changes at any specific site, the provision of services from the new land cover can be affected by the legacy effects of previous land covers. These findings can be used as an overall summary of the similarity in ecosystem service supply across these land covers in New Zealand. It does not explicitly account for temporal land cover changes. These findings also do not separate the effect of land cover from other factors (e.g. slope, soil type, local climate patterns) that may influence ecosystem service supply and also change with land cover.

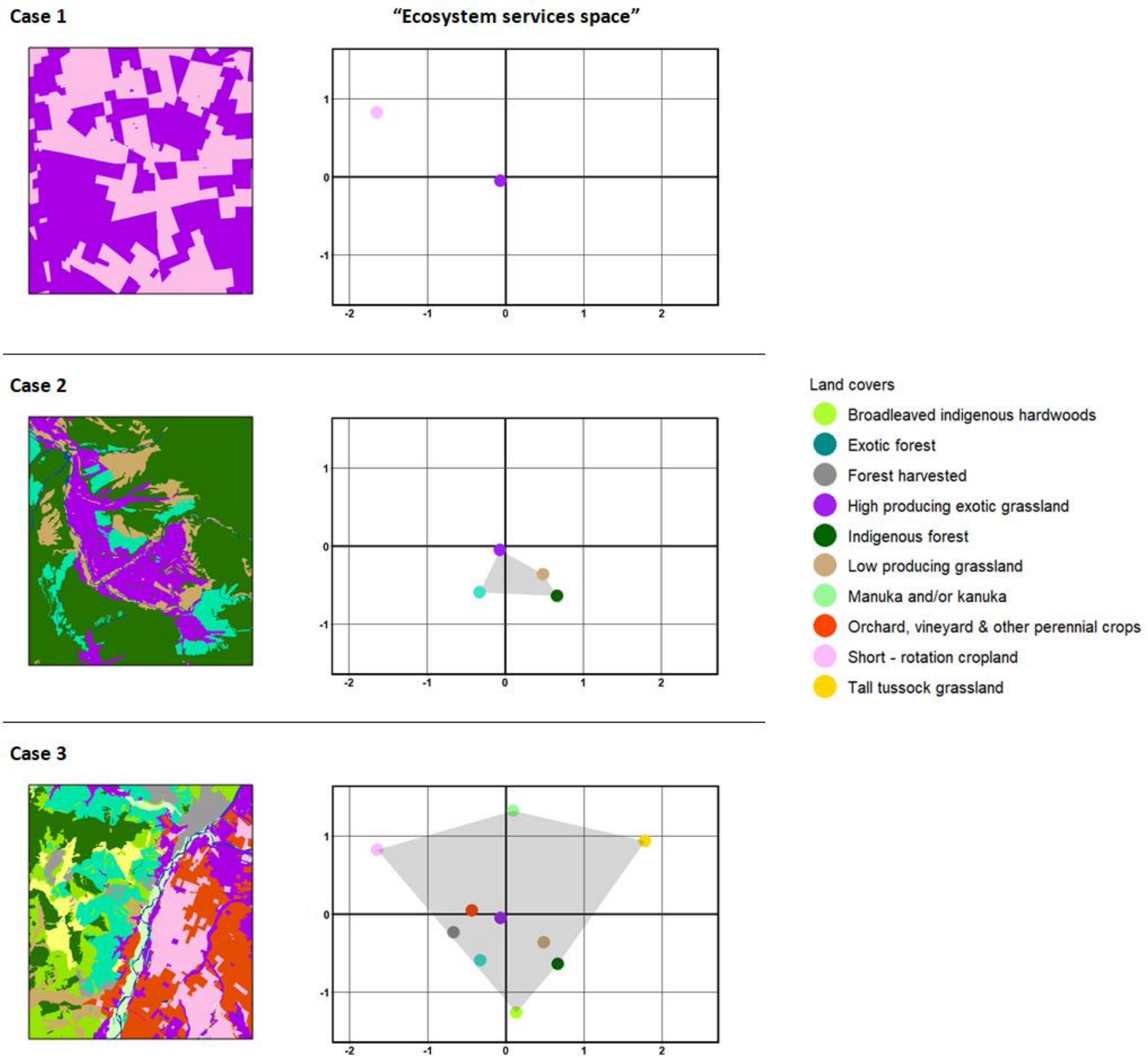

Figure 2. "Ecosystem services space" plots for three hypothetical New Zealand landscapes. As the number (and diversity) of land covers increases from Case 1 to 2 and from Case 2 to 3 the number of points in the plot and "ecosystem services space" enclosed by them increases. This reflects a greater diversity of ecosystem services being supplied. Note that the plot position remains constant in the three cases, what changes from case to case is the number and type of land covers in the landscape. Figure taken from the review by Gómez-Creutzberg et al. (2021).[7]

DOES BIODIVERSITY TELL US ANYTHING ABOUT ECOSYSTEM SERVICE SUPPLY THAT LAND COVER DOESN'T?

At a broad scale, land cover and biodiversity tend to convey similar information about the supply of ecosystem services.

The contributions of biodiversity information and land cover to explaining spatial trends in ecosystem service provision for ten services were compared using a limited dataset. The ten services were: freshwater provision, habitat provision, primary production, water cycling, soil formation, nutrient cycling, water purification, disease mitigation, erosion control and regulation of water timing & flows.

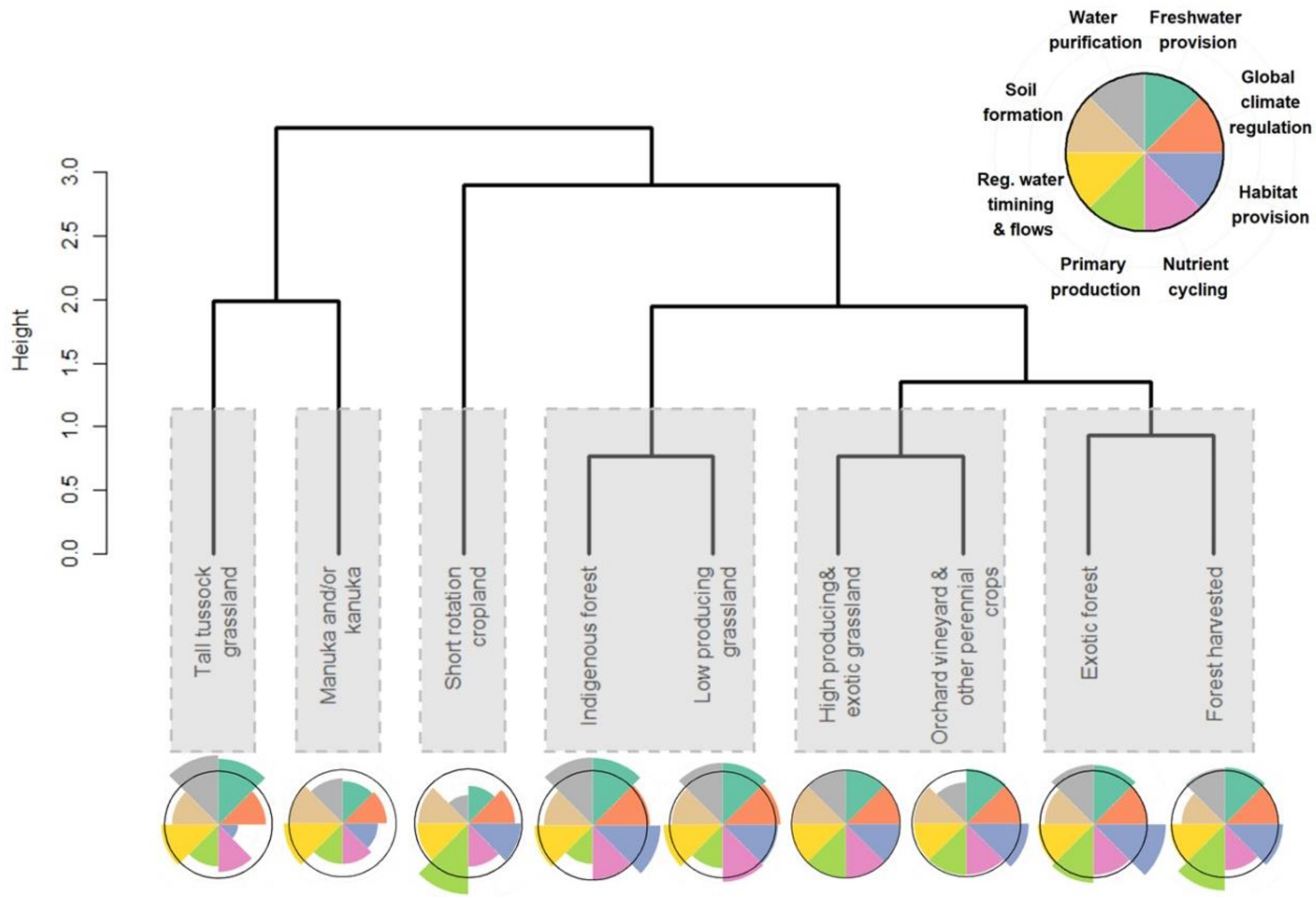

Figure 3. Comparison between nine land covers and their supply of seven ecosystem services. Land covers in the same grey box are more similar to each other in their supply of ecosystem services than those land covers in different boxes. The greater the number of "branch-off" points between land covers, the greater the difference in service provision between those land covers. For example, exotic forest is separated by six "branch-off" points from tall tussock grassland and by only one from forest harvested. The coloured charts at the bottom indicate how well each land cover supplies each of the seven ecosystem services, with larger wedges indicating greater service supply. For comparison, the black rings around each chart mark the amount of ES supplied by the high producing exotic grassland reference land cover. Figure taken from the review by Gómez-Creutzberg et al. (2021).[7]

Biodiversity has a strong influence on ecosystem properties and processes[8] as well as service provisioning.[9, 10] However, the findings of this analysis suggest that, for most services, land cover is a good surrogate for the effect of biodiversity on the supply of ecosystem services. In other words, land cover captures most of the effects that biodiversity has on ecosystem service supply. This is largely due to how biodiversity changes between land covers generally correspond to any vegetation changes that define different land covers. Therefore, using readily available land cover data as the basis to make ecosystem service decisions will likely provide similar benefits to using or collecting more costly biodiversity measures to make the same decision.

There were three exceptions to the above generalisation. For habitat provision, erosion control and regulation of water timing & flows, biodiversity contributed information on ecosystem service supply that was not conveyed by land cover. Decisions related to the supply of these services will benefit from considering broad-scale biodiversity data in addition to land cover.

For habitat provision, water cycling, and nutrient cycling, biodiversity played a role in modifying the effect that land cover had on ecosystem service provision. For these ecosystem services, changes in biodiversity could alleviate or intensify the effects that land cover had on ecosystem service provision. Here, finer-scale data on biodiversity within each land cover may contribute information on how biodiversity could be used to leverage changes in service provision without introducing any land cover changes.

A *few caveats:*

The dataset used to answer this question was derived from only 11 studies and was constrained to only one type of measure of biodiversity (total species richness) measured at a coarse spatial resolution (across land covers). Therefore, our generalisations on the role of biodiversity measures in informing ecosystem service provision are still preliminary and would benefit from data that provided more comprehensive measures of biodiversity as well as information on the role of biodiversity at finer spatial scales.

THE WAY FORWARD

Integrating ecosystem services into land-use decisions is essential for shaping landscapes that can sustainably support human well-being. This policy brief addressed key aspects that can facilitate this integration. However it also raised several questions that will require further exploration:

Separating the effect of biophysical factors and land cover on service provisioning. The effect of land cover on the provisioning of some services can be masked by biophysical factors. Some of these factors (e.g. slope, soil type) may align with the spatial distribution of different land covers. Therefore, to quantify the unique contributions of different land covers to the provision of these services it will be important to separate the effects of these factors from the effect of land cover *per se*.

Identifying the spatial scales at which land cover combinations will support the provision of multiple services. The analysis used here combines studies set across a broad range of spatial scales. This makes it difficult to define the exact scale at which different land covers should occur to provide multiple services. Further research should examine the spatial scales at which each service is provided and define the spatial extent that different land covers should occupy within a landscape to allow for the provision of different combinations of services.

Legacy effects of land cover change. The effect of former land covers can change how a specific land cover provides a service at a particular site. This policy brief examines how service provisioning changes across different land covers without considering the effect of previous land covers. Therefore, when working with scenarios of land use change it will also be important to account for the legacy effects of changing from one land cover to another.

ACKNOWLEDGEMENTS

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Box 1. Methodology used to compare ecosystem service supply between land covers

The answers to the questions posed in this policy brief are based on a comprehensive review[7] of 45 years of scientific literature for New Zealand (from 1970 to 2015). It synthesised quantitative information on how two or more land covers (defined according to the Land Cover Database, LCDB, classification) compared against each other in the provision of one or more variables that could be categorised as ecosystem services. An extension of that work also used a subset of 11 studies (out of the original 133 studies) which had additional data on biodiversity, to contrast effects from biodiversity and land cover on the supply of ecosystem services. Each of the studies in the review [Error! Bookmark not defined.]provided information on different combinations of ecosystem services and land covers. In Figure 1, any combinations that were not present in any studies are left as blank cells. Moreover, some land covers (such as flax land, fern land and surface mines) and some of the cultural ecosystem services (e.g., recreation, ethical and inspirational values) were excluded from Figure 1 due to a lack of data. Future research should aim to address these gaps before expanding on the land cover – ecosystem service combinations that already have a value in Figure 1.

Goméz-Creutzberg et al. (2021)[7] provide more details on how the values in Figure 1 were derived as well as the criteria for the branches in Figure 3.

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