6.8 Landscape connectivity

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Citation for this chapter: Etherington, T., McCarthy, J. (2024). Landscape connectivity. *In:* Lohrer, D., et al. *Information Stocktakes of Fifty-Five Environmental Attributes across Air, Soil, Terrestrial, Freshwater, Estuaries and Coastal Waters Domains*. Prepared by NIWA, Manaaki Whenua Landare Research, Cawthron Institute, and Environet Limited for the Ministry for the Environment. NIWA report no. 2024216HN (project MFE24203, June 2024). [https://environment.govt.nz/publications/information-stocktakes-of-fifty-five-environmental-attributes]

Preamble: Much of the basis of our understanding of landscape connectivity comes from theoretical modelling work. The very nature of landscape connectivity precludes the traditional experimentational manipulation needed to produce robust evidence, as it is not feasible to manipulate the connectivity of whole real landscapes many times. Therefore, while there is general agreement on how landscape connectivity could affect ecological processes, there is little data and few studies that demonstrate obvious real-world effects in New Zealand. Overall, landscape structural connectivity is widely considered nationally and internationally in policy, but currently lacks agreed measurement or a standardised approach for evaluating current state or change in response to management or land use decisions.

State of knowledge of the "Landscape connectivity" attribute: Good / established but incomplete – general agreement, but limited data/studies

Part A—Attribute and method

A1. How does the attribute relate to ecological integrity or human health?

Landscape connectivity is the degree to which landscape features facilitate or impede movement (Taylor et al. 1993) and can be further divided into structural connectivity that ignores species characteristics and simply measures habitat contiguity, and functional connectivity that considers species-specific responses to landscape features (Tischendorf & Fahrig 2000).

In terms of ecological integrity, habitat fragmentation, which includes a reduction in landscape connectivity, is considered one of the major drivers of biodiversity loss (Fahrig 2003). Conversely, habitat fragmentation often results in increases in ease of movement and dispersal for invasive plant and animal species and diseases (Meentemeyer et al. 2012; Brearley et al. 2013; Rodewald & Arcese 2016).

Overall, structural connectivity is best evaluated at regional to national scales because this attribute captures landscape-scale processes related to land cover and management, and is related to the distribution, abundance and function of both indigenous and non-native species.

In terms of human health, landscape epidemiology (Lambin et al. 2010) stresses an important link between landscape connectivity and human disease prevalence. For example, as landscapes become more fragmented via human modification, human and natural ecological systems have more interactions, and this leads to emerging infectious diseases (Despommier et al. 2006).

A2. What is the evidence of impact on (a) ecological integrity or (b) human health? What is the spatial extent and magnitude of degradation?

Within New Zealand there is very little evidence of landscape connectivity having direct impacts on ecological integrity or human health. However, as changes in landscape connectivity are largely driven by anthropogenic habitat fragmentation we can expect that the spatial extent of degradation of structural connectivity will be associated with more human-dominated landscapes. However, the exact magnitude of any degradation will vary depending on the functional connectivity of individual species, and in some instances, landscape connectivity may be improved rather than degraded.

Despite a current lack of evidence linking landscape structural connectivity to ecological integrity, there are examples or likely declines in integrity due to increased habitat fragmentation and loss of connectivity such as:

- Declines in absolute habitat availability are commonly thought to reduce population viability and cause long-term declines in indigenous biodiversity through extinction debt (e.g., Velland et al. 2006, Kuussaari et al. 2009), i.e., that increased habitat fragmentation and isolation lead to declines in multiple functions like dispersal among habitats, reproductive failure, or declines in other processes like pollination services.
- Declines in the extent and connectivity of wetlands could limit the spread and population genetic diversity for keystone species (Rayne et al. 2022).
- Understorey wood plant invasions into indigenous forests are increased largely by disturbance and close proximity to forest edges, implying decreased connectivity will be positively related to plant invasions (Jo et al. 2024).
- Increased landscape connectivity is thought to increase population viability of mobile taxa, and is suggested as crucial for scaling up restoration efforts (Norton et al. 2018).
- Reduced functional connectivity for birds between fenced ecosanctuaries and surrounding habitat (Burge et al. 2021).

A well-connected conservation network is one where ecological processes and functions connect between different sites. This includes sustaining the ability of individuals or populations of species to move between sites, providing resilience against climate change, and is considered an essential component of healthy ecosystem functioning (e.g., Tucker *et al.* 2018). Most efforts to increase connectivity have focussed on species-level conservation activities, but whether these activities are sufficient to sustain biodiversity is uncertain (Watson et all 2020).

A3. What has been the pace and trajectory of change in this attribute, and what do we expect in the future 10 - 30 years under the status quo? Are impacts reversible or irreversible (within a generation)?

Although landscape connectivity itself has not been quantified over time, several lines of evidence suggest that structural connectivity has declined. Declines of indigenous vegetation cover due to initially to fire, and subsequently from ongoing land use changes, has led to declines in forest cover and increased fragmentation of >90% for some vegetation types (e.g., see lowland forest extent attribute; Ewers et al. 2006, Dymond et al. 2017). Similarly land management for drainage has reduced both the number, extent and condition of wetlands (see wetland extent and condition). In other regions or communities (e.g., Westland forests, most alpine and subalpine vegetation), there have been far smaller changes in land cover and thus connectivity.

The largest declines in connectivity were caused over a century ago from fire, and then by major land use changes nationally with the expansion of farming and grazing operations (Greasley and Oxley 2009; Perry et al. 2014). Over the past 30 years, the rate and pace of change has slowed but is variable among regions, with some regions and vegetation-types expanding or increasing in area (and thus presumably having greater landscape connectivity) due to natural regeneration of woody species, and in some cases, active restoration of marginal vegetation (e.g., riparian plantings, wetland restoration; MacCleod and Moller 2006, but see Lee et al. 2010). On the other hand, in some areas, agricultural intensification and ongoing urbanisation have had the largest effects on fragmentation over the past decade, and this is likely to continue over the short-term (10 years; Curran-Cournane, et al. 2021).

Overall, landscape connectivity is driven largely by changes in landscape structure. Except for large-scale natural disturbance events such as major floods or earthquakes, naturalistic landscapes change relatively slowly via processes such as progressive erosion and vegetation succession. In contrast, anthropogenic disturbance has the potential to change landscape structure and connectivity very rapidly as highlighted above. Therefore, the pace of change in landscape connectivity largely depends on changes in land use, and can be both positive or negative. For example, large-scale changes in afforestation have been driven over the past decade by carbon farming and permanent forests through national-scale incentives (i.e., the NZ emissions trading scheme, the billion trees initiative). As a consequence, at least for woody vegetation, there’s likely to be increased cover and connectivity if these large-scale land use changes persist over the next 30 years.

The trajectory of change is complicated if the functional or ecological effects of connectivity are considered. Different species or functional groups of taxa respond differently to landscape structure and fragmentation, making universal generalisations about baselines and change in connectivity difficult. Rather, connectivity should be considered in terms of the structure of certain landscape features or the function for certain species, but these effects have rarely been quantified (e.g., minimum habitat requirements for population connectivity have been considered for birds, but few other taxa; MacCleod and Moller 2006). For example, both fragmentation and spillover of nutrient effects from pasture to forests have contrasting effects on different species (Didham et al. 2015).

A4-(i) What monitoring is currently done and how is it reported? (e.g., is there a standard, and how consistently is it used, who is monitoring for what purpose)? Is there a consensus on the most appropriate measurement method?

No monitoring or reporting of landscape connectivity is currently done in New Zealand. This is somewhat surprising given the long-term interest in management and reporting of land cover change and its consequences for biodiversity (e.g., Lee et al. 2005; Bellingham et al. 2020). In general, landscape connectivity metrics are most commonly used for measuring the potential movement of organisms, but can also include the movement of abiotic factors such as nutrients and water.

New Zealand currently has no standard longitudinal monitoring or reporting of landscape connectivity. More generally, there is no consensus or agreed standards for quantifying and monitoring structural connectivity, but there is a body of knowledge that could be used to develop monitoring and reporting. Structural landscape connectivity is conceptually simple and there is a wide array of metrics, mostly derived from graph theory based network measures, with which to measure it (Keeley et al. 2021).

Unfortunately, as with landscape metrics more generally, these landscape connectivity metrics are imperfect, numerous, and often correlated, so choosing an appropriate measure, or measures requires further evaluation and work. Choice of what are the most appropriate measures of landscape connectivity depends upon the specific objectives, landscape, and species involved, and there is guidance available to support such decision-making (Keeley et al. 2021).

Functional landscape connectivity is most commonly approached via a cost or resistance geographic information system map that quantifies landscape features that facilitate or impede connectivity (Zeller et al. 2012). There is a wide array of computational tools available that can support functional landscape connectivity analyses (Dutta et al. 2022), many of which are well developed and could allow landscape connectivity to be easily measured at national extents and sub-hectare resolution. The most popular methods are least-cost modelling (Etherington 2016) and circuit theory (McRae et al. 2008). Functional landscape connectivity is largely unstudied, with only one example for a native bird (Richard & Armstrong 2010) and an invasive species (Etherington et al. 2014). This is perhaps not surprising given we know very little even about the distances native forest birds will disperse (Innes et al. 2022) to measure structural connectivity, let alone the landscape features that may variably affect each individual species to measure functional connectivity.

A4-(ii) Are there any implementation issues such as accessing privately owned land to collect repeat samples for regulatory informing purposes?

There are relatively few implementation issues for measuring and reporting state and change for structural landscape connectivity. Structural landscape connectivity could be measured from land cover or land use datasets, and as such would not require any land access or sampling. Functional connectivity would be harder to achieve, as this would require some form of land access to directly measure a population in some manner. These population connectivity measurements could be from one-off sampling using a landscape genetic approach, or via repeated sampling using a mark-recapture approach (Zeller et al. 2012).

State and change through time could also be assessed using past datasets such as changes in land cover (i.e., versions of LCDB) or remote sensed imagery (e.g., using repeated measured of overlaps of imagery collected over time; e.g., Parracciani et al. 2024). If habitat quality is to be taken into account, possibly as a metric for the quality of interconnected habitat as a whole, this may necessitate on-site visits to private (and public) land.

Functional connectivity requires improvements to knowledge and underpinning data, so implementation requires additional research and a stronger evidence base prior to using it for monitoring or reporting. Overall, most structural connectivity metrics use data including the size, shape, and distances between habitat patches that are readily available. In contrast, measures of functional connectivity require information about the species behaviour, population responses or ecological processes, and this information is available only for few, well-studied species.

A4-(iii) What are the costs associated with monitoring the attribute? This includes up-front costs to set up for monitoring (e.g., purchase of equipment) and on-going operational costs (e.g., analysis of samples).

For structural landscape connectivity of vegetation-types or discrete habitats, data or information are already collected for other purposes (e.g., LCDB updates, satellite imagery, LiDAR in some areas). Structural landscape connectivity can be quantified through analysis of land cover or land use datasets, and this would be a relatively low-cost monitoring approach requiring resource for collation, analyses and interpretation of information. No additional up-front costs for equipment or operations are required assuming the thematic and spatial resolution of existing data products provide the required levels of geographic information. In some cases, imagery of higher resolution may be required, incurring additional costs for purchasing from commercial sources (e.g., for some higher resolution satellite imagery) or data collection (e.g., expanded LiDAR collection). Additional, ground-truthing or ground-based data collection may be required to validate remotely sensed information that underpins connectivity metrics, or to assess habitat quality.

Functional connectivity is much harder and expensive to measure. One of the more promising methods for rapid large-scale studies would be landscape genetics/genomics approaches to measure landscape connectivity via gene flow within a population – though the suitability of this approach will vary by species and landscapes (Keeley et al. 2021; Rayne et al. 2022).

A5. Are there examples of this being monitored by Iwi/Māori? If so, by who and how?

We are not aware of any landscape connectivity monitoring being undertaken by iwi/hapū/rūnanga.

A6. Are there known correlations or relationships between this attribute and other attribute(s), and what are the nature of these relationships?

Landscape connectivity influences the distribution of all organisms, and in its broadest sense also influences the flow of physical material and energy through ecosystems. In this regard landscape connectivity is connected to and will influence all other attributes as it underpins where everything is or could be. Attributes like lowland forest extent, and wetland extent will be positively associated with landscape structural connectivity because declines in connectivity are often driven by loss of total area and fragmentation of vegetation. Connectivity could also be positively related to canopy tree dieback extent but for different reasons; increased connectivity could exacerbate some of the drivers of tree canopy declines such as providing contiguous habitat or facilitating movement of pest species or some pathogens.

Part B—Current state and allocation options

B1. What is the current state of the attribute?

The state of landscape connectivity has not been monitored or reported at the national scale (see A4i). However, most metrics of connectivity use spatial change in habitat or vegetation to estimate state and change in connectivity. As a consequence, given ongoing data collection to understand changes in land cover including reductions in extent and size of land cover classes or vegetation-types, and the national declines in many vegetation-types like forests and wetlands (see A3), the current state of this attribute is undoubtably lower than historical baselines. Landscape connectivity could be evaluated using current national spatial databases such as LCDB to determine its suitability as an indicator (see A4ii).

Some effort to understand fragmentation and potential risks of declining habitat availability or connectivity has been done at regional scales. For indigenous forests, fragmentation effects vary widely among regions, with smallest average habitat fragment area in Northland and Auckland (of ca. 20ha), and greatest edge density effects in Northland, Auckland, Taranaki, Tasman, Nelson and West Coast (Ewers et al. 2006). Loss of connectivity is also assumed to be an issue for relatively small remnant wetlands, lowland indigenous forests, shrublands, some grasslands and riparian ecosystems that occur in anthropogenically-modified landscapes; these are areas that have sustained greater habitat loss already (Walker et al. 2006; Weeks et al. 2013; DOC 2015).

Combinations of data including abiotic land environments (LENZ), land cover (LCDB) and protected status of land cover have been used to determine rates of change in areal extent of environments as a proxy of biodiversity and the role of protection (e.g., Brokerhoff et al. 2008, Walker et al. 2008, Cieraad et al. 2015). These analyses have not considered state or change of spatial connectivity of protected areas. Global assessments of protected area connectivity (e.g., ProcConn metric) have been developed and show, at a national scale, that connectivity is >17% (e.g., Saura et al. 2018; WWF2020); this metric was developed based on the dispersal of mobile/migratory taxa over >10km, but could be downscaled to understand connectivity at finer spatial scales.

Overall, there are both data and potential metrics that could be applied to understand the current, and recent historical, change in connectivity, but this has not been done to date.

B2. Are there known natural reference states described for New Zealand that could inform management or allocation options?

There are no fine-scale maps representing natural reference states from the distant past that we are aware of. Broad-scale pre-human land cover maps do exist (e.g., Weeks et al. 2013, Fig. 2a), to which current levels of connectivity could be compared, however any such comparison would be limited by the accuracy of these maps. Historic information that could be evaluated for spatial connectivity such as aerial imagery have been captured decades after major land use changes and declines or fragmentation of many habitats or vegetation-types from fire and land clearance, and many areas are actually reverting to woody cover as marginal farming lands are retired. As a result, natural reference states or baselines are unavailable although changes at the decadal scale, and comparisons between protected or managed areas and other management regimes could be assessed to inform the effects of management interventions on connectivity.

B3. Are there any existing numeric or narrative bands described for this attribute? Are there any levels used in other jurisdictions that could inform bands? (e.g., US EPA, Biodiversity Convention, ANZECC, Regional Council set limit)

None that we are aware of. International efforts to quantify the connectivity of only protected areas have been developed (e.g., Saura et al. 2018, WWF 2020), and considered for reporting to meet international obligations and goals such as the Kunming Montreal Target 3 in the Global Biodiversity Framework). Most goals or levels establish a total area of protected land rather than setting bands or targets for connectivity itself; rather, increased connectivity is usually assumed to occur from increasing total area under protection.

B4. Are there any known thresholds or tipping points that relate to specific effects on ecological integrity or human health?

In theory yes, but these have not been described or reported for New Zealand. Early modelling work demonstrated that as habitat fragmentation increases, we can expect there to be a tipping point in structural connectivity where a landscape can suddenly shift from being fully connected to fully disconnected (Gardner et al. 1987). While these theories are generally well accepted, we are unaware of any empirical studies that have demonstrated such tipping points in landscape connectivity in real landscapes.

Given the international focus on protected areas for highly mobile or migratory species such as birds, there is an opportunity to quantify thresholds or tipping points for our indigenous bird species that are highly variable in both habitat requirements and dispersal ability by considering how reintroductions of species succeed or fail in different landscapes (e.g., Miskelly et al. 2013; Innes et al. 2022).

B5. Are there lag times and legacy effects? What are the nature of these and how do they impact state and trend assessment? Furthermore, are there any naturally occurring processes, including long-term cycles, that may influence the state and trend assessments?

There is certainly the potential for ecosystem effects to lag behind changes in landscape connectivity. For example, a reduction in landscape connectivity may result in a species population becoming fragmented into isolated non-viable sub-populations, but the actual extinction of the sub-populations may take some time to become evident, especially for long-lived species. These processes are part of 'extinction debt', where past habitat loss and fragmentation cause longer-term declines in biodiversity over decades (e.g., Velland et al. 2006).

B6. What tikanga Māori and mātauranga Māori could inform bands or allocation options? How? For example, by contributing to defining minimally disturbed conditions, or unacceptable degradation.

Both tikanga Māori (e.g., for biocultural monitoring) and mātauranga Māori (e.g., for understanding changes in ecosystem condition) might be used for evaluating the condition of the environment and people and interdependencies (Lyver et al. 2019), but we are not aware of any bands or allocation options with respect to landscape connectivity.

Although we cannot comment directly on mātauranga Māori, we suggest that for structural or functional connectivity, there could be condition or states described from a te ao Māori perspective, but we are unaware of any examples. Given the crucial importance of interconnectedness of people and environment, connectivity is a likely (but undeveloped) indicator (e.g., Lyver et al. 2021). Place-based goals or acceptable changes in structural or functional connectivity will require community-specific approaches that cannot be directly applied to other sites.

Part C—Management levers and context

C1. What is the relationship between the state of the environment and stresses on that state? Can this relationship be quantified?

The current state of landscape connectivity in New Zealand is unknown, which precludes relationships with stresses from being quantified. However, the relationship between landscape connectivity and environmental stresses could be evaluated from currently available data sources (see B1).

The well documented declines in habitat or indigenous vegetation from past disturbance and land use change and intensification (e.g., Ewers et al. 2006; Walker et al. 2008; Weeks et al. 2013) has likely driven losses of connectivity through reduction in the extent, number and size of habitats. For example, we have a good general understanding of how vegetation clearance leads to loss of structural connectivity. However, there is a great deal of complexity in how structural connectivity (or the physical layout of habitat) leads to functional connectivity or fragmentation. Different species and processes operate at different scales, and this depends on their dispersal ability, range size requirements, and tolerance to disturbance. Additionally the permeability of the matrix affects functional connectivity (e.g., what the habitat patches are surrounded by).

Structural connectivity is relatively simple but functional connectivity is more complex and highly dependent on local focus (e.g., which particular species or processes exist in a locality and which local people are concerned about protecting). Overall, landscape connectivity strongly reflects land use and management over decades, and these relationships could be quantified with currently available information. Functional connectivity is far more complex, but likely responds to a greater number of environmental stresses associated with habitat fragmentation, but will require additional research to understand how population or ecological functions are altered by connectivity. Bird movement including from restoration or translocation is relatively well studied, and knowledge of bird population movement and connectivity could be used to better understand the effects of fragmentation and other stresses at the landscape scale (Innes et al. 2021, 2022; Allen et al. 2023).

C2. Are there interventions/mechanisms being used to affect this attribute? What evidence is there to show that they are/are not being implemented and being effective?

C2-(i). Local government driven

Several local government policies refer to the importance of habitat fragmentation or connectivity of habitats, but connectivity is usually poorly defined and not quantitatively assessed. For example, connectivity is considered an important characteristic of environmental condition by local government NZ (e.g., the Willis 2017 report ‘‘Biodiversity and the role of Regional Councils’). However, landscape structural connectivity is not currently included in National Environmental Monitoring Standards (NEMS) or as part of legal biodiversity protection (e.g., in the EMaR biodiversity M18; see Bellingham et al. 2016). Despite this uncertainty of how to measure and monitor connectivity, at least two councils are monitoring or measuring connectivity: Wellington City Council (2015), and Auckland Council (2021).

C2-(ii). Central government driven

Landscape structural or functional connectivity *per se* is not reported in national state of environmental reporting by MfE and Stats NZ. Land fragmentation is reported but focusses on the effects on urbanisation on high quality soils or productive lands rather than biodiversity or indigenous ecosystems.

Connectivity of natural areas is considered in the National Policy Statement – Indigenous Biodiversity, which recognises connectivity as important for maintaining and indigenous biodiversity and promoting resilience to climate change and requiring prioritisation (amongst other considerations) in restoration. Connectivity is also referenced in the NZ Coastal Policy Statement (2010, Policy 11) to avoid significant adverse effects on ecological corridors. Similarly, recent strategies by DOC for public conservation land (and public-private partnerships) in Te Mana o te Taiao for freshwater management (see also Lee et al. 2005 and Bellingham et al. 2020) highlight a goal of restoring river corridors at landscape scales; here the goal is to increase connectivity of riparian and floodplain systems usually administered by LINZ.

Overall, despite fragmentation or connectivity being included in multiple national strategies across central government departments, current state and change of connectivity is not yet part of biodiversity or environmental monitoring and reporting.

C2-(iii). Iwi/hapū driven

We are not aware of any interventions to improve connectivity specifically led by Iwi/hapū; but this should be investigated further given there is general awareness of the importance of connectivity in many restoration initiatives and in Iwi Environmental Management Plans (e.g., Te Kotahitanga o Te Atiawa) and part of collective restoration efforts (e.g., the Kotahitanga mō te Taiao Alliance).

C2-(iv). NGO, community driven

Although spatial connectivity is usually not explicitly stated as a management goal for community-based restoration or management, improving the number and proximity of habitats containing indigenous biodiversity is. For example, sheep and beef farms as an industry have considered the role and benefits of indigenous vegetation on farms at the national scale, and restoration or retiring of grazing could contribute to increased connectivity of habitats (see Pannell et al. 2021).

In general, there are only a few examples of both structural and functional landscape connectivity interventions (Etherington 2015). Within New Zealand there are efforts such as the Te Ara Kākāriki Greenway Canterbury Trust whose aim is to promote structural connectivity via native plantings primarily for forest birds (https://kakariki.org.nz/) but the landscape-scale effectiveness of habitat restorations remains unclear. Another New Zealand example would be the use of predator-proof fences to reduce functional connectivity for invasive predators, and the positive effect of such interventions on native birds is beyond doubt (Innes et al. 2012).

Overall, there are practical efforts to restore habitat for species taking the landscape and spatial availability of habitat into consideration, but these efforts are largely driven by landscape-scale conservation management efforts rather than explicit regional or national strategies or international obligations.

C2-(v). Internationally driven

There are numerous international efforts, agreements and strategies that consider habitat fragmentation and spatial connectivity of habitats. We mention only a few of these here. Overall there is general agreement and commitment to improving the connectivity of habitats internationally, as demonstrated in:

- The "2030 Nature Compact" agreed by the 2021 G7 Leaders Summit advocates for "improved quality, effectiveness and connectivity of protected areas".
- The United Nations General Assembly in 2021 adopted Resolution 75/271, which encouraged member States to "maintain and enhance the connectivity of habitats…"
- The International Union for the Conservation of Nature (IUCN) Policy Resolution 073 on "Ecological connectivity conservation in the post-2020 global biodiversity framework: from local to international levels" emphasizes the importance of ecological networks and corridors to sustaining biodiversity and nature's contributions to people, and recommends that all IUCN Members work to conserve connectivity by documenting it across ecosystems, informing policies, laws, and plans, identifying key drivers and building synergies across institutions and borders to implement solutions.
- The UK is developing an indicator (D1: Quantity, quality and connectivity of habitats) as part of their 25 Year Environment Plan, but there are not yet any proposed targets associated with habitat connectivity (DEFRA 2023).
- The EU's recently released Biodiversity 2030 Strategy aims to protect 30% of EU land and sea area and includes references to ecological corridors and a 'coherent network'. Although connectivity is not explicitly monitored in this strategy, effective mesh density for landscape fragmentation is (i.e., the number of landscape elements/km^2); see EU biodiversity strategy for 2030).
- International efforts to understand the extent and connectivity of protected areas has developed methods and a global assessment (e.g., the Protected Planet Reports), for example, using Protected Connected (ProtConn) and PARC-Connectedness metrics for evaluating progress against Aichi Target 11. Based on the ProtConn method, 7.84% of global terrestrial ecosystems are considered both protected and connected, but this is far below the 17% required by Aichi Target 11 (Saura *et al.* 2019).
- The IUCN WCPA Connectivity Conservation Specialist Group (CCSG) published the IUCN Guidelines for Conserving Connectivity through Ecological Networks and Corridors (Hilty *et al.*, 2020). These Guidelines are an important step towards a coherent global approach for connectivity conservation, providing clarity on the role of ecological corridors.

What these examples demonstrate is a growing international interest in landscape-scale increases in protected or managed areas that are more structurally and functionally linked. This goal is strongly reflected in major biodiversity strategies and obligations.

<u>Part D—Impact analysis</u>

D1. What would be the environmental/human health impacts of not managing this attribute?

Many ecological processes required to maintain ecosystem health, such as seasonal food migrations or seed dispersal, are reliant on sufficient landscape connectivity. Therefore, a loss of sufficient levels of landscape connectivity could result in a collapse of ecosystem health. But landscape connectivity can have both positive and negative impacts. For example, a heavily forested landscape would be highly connected for native forest birds, and if combined with human access could provide recreational opportunities to support physical and mental health. However, this highly forested and connected landscape could exacerbate the potential for massive wildfires, or could provide vectors for wildlife diseases that could affect livestock and humans, or some plant pathogens (e.g., kauri dieback).

D2. Where and on who would the economic impacts likely be felt? (e.g., Horticulture in Hawke's Bay, Electricity generation, Housing availability and supply in Auckland)

There are no obvious or documented economic impacts of changes in landscape connectivity.

We would envisage that economic impacts would be most likely be felt by people living in rural areas and working in production industries as these are more exposed to more natural areas that will be affected by changes in landscape connectivity. Remnant habitat patches often occur on privately held land and the subset of owners with habitat patches on their land (potentially as a result of good stewardship) will be impacted by policy changes. Additionally, Māori land contains proportionately more indigenous vegetation cover, and may also have more remnant habitat patches.

D3. How will this attribute be affected by climate change? What will that require in terms of management response to mitigate this?

Climate change will be most likely to influence landscape connectivity via gradual changes in habitat distributions in natural areas, changes to the ability for species to passively improve connectivity through natural regeneration, or by potentially sudden changes in human land use and hence land cover in human dominated landscapes. Identification and management of areas critical to landscape connectivity would help to mitigate any effects of climate change on landscape connectivity. Planning for 'climate smart landscapes' (Lavorel et al. 2022) can include consideration of connectivity and its potential role in maintaining indigenous diversity and ecosystem processes in the face of multiple climate change impacts like increasing disturbance, drought and climatic variability.

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