

A Review of Mapping Support Tools -Ecosystem Connectivity and Ecological Networks



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Executive Summary

The Action for Adaptation Project is being delivered by UBC Botanical Garden, the Coastal Douglas-fir Conservation Partnership (CDFCP) and UBC Okanagan. The project is focused on supporting local governments and First Nations in south-west British Columbia (BC) that are looking to accelerate how they mitigate and adapt to the effects of climate change through direct land protection, restoration of degraded habitats, and development of new or enhanced nature-based solutions.

This report is part of a series that presents the results of conversations and a review of mapping layers currently used for planning and decision making. Local government and First Nations representatives have indicated that six mapping layers are needed to inform planning and land use decision making. This report series is focused on four of these layers: terrestrial carbon; ecosystem connectivity; land cover and species at risk; and, culturally significant species and places.

This report is specifically focused on ecosystem connectivity and ecological network mapping layers. The review had the following objectives:

- To identify through conversations what elements of mapping improved user experience.
- To identify mapping layers that are actively used in decision making and have features that enhance the user experience.
- To identify mapping layers that have led to a change in behaviour and management of the natural environment.

Through conversations and the review of existing ecosystem connectivity and ecological network mapping, the following issues were identified:

- **The scale** at which mapping is undertaken will alter the appearance of the connectivity map
- A connectivity network will be different for **different species** depending on their dispersal ability and their habitat requirements.
- Functional mapping needs to focus on species that have **defined habitat** requirements e.g. mature forest, wetland etc.
- There are **different approaches** to mapping connectivity leading to confusion over which is the most appropriate approach in different situations.
- Urbanisation means that species have often been extirpated from these landscapes not only through habitat loss and fragmentation but also **social responses** e.g. fear of large carnivores.
- Connectivity needs to take into consideration **man made hazards** for the species the network is aiming to protect.
- The **lack of control over the management** and maintenance of a connectivity network due to private landownership is an issue that needs consideration.
- Planning by local governments and First Nations has historically been undertaken in their own **jurisdictional silo** which may limit efforts to improve connectivity.
- There is an **absence of legislation and policy** to enable the protection of connectivity networks.

The review has identified that ecosystem connectivity and ecological network mapping should draw on several spatial layers, biological data and information held by non-indigenous and Indigenous knowledge holders. Below are things to consider when developing this mapping.

The purpose and scope of the mapping needs to be confirmed – what is the landscape context of the mapping; what area is to be included; what species is the network for; will man made ecosystems be included; will interrupted corridors be included; will buffers be included etc

Engagement with Indigenous and non-Indigenous knowledge holders is a priority and this engagement should be on going through the mapping process.

Land Cover / Land Use Mapping - obtain detailed up to date land cover mapping.

Identify Known High Value Biodiversity Areas - identify areas that are known to have high value for biodiversity e.g. Sensitive Ecosystem Inventory Mapping, Terrestrial Ecosystem Mapping, National and Provincial Parks etc.

Scale of Ecosystem Features that Support Target Species – determine the appropriate scale of habitat patches and linkages between them based on the landscape and the target species.

Structural Modelling - This can take several forms such as least-cost pathway, Circuitscape, Omniscap, Conefor or Zonation. The choice will depend on budget and the skill / training of the analyst. The scale at which mapping is done will impact on the value of this process to species that rely on small habitat features.

Functional Modelling - species modeling such as Conefor can build on the information provide by structural models as it draws on the species requirements.

Iterative Development of Mapping - share mapping with knowledge holders to identify where gaps may have occurred during the mapping process.

Indices to Analyse Multi Layers – the best approach to understanding ecosystem connectivity is to pull multiple layers and this can require the use of indices to interpret this information.

Live Document – test the mapping with the wider community to see if they understand and support the mapping that has been produced.

It is considered that an ecosystem connectivity and ecological network map will develop with time and that the first map doesn't need to be perfect.

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1 Introduction

1.1 Background

The Action for Adaptation Project is being delivered by UBC Botanical Garden, the Coastal Douglas-fir Conservation Partnership (CDFCP) and UBC Okanagan. The project is focused on supporting local governments and First Nations that are looking to accelerate how they mitigate and adapt to the effects of climate change by protecting, restoring, and creating nature-based solutions on the south-west coast of BC.

In 2022 and 2023 conversations were undertaken with representatives from federal, provincial and local government, First Nations, not for profit conservation organisations, consultants and ecosystem services finance companies. The purpose of the conversations was to identify gaps and opportunities relating to policy, decision making tools and incentives.

These discussions highlighted the need for specific mapping layers and guidance on the integration of nature-based solutions into local and regional government and First Nations plans and strategies. To meet the needs of the targeted end users Action for Adaptation is working on the production of a Biodiversity Atlas and a Regional Climate Adaptation Plan.

1.2 Study Area

The study area for the Action for Adaptation project is indicated in **Figure 1** by the blue line boundary. The layers reviewed in this report are not limited to those developed in the area of interest.



Figure 1. The red line boundary represents the CDFCP area of interest which includes the CDFmm and CWHxm1. The blue line boundary represents the Action for Adaptation boundary which includes the catchments that feed the ecosystems in the CDFmm and CWHxm1.

1.3 Purpose of this Report

This report is part of a series that presents the results of conversations and a review of mapping layers currently used for planning and decision making. Local government and First Nations representatives have indicated that the mapping layers that are currently missing at a resolution that they can use are:

- Terrestrial carbon
- Land cover and land cover change
- Environmentally Sensitive Areas (ESAs)
- Ecosystem Connectivity
- Species at Risk and Culturally Significant Species and Places
- Hydrologically sensitive ecosystems.

This report is specifically focused on ecosystem connectivity and ecological network mapping layers. The review had the following objectives:

- To identify through conversations what elements of mapping improved user experience.
- To identify mapping layers that are actively used in decision making and have features that enhance the user experience.
- To identify mapping layers that have led to a change in behaviour and management of the natural environment.

This report should be read in conjunction with the following reports:

- A Review of Decision Support Tools that Protect Nature-Based Solutions.
- A Review of Mapping Support Tools – Land cover.
- A Review of Mapping Support Tools – Carbon.

2 Ecosystem Connectivity

The Kunming-Montreal Global Biodiversity Framework (2022), was signed by Canada during the UN Convention on Biological Diversity. The framework highlights the importance of conserving ecological connectivity. Ecosystem connectivity needs to be maintained to enable the natural environment to respond to climate change. Habitat fragmentation leads to the isolation of species, meaning that they are not able to relocate themselves when localised conditions become unsuitable. In addition, gene flow is interrupted meaning that species will struggle to evolve to the changing conditions (United Nations, 2023¹).

2.1 Summary of Conversation Comments

During conversations in 2022 and 2023 the following issues were identified in relation to developing an ecosystem connectivity network:

- **The scale** at which mapping is undertaken will alter the appearance of the connectivity map e.g. international, national, regional or municipal and also urban vs rural community.
- A connectivity network will be different for **different species** depending on their dispersal ability and their habitat requirements e.g. amphibians versus ungulates.
- Functional mapping needs to focus on species that have **defined habitat** requirements e.g. mature forest, wetland etc. **Habitat generalists cannot be used to define corridors** as they can overcome human barriers that many other species can't.
- There are **different approaches** to mapping connectivity leading to confusion over which is the most appropriate approach in different situations e.g. circuit theory; functional vs structural; indigenous knowledge; habitat suitability modelling; records of species etc.
- Urbanisation means that species have often been extirpated from these landscapes not only through habitat loss and fragmentation but also **social responses** e.g. fear of large carnivores.
- Connectivity needs to take into consideration **man made hazards** for the species the network is aiming to protect e.g. roadkill, elevated predation risk around seismic lines etc.
- The **lack of control over the management** and maintenance of a connectivity network due to private landownership is an issue that needs consideration.
- Planning by local governments and First Nations has historically been undertaken in their own **jurisdictional silo** which may limit efforts to improve connectivity.
- There is an **absence of legislation and policy** to enable the protection of connectivity networks.

Most connectivity mapping products are available as single layer downloads from websites rather than being presented within an online mapping / decision tool. However, there are some exceptions (e.g. TerrAdapt and Whatcom County Watershed Portal).

As indicated above, the connectivity mapping products being produced reflect the scale at which an organisation is operating and do not translate well to a different scale. Consequently, local governments or First Nations have needed to undertake their own connectivity mapping rather than being able to use national or regional models. This has meant that the maps that have been produced use different methodologies and do not typically link to neighbouring jurisdictions.

¹ United Nations (2023) Connecting Nature in a Fragmented World: The Importance of Conserving Ecological Connectivity in the next Decade. Accessed [here](#) 020524

The following review of tools starts with products applicable at a national scale, then provincial and finally local government and First Nations level.

2.2 Summary of Ecosystem Connectivity Mapping Tools

There are ecosystem connectivity and ecological network mapping tools that have been used by multiple organisations that are subsequently the focus of this review. A summary of these tools is provided below:

- [Linkage mapper](#) - this is considered the simplest approach to connectivity mapping and uses least-cost paths, or paths of least resistance, between patches of habitat. The first step is to identify areas used by the target species. Then classify the landscape as to its likelihood to facilitate animal movement e.g. land cover and then consider barriers e.g. highways (**Section 2.7**).
- [Circuitscape](#) – is a model that predicts patterns of species movements across a landscape using circuit theory. This approach identifies habitat cores/nodes and then models the probable path from one node to another by simulating individual animals as electric current flow. Linkage mapper finds one path of least resistance, while Circuitscape will find multiple viable paths (**Section 2.3 and 2.4**).
- [Omniscape](#) – is a newer model which uses the same landscape resistance information without being limited to movement from a core habitat. This produces a heatmap (**Section 2.7 and 2.10**).
- [Conefor Sensinode 2.2](#) (CS22) software (graph theory) – allows the quantification of the importance of individual habitat patches for the maintenance of functional landscape connectivity, as well as evaluating the connectivity improvement provided by new potential habitat sites that may be added through habitat creation or restoration. This is a functional approach which considers the spatial arrangement of habitat and the dispersal distances and behavioural responses of species to the physical structure of the landscape (**Section 2.6**).
- [Zonation 5 \(prioritisation\)](#) – spatial prioritisation software that can be used to identify priority areas to support conservation planning, land use planning, ecological impact avoidance etc. Zonation can account for habitat quality and ecological connectivity together with costs, threats and land tenure.
- [Optimal Region Connections](#) – is a tool that could be used to understand ecosystem connectivity and ecological networks but it has been developed as a logistical tools and is therefore not specific for the use of identifying ecological networks. The tool considers the location of hubs and the least cost path between them.

2.3 Parks Canada’s National Program for Ecological Corridors

In response to Canada’s commitment to the Kunming-Montreal Global Biodiversity Framework (2022). The [Parks Canada’s National Program for Ecological Corridors](#) undertook consultation on a draft document in 2023 highlighting the location of 23 priority areas. The *aim of the program is to support connectivity conservation across Canada by forming ecological networks that allow species to move freely between habitats across large landscapes and coastlines*. The priority areas are *not ecological corridors themselves but indicate areas that have significant need for connectivity conservation*.

The identification of these priority areas aims to *enable local and regional proponents to improve or maintain ecological connectivity*. **Figure 2** presents the location of the proposed priority areas which will be finalised in 2024. Local governments and First Nations would need to undertake additional

connectivity mapping to translate the intent of protecting connectivity to action on the ground. The analysis was based on a number of different information layers and models including: circuitscape which mapped potential resistance / barriers to species movements (refer to **Section 2.2** for description); protected areas; species at risk range density data; the threat of land use change ([Hirsh-Pearson et al., 2022](#)) and long term threats from climate change.



Figure 2 draft priority areas for Parks Canada's National Program for Ecological Corridors.

2.4 Predicting Areas Important for Ecological Connectivity Throughout Canada

Parks Canada's National Program for Ecological Corridors (**Section 2.3**) drew on several different information sources, including an ecosystem connectivity modelling approach applied by Pither et al. (2021) at a national scale. Pither et al. (2021) tested the hypothesis that functional connectivity for multiple species could be estimated across Canada using a single, upstream connectivity model. This approach doesn't have the detail of species-specific models built on field data but it is potentially a cost effective way to prioritise conservation efforts on a national scale when biodiversity is in rapid decline. The circuit theory modelling undertaken by [Pither et al. \(2021\)](#) is a structural approach to mapping ecosystem connectivity based on land cover and the resistance this might provide to the movement of species. Pither et al. (2021) applied this methodology to all of Canada at a 300 m resolution and **Figure 3** presents an image of the resistance layer generated from this analysis on the Sunshine Coast². Pither et al. (2021) conclude that their approach correlates well with species data for mountain caribou, grey wolves, moose and Rocky Mountain elk, particularly for individuals that travelled over large areas. The correlation was less for Rocky Mountain elk that travelled over shorter distances. High current density (area of connectivity) did not correlate well with herpetofauna roadkill data in Ontario. This is thought to be due to the 300 m spatial resolution of Pither et al. (2021) mapping, particularly as another study

² The Sunshine Coast has been the focus of a mapping pilot completed in 2023/24 at part of the Action for Adaptation project that demonstrated how information within existing provincial data layers can be re-presented in a manner that can be used by local governments and First Nations in their land use planning and decision making.

completed at 100 m did find a good correlation. The movements of herptofauna will be driven by small habitat features e.g. ponds, that would not be picked up when mapping at 300 m.

The resistance map for the Sunshine Coast reflects the location of old forest on the landscape, but this is predominately alpine / sub alpine forest with small trees. The model does not reflect the development and value of forest >80 years adjacent to the coastline which is dominated by large trees and provides high value habitat to a range of species that would not be found in the alpine / sub alpine forest (**Figure 4**).



Figure 3 Pither et al (2021) resistance map for the Sunshine Coast (left) to be compared to Figure 4.



Figure 4 Vegetation Resource Inventory of the Sunshine Coast. Left figure illustrating height of trees and the right representing age. The image on the right aligns with the results of Pither et al (2021) but not

the image on the left. Many fauna species on the southwest coast of BC are found in the big tree forests and will move along the coast. Illustrating a limitation with the circuit theory approach.

2.5 Habitat Suitability Layers- TerrAdapt

[TerrAdapt](#) includes habitat suitability layers for five species: fisher, greater sage-grouse, grizzly bear, wolverine, and Canada lynx.

Habitat suitability. Values range from 0 to 100 and correspond to the relative similarity of a pixel to environmental conditions that are used by this species. A value of 0 is below the 5th percentile of similarity from all species locations observed in the region. A value of 50 is the median similarity from all species locations observed in the region. A value of 100 is the 95th percentile of similarity from all species locations observed in the region.

The mapping extends from 1985 to 2020 and presents how habitat suitability has changed for each of these species through time (**Figure 5**). This allows a user to take a functional approach to connectivity, but the limited number of species means that it would be difficult to extrapolate from this information to present a comprehensive connectivity mapping for a local government or First Nation. The scale of the mapping is also likely to be of greater value for provincial or territorial species mapping as it does not provide connectivity that can be associated with individual land parcels.

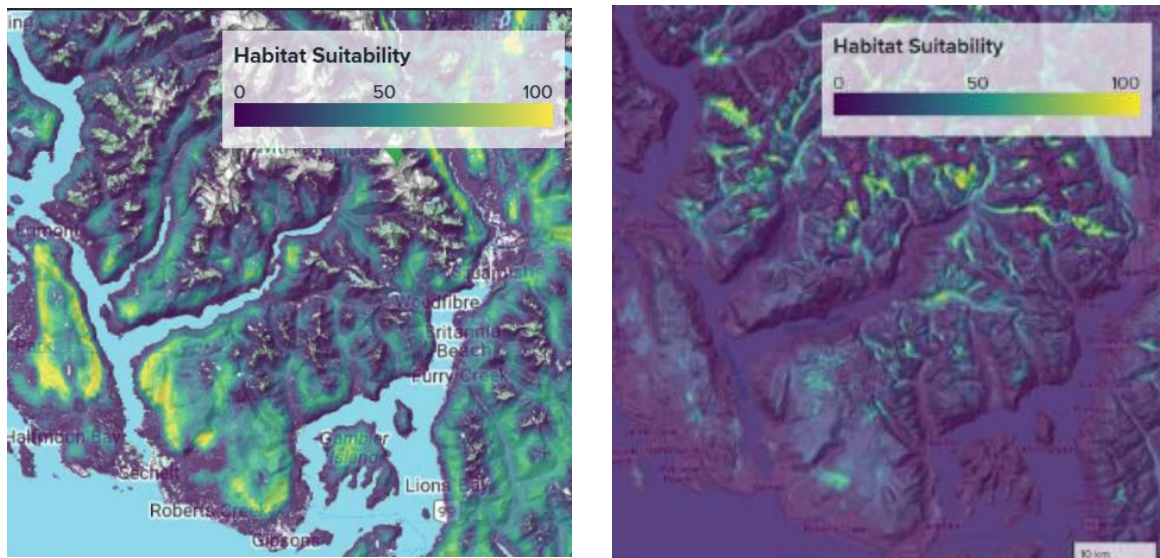


Figure 5 habitat suitability for fisher (left) and grizzly bear (right) in 2020 on the Sunshine Coast, BC.

2.6 Regional Green Infrastructure Network (RGIN) – Metro Vancouver

Since 2023 Metro Vancouver has been working collaboratively to map a Regional Green Infrastructure Network (RGIN). RGIN mapping has incorporated structural and functional modelling. Important terrestrial habitat areas were identified using the regional [Land Cover Classification and Sensitive Ecosystem Inventory](#) (SEI) Mapping which were updated in 2020. The analysis then included ecosystem connectivity mapping that was undertaken in 2020 by Metro Vancouver for eight focal species using Conefor Sensinode Software (**Figure 6**). The [Conefor model](#) uses certain habitat requirements of each species to

evaluate the connectivity of greenspaces in Metro Vancouver. Each focal species was intended to be representative of a group of animals which share similar habitats. The connectivity mapping outputs generated by the Conefor model were used to rate the value of habitat patches using two metrics 1) probability of connectivity and 2) importance of patches for connecting other patches.

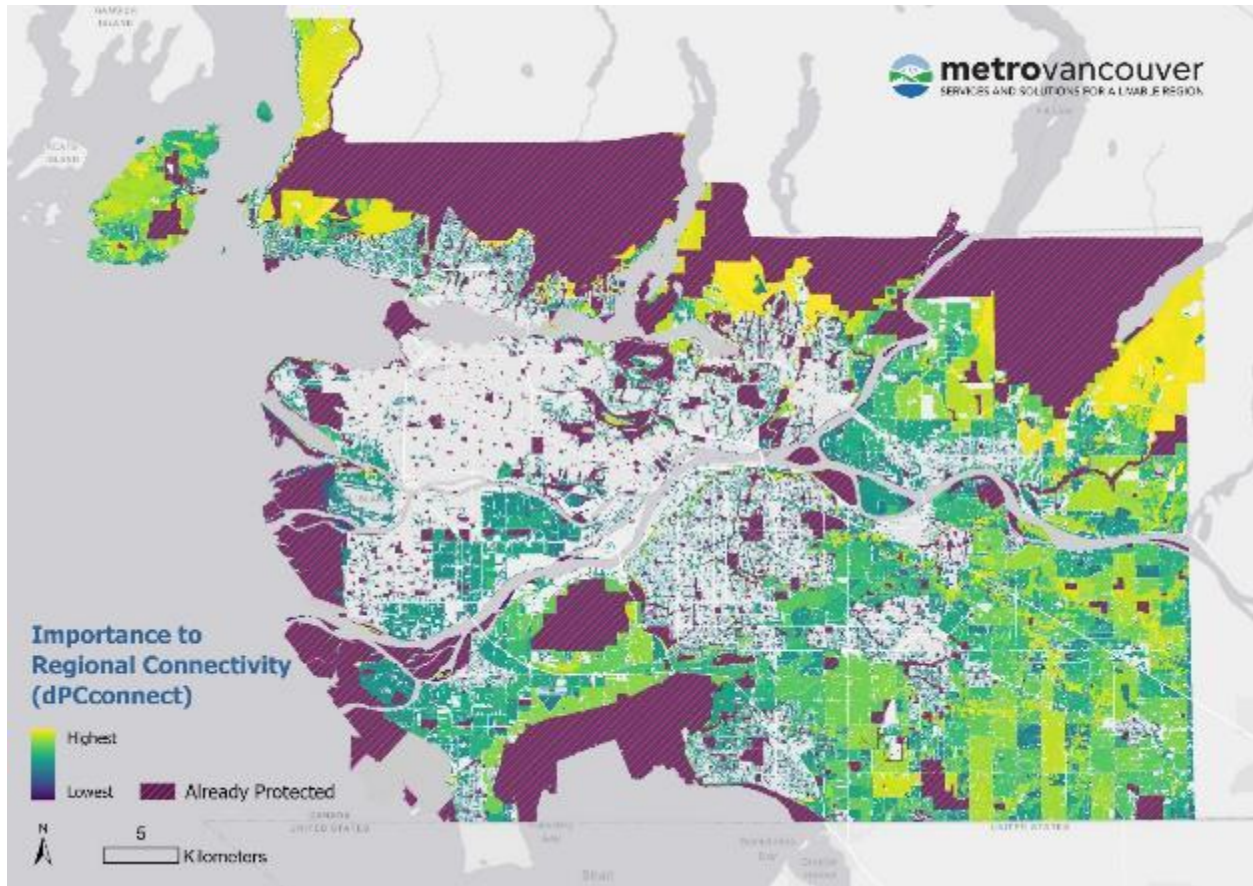


Figure 6 Importance of sites to regional connectivity presented in Metro Vancouver’s Evaluation of Regional Ecosystem Connectivity.

The identified important terrestrial habitat areas then were classified into the categories in **Table 1**

Table 1 Classification of terrestrial habitat areas into major and minor habitat patches.

Criteria	Major Habitat Patches	Minor Habitat Patches
Patch size (ha)	>10 ha of total habitat area.	>0.5 ha of total habitat area.
Wildlife refuge areas that are 100 m from urban edges	0.25 ha of refuge area.	none or <0.25 ha of refuge area.
Regional connectivity importance	High and very high dPC and dPCconnect values that are in the top 15 – 20% of regional connectivity importance.	Lower connectivity values compared to major habitat patches, but still important to regional connectivity.

To identify and map important corridors, a modelling tool called Optimal Region Connections was used to identify the most effective path for species movement across the landscape (the least-cost paths). The draft network identifies existing natural linear corridors and does not consider restoration opportunities to create new corridors. In some cases, patches are surrounded by urbanized landscapes and no corridors exist. The following definitions were followed to classify corridors:

Habitat corridors – Existing natural linear natural areas that best connect major habitat patches, the marine foreshore, or the Fraser River together.

Foreshore corridors – The foreshore condition of the ocean and Fraser River are highly disturbed in many areas. These corridors include areas of the foreshore that provide some natural habitat and connect two major habitat patches together.

The project then incorporated some professional judgment to refine the RGIN. The mapping approach focused on developing a product that was automated to facilitate future remodelling and mapping updates as the network evolves. However, there was still a need for a review to remove anomalies that occurred during mapping e.g. realignment of corridors to better follow natural areas.

During the RGIN mapping exercise, Metro Vancouver has also taken into consideration local network mapping completed by municipalities such as the City of Surrey. The RGIN map is still in development and the figure shown below is a draft that will be refined in 2024-2025 (Figure 7 – draft).

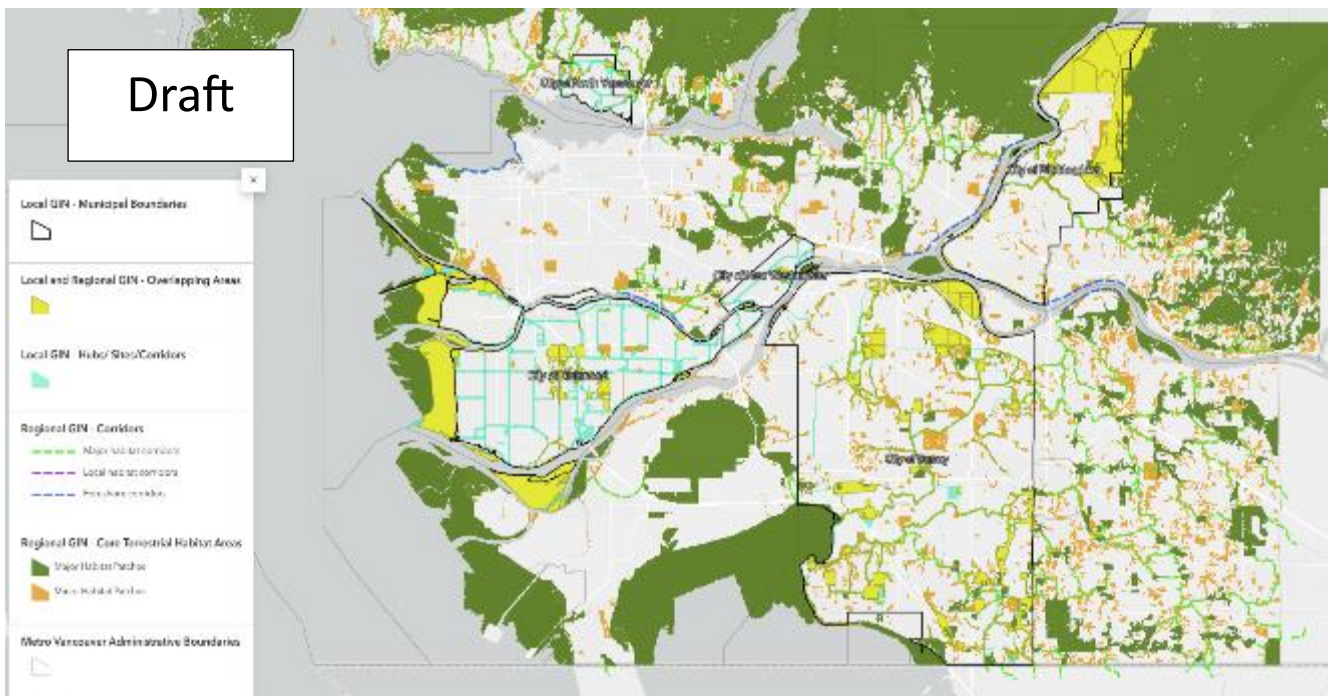


Figure 7 Metro Vancouver’s Draft Regional Green Infrastructure Network.

2.7 Whatcom County Watershed Portal

[Whatcom County Watershed Portal](#) includes connectivity mapping that extends into Metro Vancouver to reflect that watersheds extend beyond jurisdictional boundaries. This mapping uses two tools: **Linkage Mapper** and **Omniscape** (refer to **Section 2.2**).

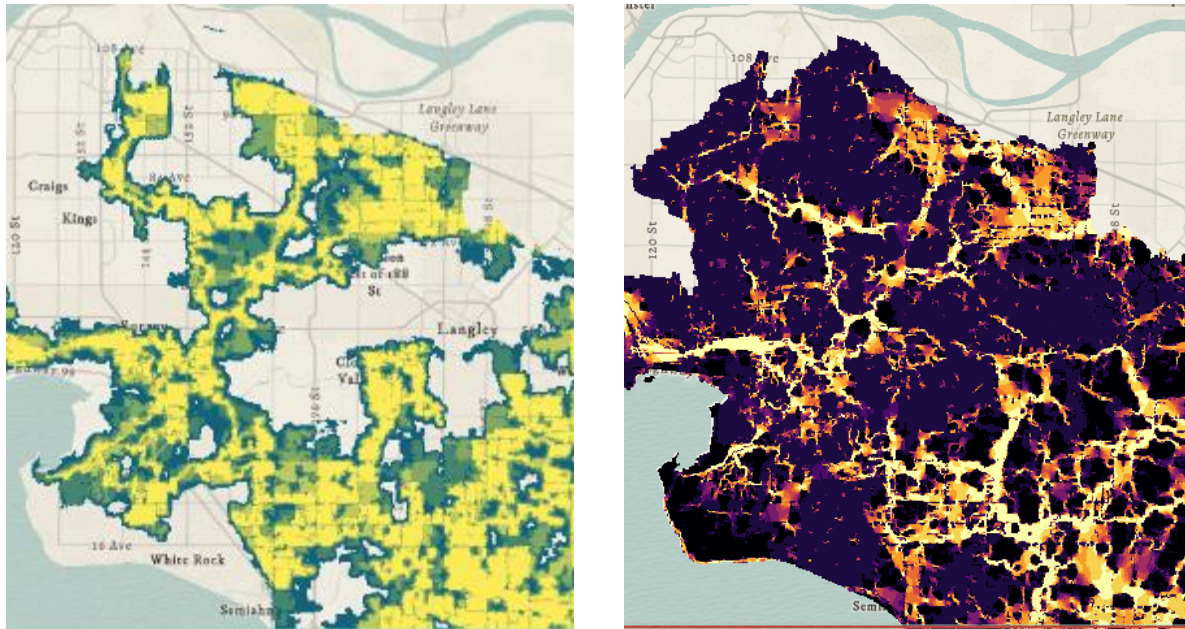


Figure 8 Least cost pathways generated by Linkage Mapper (left) and cumulative current generated by Omniscape (right).

On completion of the analysis using Linkage Mapper and Omniscape (**Figure 8**), Whatcom County then prepared a summary index of Connectivity Value, the intent was to provide a means of quickly assessing how each part of the landscape contributes to wildlife habitat connectivity. The index was produced from the following layers:

- Pacific climate connectivity³.
- Pacific non climate connectivity³.
- Landscape resistance.
- Least-cost corridors.
- Omniscape cumulative currents.
- Riparian buffers.

A total of six different scores were calculated and then averaged to calculate the Connectivity Value (**Figure 9**)

³ Nuñez, T., Littlefield, C., Michalak, J., and Lawler, J. 2022. Climate and Non-Climate Connectivity Networks in the Far Western U.S. *Frontiers in Ecology and the Environment*, under review.

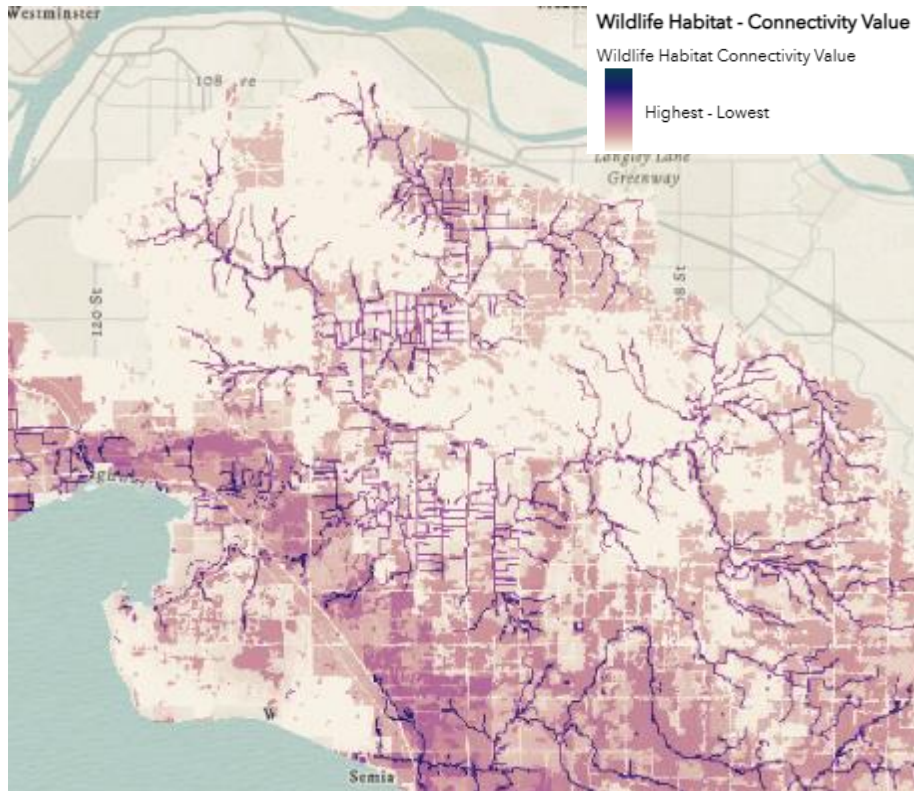


Figure 9 Connectivity value index map produced by Whatcom County from six different indices of connectivity.

Whatcom County have included the ecosystem connectivity mapping into their Watershed Portal which will enable staff and community to view this information against watershed and planning layers (**Figure 8**).

2.8 The City of Surrey Green Infrastructure Network

The [City of Surrey's Biodiversity Conservation Strategy](#) (BCS) (2014) includes the following figures:

- Habitat types map (land cover / use).
- Habitat suitability map.
- [Green Infrastructure Network](#) (**Figure 10**)

The figures in the BCS include information from several sources, including the [Ecosystem Management Study](#) (EMS) (2011). The EMS included several mapping layers:

- Sensitive species occurrences and habitat.
- Vegetation inventory (land cover / use).
- Naturalness of vegetation.
- Relative impedance.
- Green infrastructure opportunities.
- Ecological significance of hubs.
- Sites inside and outside of corridors.
- Ecological significance of potential corridors.

- Ownership of network.

The EMS presented terrestrial and aquatic hubs and corridors as green infrastructure opportunities. Not all these sites were incorporated into the BCS GIN. Notably some sites identified in the EMS as of moderate to high ecological value were excluded. There is no documentation detailing the decision process followed for development of the BCS GIN from the EMS, so it is unknown why sites were excluded. This could be a challenge when this tool is updated or for tracking change.

The size parameters of the hubs and corridors in the GIN include:

- Hubs – large intact habitat areas - >10 ha
- Sites – small habit patches - <10 ha
- Regional corridors - 50-100 m
- Local corridors – 10-50 m

The GIN has not been updated since 2014, even though the City of Surrey has gathered significant species information through their community science project (iNaturalist / City Nature Challenge). If this information were to be incorporated potentially the appearance of the GIN would change. Initially the assessment of species abundance (BCS and EMS) was guided by professional judgement rather than species data.

The City of Surrey is currently reanalysing its GIN using Circuitscape.



Figure 10 Green Infrastructure Network of south Surrey.

The City of Surrey has a [mapping portal](#) (COSMOS) where a lot of mapping layers can be viewed together (overlaid). This includes the Green Infrastructure Network Corridors and Hubs. The audience for these

tools includes internal staff, Qualified Environmental Professionals, private land development interests and members of the community such as conservation and stewardship organizations.

2.9 Okanagan Collaborative Conservation Program

The [Okanagan Collaborative Conservation Program](#) started considering connectivity in 2014. Initial consultation was undertaken using maps generated by the Complex Environmental Systems Lab at UBC Okanagan using Circuitscape. The focus of the work was then concentrated to the District of Lake County in 2017 (**Figure 10**).

A 20-person advisory team was established to develop land use guidelines and stewardship activities for protecting the corridor in 2020 which enabled the inclusion of the wildlife corridor in the relevant Official Community Plans.

Work is ongoing in relation to the protection of this corridor including engaging with First Nations knowledge holders / hunters in relation to their knowledge of how ungulates are using the land. These conversations were able to generate maps (**Figure 11**) that support the western approach to mapping (**Figure 10**) but also highlighted that there were important areas that had not been highlighted by western science.



Figure 10 Central Okanagan Wildlife Corridor.

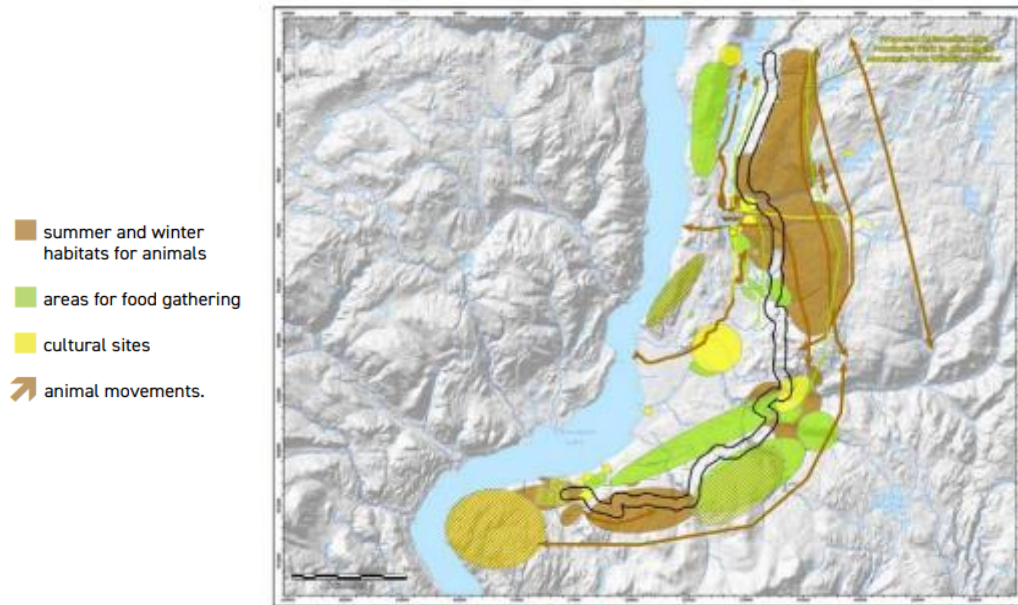


Figure 11 Information gathered during Syilx conversations of some of the known areas for culturally important wildlife⁴.

2.10 Systematic Conservation Planning- Tsay Keh Dene Nation

A key part of ecosystem connectivity mapping is defining the goals of the process, as this will influence what the mapping looks like. Tsay Keh Dene Nation, near Prince George, BC, worked with Christopher Morgan, a Master’s student at the University of Northern British Columbia (UNBC), to conduct Systematic Conservation Planning.

The purpose of the process was to help identify priority areas for conservation within their territory. This included the identification of ecosystems of high conservation value, ecosystem connectivity, the effects of climate change on ecosystems, and indigenous knowledge.

Table 2 presents the steps followed in the Systematic Conservation Planning process and how ecosystem connectivity modelling (Linkage Mapper and Omniscape) was reinforced with Traditional Ecological Knowledge about known species movement corridors.

Table 2 Systematic Conservation Planning process.

Systematic Conservation Planning Process	Traditional Ecological Knowledge (TEK) / Community Guided Elements
Set conservation goals	Confirm conservation goals for the territory. Identify key indicators of ecosystem health. Review assembled data with community team. Identify any existing TEK data.
Develop human footprint layer	Compile footprint and validate with community. Community identifies any missing footprint elements.

⁴ Okanagan Nations Alliance and Okanagan Collaborative Conservation Program (2023) [Okanagan Mountain – K’nmalka – Wildlife Corridor Action Plan](#).

Systematic Conservation Planning Process	Traditional Ecological Knowledge (TEK) / Community Guided Elements
	Review buffers and weights. Identify future potential footprint.
Connectivity analysis	Identify known movement corridors. Verify intact or core areas.
Set targets	Review and adjust conservation targets.
Gap analysis	
Scenario modelling	Develop analysis scenarios. Conduct interactive workshop to examine alternative scenarios.
Analyse solutions	Review solutions to ensure they capture community values.

To identify priority areas for protection a prioritisation tool called prioritizr R / Marxan was used to overlay the following information:

- Ecosystem connectivity (**Figure 11**).
- Species information.
- Climate change information.
- Cultural features.
- Human footprint

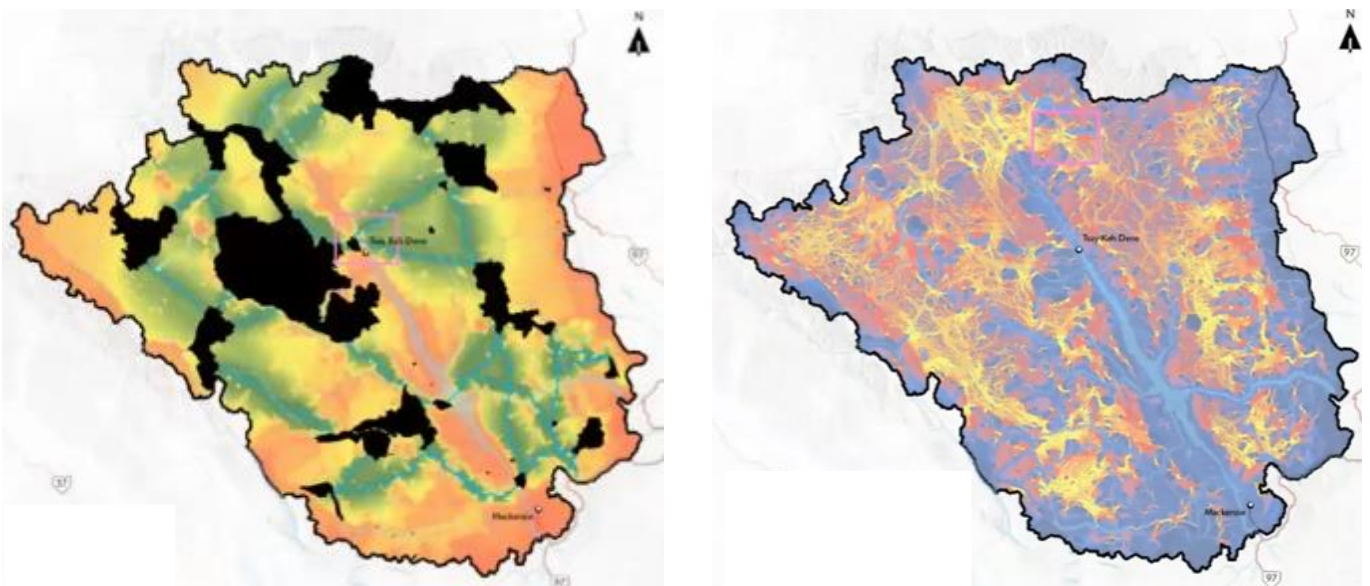


Figure 12 Linkage Mapper (left) and Omniscape (right) highlighting ecosystem connectivity.

The Tsay Keh Dene Nation considered the Systematic Conservation Planning approach as a way of translating indigenous knowledge into a GIS format which provincial and local governments would understand.

3 Recommendations for Ecosystem Connectivity or Ecological Network Mapping

The purpose of this report was to understand current approaches to ecosystem connectivity and ecological network mapping and to provide some guidance on potential approaches when undertaking mapping at a scale that can be used by local governments and First Nations in their planning and decision making.

The review identified that current practice for generating ecosystem connectivity or ecological network maps have drawn on several spatial layers, biological data and information held by non-Indigenous and Indigenous knowledge holders. It is not considered sufficient to undertake structural modelling using tools such as circuitscape or omniscap, but they do provide a valid starting point.

Purpose and scope of the mapping – At the start of the project it is important to consider:

- The context of the mapping e.g. highly urbanised landscape versus a rural area dominated by agriculture or forestry. Both are modified landscapes but the approach to corridor classification will differ e.g. not all forest is equal in its value to species.
- The goals of the connectivity or ecological network mapping project need to be clearly defined e.g. maintain connectivity for species at risk; large mammals; key indicator species etc..
- The extent of mapping needs to be considered as linkages extend beyond jurisdictional boundaries.
- Consider who will be using the mapping (the audience) e.g. planners, developers, biologists etc., as this will influence appearance and what is included and excluded.
- Define the scale of hubs, sites, regional and local corridors. This will differ depending on the level of urbanisation and the target species.
- Determine if the reinstatement of corridors a priority.
- Determine if existing barriers to movements lead to the exclusion of corridors or an indication of an area for improvement.
- Determine if modified ecosystems such as amenity areas and farmland should be included and if so how, as they are potentially of lower value than other ecosystems.
- Determine if buffers will be incorporated into the network with the objective of reducing human pressure e.g. extend hub 30 m from the existing ecosystem edge with a view of protecting this area through policy or acquisition.
- What resolution will the mapping be completed at? As this will impact on the accuracy of mapping which can have positive and negative impacts in relation to planning and decision making.

Engagement with Knowledge Holders - engage with Indigenous and non-Indigenous knowledge holders in relation to the location of areas that support species of importance. This engagement will be ongoing through the development of the mapping and will need to include knowledge holders that work with a broad range of species and species groups. This should include community science, hunters and ethnobotanists who historically have been excluded from western science.

Land Cover / Land Use Mapping - obtain detailed land cover mapping. Ideally this should be derived from imagery at a resolution of ≤ 10 m, be up to date and have sufficient classifications to divide the

landscape, while maintaining high accuracy of automated identification (e.g. approx. 15) (refer to CDFCP (2024) [Mapping Support Tools for NBS – Land cover](#)). The CDFCP is working with UBC Botanical Gardens and UBC Okanagan on [land cover mapping](#) of the south west coast at a resolution of 3 m using Planet imagery.

Identify Known High Value Biodiversity Areas - identify areas that are known to have high value for biodiversity e.g. Sensitive Ecosystem Inventory Mapping, Terrestrial Ecosystem Mapping, National and Provincial Parks, streams and wetlands mapping, indigenous and non-indigenous knowledge, species data collected by traditional and community science etc.

Scale of Ecosystem Features that Support Target Species – Most connectivity / network projects include the identification of hubs, which are areas of habitat that are known to or are likely to support the target species and the corridors used by the target species to move between hubs. The scale of these features will vary according to the target species and the level of urbanisation or degradation of surrounding habitat.

Metro Vancouver (in development) and the City of Surrey (2014) used the divisions in **Table 3**.

Table 3 Classification of terrestrial habitat areas into major and minor habitat patches.

Criteria	Major Habitat Patches	Minor Habitat Patches
Patch size (ha)	>10 ha of total habitat area.	>0.5 ha of total habitat area.
Wildlife refuge areas that are 100 m from urban edges	0.25 ha of refuge area.	none or <0.25 ha of refuge area.
Connectivity importance	High and very high dPC and dPCconnect values that are in the top 15 – 20% of regional connectivity importance.	Lower connectivity values compared to major habitat patches, but still important to regional connectivity.

In a rural setting the identification of hubs / patches would reflect habitat degradation e.g. the value of forested land to a target species is likely to depend on the age and structure of the forest. For example, marble murrelet requires old growth forest to nest. Elk needs a matrix of old growth and cleared areas. At first glance forest landscapes may appear to provide habitat and connectivity to all species, but that is not always the case.

Structural Modelling - This can take several forms depending on resources available. An approach taken by Metro Vancouver, Whatcom and previously by City of Surrey⁵ is called Least-Cost path. Linkage Mapper or Optimal Region Connections are tools that can be used to undertake this modelling. *Linkage Pathways uses GIS maps of core habitat areas and resistances to identify and map linkages between core areas. Each cell in a resistance map is attributed with a value reflecting the energetic “cost”, (i.e. difficulty and mortality risk) of moving across that cell. Resistance values are typically determined by cell characteristics, such as land cover or housing density (Linkage Mapper, [click here](#)).*

If funding is available, then additional modelling can be undertaken using tools such as Circuitscape, Omniscape, Conefor or Zonation. The difference between these tools is detailed in **Section 2.2** of this report.

⁵ The City of Surrey is presently reanalyzing its GIN using Circuitscape

The important thing to note about these tools is that the output will vary depending on the scale that the model is run e.g. municipal vs regional scale or 100 m vs 10 m. At a low resolution (>100 m) the intent of these tools is to highlight key corridors rather than corridors for all species e.g. good for predicting connectivity for mammals but less useful for herptofauna and species dependant of small habitat features. Therefore, these models when applied at a low resolution should be considered a step in the process rather than relying on them as the sole means of mapping ecosystem connectivity.

Functional Modelling – if available or resources allow, overlay existing species models (e.g. provincial resources) or consider applying species modeling approaches such as Conefor (refer to **Section 2.6**). These can build out from species records to reflect how species use the landscape.

Iterative Development of Mapping - share mapping with knowledge holders to identify where gaps may have occurred during the mapping process e.g. habitat missed that are known to support species. Consider barriers to movement, risks to species and areas where connectivity has been lost.

Indices to Analyse Multi Layers – the best approach to understanding ecosystem connectivity is to pull multiple layers of information together Whatcom and the City of Surrey's BCS include approaches to indices development that could be considered, but they do include human bias in them.

Live Document – test the mapping with the wider community to see if they understand and support the mapping that has been produced. The ecosystem connectivity map should remain a live document that evolves as land use changes and restoration is completed.

It is considered that an ecosystem connectivity and ecological network map will develop with time and that the first map doesn't need to be perfect. It should provide a good baseline, that can be advanced as knowledge is built, and it should enable decisions to be made based on best available knowledge.

Appendix A – Overview Table

A1- Overview of Ecosystem Connectivity Mapping Layers

Table A1 Review of decision support tools presenting **ecosystem connectivity**.

Name of Product	Single (S) or multiple (M) layers	Mapping / model used to generate network	Resolution	Species record	Scale – National Regional Local	First Nation Led / Involved	Description
Parks Canada	S	Circuitscape Protected areas Threat – land use Threat – climate change Species at risk range data	300 m	Yes	National	Yes	The priority areas have been identified in areas where loss of connectivity could disproportionately impact on species movements. The intent is that detailed mapping is undertaken at a regional and local level to identify connectivity corridors.
Pither et al, 2021 – Connectivity throughout Canada	S	Land cover Circuitscape	300 m	To validate but not in the model	National	No	This model takes a structural approach to connectivity placing a resistance value of land cover types. It is not based on species data, but it was used to tests its validity.
TerrAdapt – Species habitat suitability models	M	Land cover Habitat suitability	30 m	Yes	Provincial / Regional	Unknown	This decision support tools includes habitat suitability models for fisher, grizzly bear, wolverine, Canada lynx and greater sage-grouse. It presents habitat suitability from 1985-2020 for each species.
Metro Vancouver	S	Land cover / SEI Optimal Region Connections – Least-cost paths	5 m	Yes	Regional	On going	This connectivity approach pulled in a number of sources of data, similar to Parks Canada but at a local scale rather than a national scale. The valuation of agricultural land to connectivity led to a lot of discussion as did the inclusion of existing municipal connectivity mapping.

Name of Product	Single (S) or multiple (M) layers	Mapping / model used to generate network	Resolution	Species record	Scale – National Regional Local	First Nation Led / Involved	Description
Whatcom County Watershed Portal	M	Linkage Mapper Omniscape	30 m	No	Regional	No	Mapping combined the results from Linkage Mapper and Omniscape to produce a Connectivity Value map . This is presented in a mapping portal which allows land use and watershed information to be overlaid. The portal is a standard ESRI portal and easy to use.
City of Surrey – My COSMOS	S	Land cover / SEI Least-cost	?	Yes	Local	No	Single mapping layer which can be accessed through the City of Surrey Mapping Online System (COSMOS). This enables multiple layers to be overlaid to inform decision making. A lot of layers which could improve or negatively impact on user experience.
Okanagan Connectivity Corridor	M	Circuitscape Indigenous knowledge	?	Yes	Regional Local	Yes	The ecosystem connectivity corridor has been incorporated into Official Community Plans. The location of the corridor can be viewed through the City of Kelowna Map Viewer under OCP2040 and DPA Layers