Spatial Analysis of Ecological Connectivity Through UBC – An Omniscape Approach

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FCOR 599
The University of British Columbia

(30 April 2024)

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Executive Summary

Human activities and rapid urbanization have led to habitat destruction and fragmentation, severely impacting biodiversity and ecosystem services globally. This study focuses on the UBC campus, surrounded by the Pacific Spirit Regional Park, to assess and enhance ecological connectivity through the urban landscape. Using advanced remote sensing techniques, including Planet SkySat satellite imagery and British Columbia 2022 LiDAR data, we classified the landscape and identified key habitats. Keystone species were selected based on habitat dependency, observation density, and conservation status, utilizing datasets from the Global Biodiversity Information Facility (GBIF) between 2010 to 2023. The study employed Omniscape, an implementation of Circuitscape 4.0, to model the randomized movement of animals across a resistance-weighted landscape, providing a nuanced understanding of how urban features influence ecological flows.

Our findings indicate that urban areas, especially the central UBC campus, act as barriers and funnel species movement, particularly affecting those with small movement ranges and unique habitat requirements, such as the Pacific Tree Frog and Douglas's Squirrel. The analysis highlighted areas of highly channelized flows where predicted movement exceeds landscape capacity, leading from Pacific Spirit Regional Park to UBC's Central core. UBC’s Main Mall was predicted to have highly channelized flow across all species and is a critical corridor for conservation and enhancement. Other recommendations for UBC include creating an East-West Ecological Corridor, replicating Main Mall’s design. The existing landscape should be intensified by integrating more water bodies and riparian areas to support amphibian species and interspersing shrub planting between trees to expand habitat availability.

Keywords: UBC, Pacific Spirit Regional Park, Omniscape, Ecological Corridor, Habitat Connectivity, species movement

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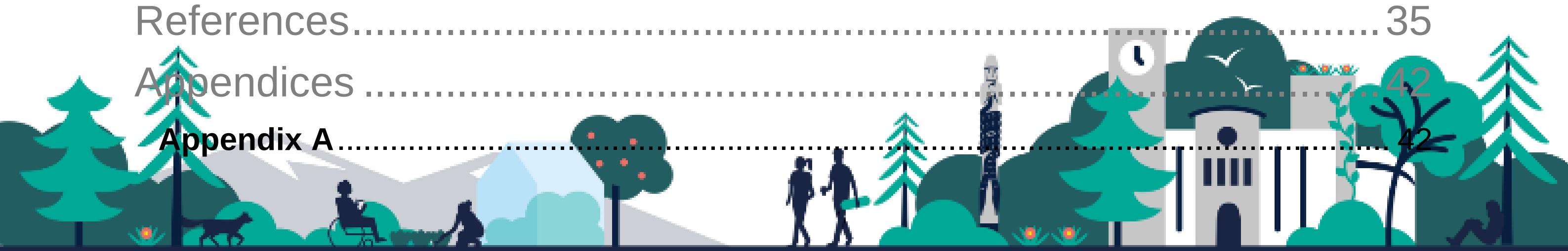

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Introduction

Human activities such as rapid urbanization are the leading cause of habitat destruction globally (Ren et al., 2023). The resultant loss of ecosystem services - direct and indirect benefits provided by nature - has a large impact on both biodiversity and humans (McElwee & Shapiro-Garza, 2020). Decades of studies have documented these impacts, including increased run-off, erosion, urban heat island effects, loss of biodiversity and carbon emissions, all of which accelerate climate change (Grimm et al., 2008; Liu et al., 2016; Pathak & Dubey, 2023).

Habitats which remain from urban development become increasingly fragmented. Newly created forest edges rapidly expose previously protected habitats to environmental changes, including stronger winds and infiltration of invasive species, leading to further habitat degradation (Brown, 2004; Hending et al., 2023). Migration, food and mating opportunities for the remaining biodiversity becomes limited as urban structures such as roads and buildings restrict movements between fragmented habitats (Fahrig, 2003).

Additionally, fragmented habitats require species to expend more energy to move between them. Plants and animals with a small dispersal and movement range are especially vulnerable to risk of extinction (Crooks et al., 2017; Rus et al., 2021; Staude et al., 2020). Degraded habitats become more susceptible to invasion by exotic plant and animals, which compete with the native biodiversity for the limited resources. Globally, human activities have led to an average 69% decline in population sizes of approximately 5230 species of animals between 1970 – 2018 (Almond et al., 2022; Westveer et al., 2022).

Restoring nature within the urban fabric is key to combating the negative effects of urbanization, restoring ecosystem functions, and facilitating biodiversity connection between fragmented habitats. Curated landscaping, such as using native plants, multi-tiered plantings are introduced within cities to mimic natural habitats. This approach creates ecological corridors - highways within urban fabric - that fauna use to move between previously fragmented habitats (Bierwagen, 2007; Fernández-Juricic, 2000; Öckinger et al., 2012). Studies have increasingly shown the health benefits of human interactions with greenery, including reduced stress, illness and faster recovery (Shanahan et al., 2019). During the COVID19 pandemic, green spaces became refuges for people to cope and adapt to the highly stressful circumstances (Doughty et al., 2023; Li et al., 2023). Access to nature has also been shown to reduce stress in college students and improve attention and creativity (Sharam et al., 2023; Vitagliano et al., 2023).

The University of British Columbia Vancouver Campus (UBC), is an urban campus with a diverse range of greenery, ranging from urban linear plantings to parks and conserved forest patches. These isolated greeneries may function as important habitats and provide ecosystem services. Conserving and enhancing these habitats could allow the creation of ecological corridors within UBC, connecting to the adjacent Pacific Spirit Regional Park. The new ecological corridors will function as node and conduits to facilitate fauna movement, bringing nature into the campus and improving its liveability.

Data Description

1.1 Study Area - UBC and Surroundings

The University of British Columbia's Point Grey Campus comprises of 400 hectares of publicly accessible spaces with an estimated 160 hectares of built-up land. It is enveloped by the Pacific Spirit Regional Park (PSRP), which consist of 763 hectares of dense forest (*Our Campus | Building Operations*, n.d.). The UBC has a large diversity of trees, with approximately 8000 planted and over 10000 native trees in natural settings. There is a campus-wide biodiversity and tree strategy in place to mitigate the impacts of urban development and enhance the campus's urban forests (UBC Campus & Community Planning, n.d.). The Pacific Spirit Regional Park is home to a wide variety of flora and fauna (*Pacific Spirit Park*, n.d.), providing potential source habitats which UBC can form connectivity with. The study site shown in Figure 1, highlights the UBC campus in yellow and the Pacific Spirit Regional Park in dotted red.

Figure 1: Map of the study area, with UBC edged in yellow and Pacific Spirit Regional Park in dotted red. Map sourced from Planet Satellite imagery taken on 13 July 2023

1.2 Remote Sensing Dataset - Planet SkySat Satellite Imagery

Operated by Planet, the SkySat constellation consists of approximately 21 satellites, revisiting any location on Earth up to 10 times daily. These satellites produce images with a resolution of approximately 0.5 meters per pixel. Each SkySat satellite is equipped with Cassegrain telescopes with focal lengths of 3.6km, and three 5.5-megapixel CMOS imaging detectors making up the focal plane.

SkySat imagery encompasses scenes of 1 by 2.5 square kilometers in size, containing 4 spectral bands: Red, Green, Blue, Near-infrared. The detailed breakdown of spectral bands and available SkySat imagery products is shown in Table 1 and Figure 2. The Analytical Ortho Scene Product, a post-processed level 2 SkySat product will be used in this study. Atmospheric correction, normalization and resampling is carried out in this level 2 product to ensure atmospheric effects, terrain effects and imagery color are optimized for further processing (*SkySat*, n.d.).

SkySat Scene imagery from 13 July 2023 was selected as there was minimal cloud cover and the time period was in summer, the peak period of vegetation growth.

*Table 1: SkySat Spectral Bands (*SkySat - Earth Online*, n.d.)*

Band	Name	Wavelength (nm)
1	Blue	450-515
2	Green	515-595
3	Red	605-695
4	Near Infrared	740-900
5	Pan	450-900

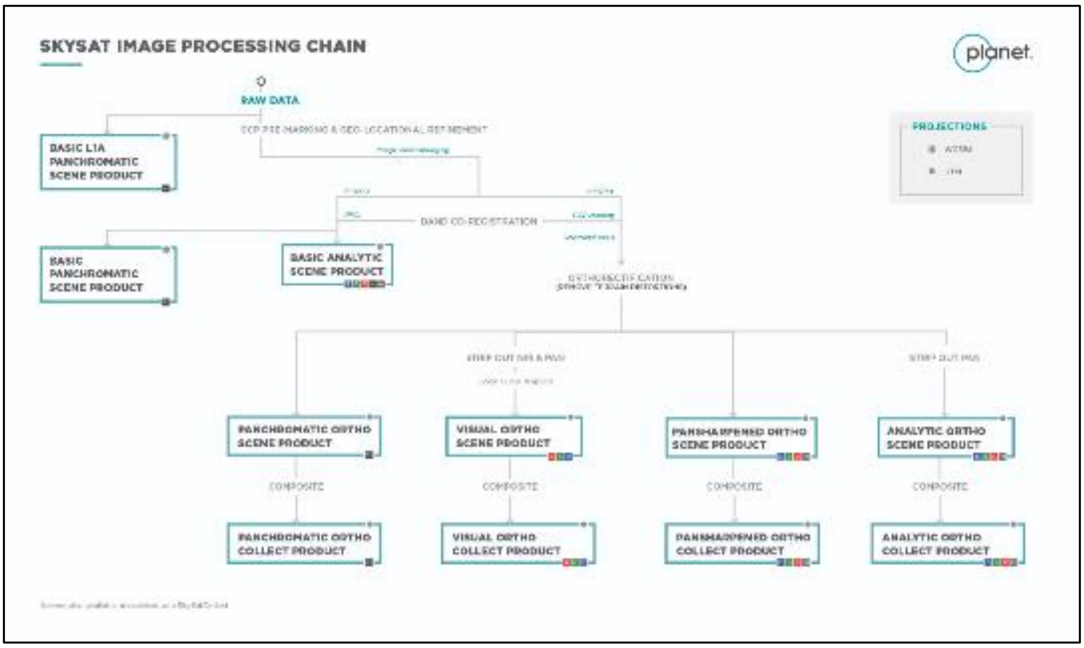


Figure 2: Products derivable from SkySat, the Analytical Ortho Scene Product on 13 July 2023 is used in this study.

1.3 Light Detection and Ranging (LiDAR)

LiDAR is a remote sensing technique which uses light in the form of pulsed laser to measure distances between the sensor and the target object. The distance of each feature is recorded as a point and the resulting point cloud generated from a scan is used to produce a precise map of the scanned features (*The Basics of LiDAR*, n.d.). For this study, LiDAR data was obtained from the City of Vancouvers 2022 LiDAR scan, which is publicly available (*LiDAR 2022*, n.d.). The LiDAR data was acquired on 7 and 9 September 2022 and has a spatial resolution of 49 points per square meter, a minimum side lap of 60% in the north-south and east-west directions. The data also has a vertical accuracy of 0.081 meters with a 95%

confidence level and is projected in UTM Zone 10. An example of derivable data from LiDAR dataset, is the forest canopy height shown in Figure 3.

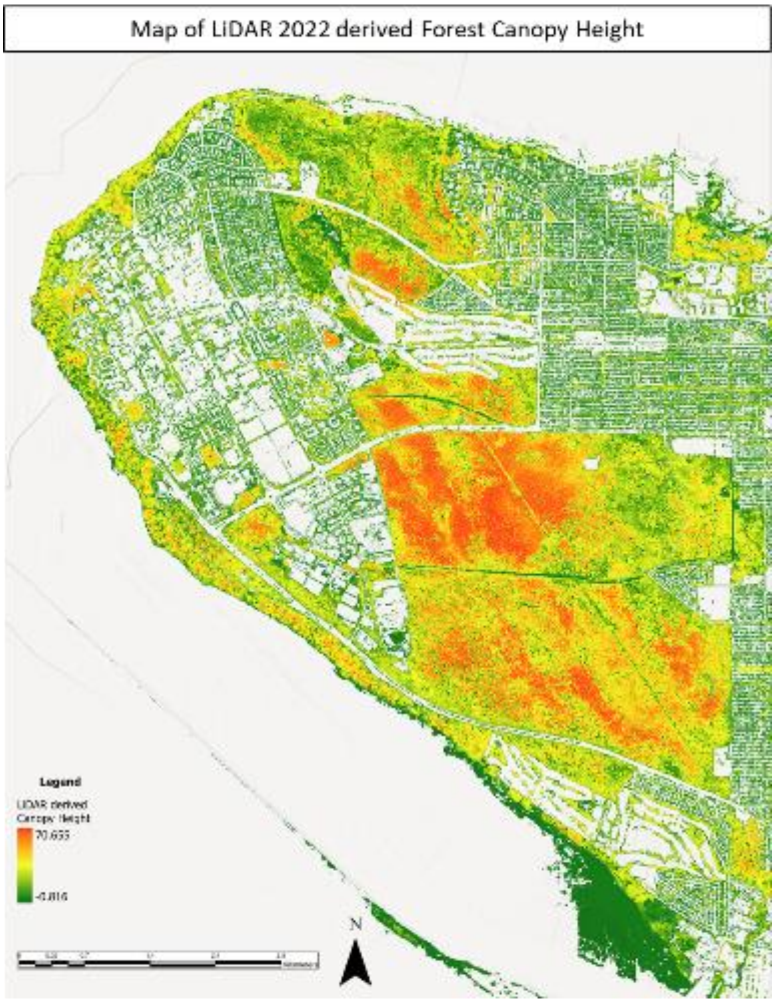


Figure 3: LiDAR derived Canopy Height Model of UBC campus which is added as a variable for the supervised habitat classification in Section 2.3. LiDAR dataset is also used to derive slope and the Digital Terrain Model (DTM) to determine streams in Section 2.4

1.4 <u>Selecting Keystone Species from GBIF data</u>

The Global Biodiversity Information Facility (GBIF) is an international network and data infrastructure which consolidates biodiversity observations from both research publications and research-grade citizen science platforms such as eBird and iNaturalist (*What Is GBIF?*, n.d.). For this study, all research-grade biodiversity observations from 2010 to 2023 were extracted from GBIF (*GBIF Occurrence Download*, 2024). The species were then matched with the BC Biodiversity Conservation Status to determine the conservation status of each species. The conservation statuses are grouped into three categories, Red for species at the greatest risk of being lost, Blue for species of special concerns (formerly vulnerable) and Yellow for species that are apparently secure or secure (least risk of being lost).

The GBIF data was divided into four classes, Amphibians, Insecta, Aves, Animalia. Species within each class were then grouped by conservation status and number of observations. Species with fewer than 10 observations were excluded, as it was determined to be insufficient for meaningful modeling.

Clients were consulted on the list to select the keystone species, and the species in Table 2 were selected to cover taxonomic class, unique habitat requirements, movement ranges in the study area.

Pacific Tree Frogs were selected as they represented a species with a medium movement range and specific habitats such as Streams, Riparian Areas and Forests (Green et al., 2021).

Salamanders have highly restricted movement ranges and mainly travel within leaf litter in the forest understory (Fang et al., n.d.; Ovaska', 2024; Rosenberg et al., 1998).

Bees are selected for their significance importance in ecology, promoting pollination and ensuring the long-term continuation of ecosystems (Osborne et al., 2008). Six species of Bumblebees were consolidated into a single group to improve the accuracy of the model.

Killdeers are selected to represent urban-adapted birds as they are known to nest within open gravel and grasslands, though they primary live in coastal areas (*Killdeer_BC_Data_Centre*, n.d.).

Band-tailed Pigeons cover the ecological niche of forest bird species with limited forage into forest-urban interfaces (*Band-Tailed Pigeon(Patagioenas Fasciata)*, n.d.).

Douglas's squirrels are selected to represent conifer dependent mammalian species (*Douglas Squirrel_BC_Data_Centre*, n.d.).

Coyotes are selected to represent highly adapted urban wildlife (*Coyote_BC_Data_Centre*, n.d.). Species information is also referenced from the BC Species & Ecosystems Explorer (*BC Species & Ecosystems Explorer*, n.d.).

Table 2: Species selected, some species of similar Taxon, movement and habitat requirements were grouped together to increase the number of observations for a more meaningful model.

Taxon	Species	Obs	BC Cons Status	Habitats	Range
Amphibians	Pacific Tree Frog	215	Yellow	Streams, Riparian, Forests	Medium
Amphibians	Ensatina, Western Red-backed Salamander	66	Yellow	Understory, leaf-litter, Riparian	Small
Insecta	Yellow Cuckoo Bumble Bee, Black-tailed Bumble Bee, Yellow-fronted Bumble Bee, Brown-Tailed Bumble Bee, Sitka Bumble Bee, Yellow-faced Bumble Bee	221	Blue (Yellow Cuckoo) Yellow (Rest)	Forests	Large
Aves	Killdeer	654	Blue	Coastal, Open Gravel or Grass for nesting	Large
Aves	Band-tailed Pigeon	344	Blue	Forest	Large
Animalia	Douglas's Squirrel	45	Yellow	Coniferous Forest	Medium
Animalia	Coyote	43	Yellow	Multi-habitat, urban adapted	Large

Methods

2.1 Overview

The analysis makes use of Omniscape, (Landau et al., 2021; B. McRae et al., 2016) an advanced implementation of Circuitscape 4.0 (Dickson et al., 2019; B. H. McRae et al., 2008; Shah & McRae, 2008) to model randomized movement of animals within a resistance weighted landscape.

Circuitscape utilizes circuit-theory, conceptualizing animal movements as electrical currents travelling from a source, across electrical resistances to a ground. This model requires two inputs: a source layer, determined by assigning a probability to each landscape pixel of being used as habitat, and a resistance layer, based on the probability of a pixel resisting movement.

Circuitscape overcomes the limitations of older Least Cost Path models by assuming random movement across all landscape types rather than a single path (Rudnick et al., 2012). For example, a Coyote might choose to climb a slope even if it presents a greater resistance because it might choose to gain height advantage.

However, Circuitscape still required designation of a start and end point which influenced the results of the output (B. McRae et al., 2016). The Omniscape addresses this by adopting a moving window when assessing the animal's potential to move across the landscape. The Omniscape method is further explain in Section 2.2.

The resistance-weighted landscape and a source weighted landscape is derived from compiling and classifying landscape and fauna data from the Habitat and Fauna Datasets listed in Figure 4.

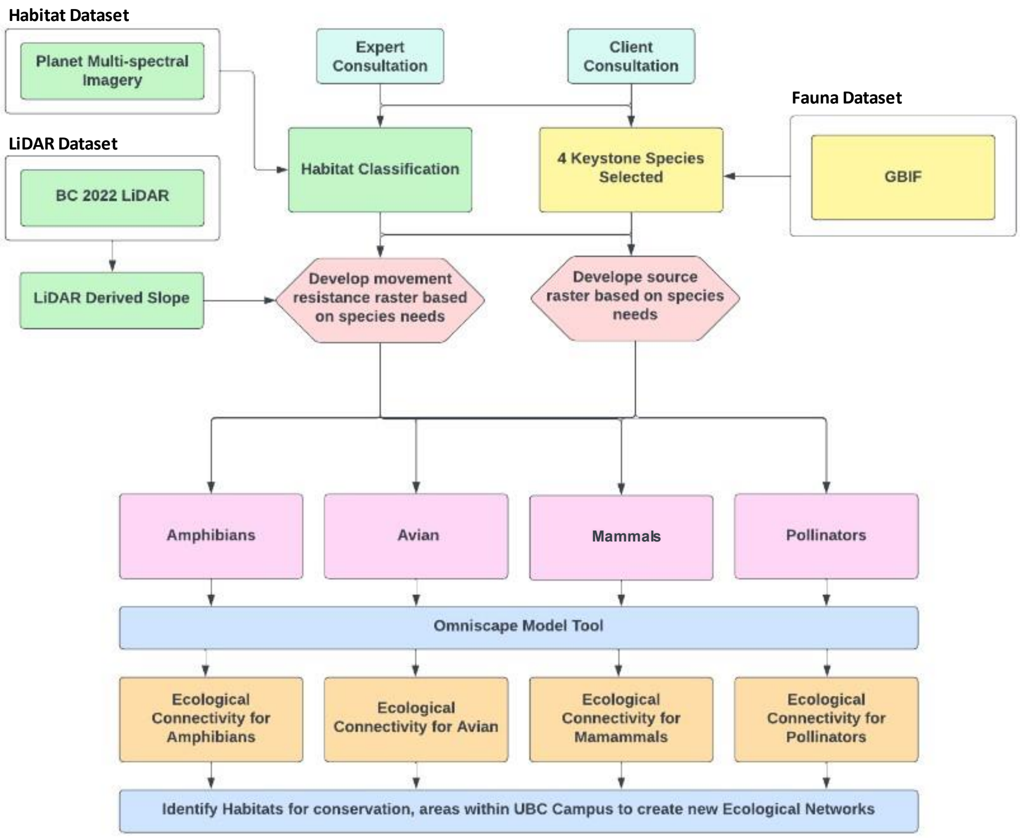


Figure 4: Landscape classification is conducted through supervised classification. The BC 2022 LiDAR is used to model Slope (DTM) and Streams. These three layers are combined to develop the resistance and source layers. Source layers also take into consideration of the observations in GBIF.

2.2 Omniscape Modelling

The Omniscape model methodology is shown in Figure 5 and described below:

1) The model first selects a central pixel from the source strength raster and assesses if the pixel has a source strength greater than 0.
2) If the source strength is greater than 0, the user defined moving window is set around the central pixel. The resistance raster (see Section 2.7) and source raster (see Section 0) are clipped to this moving window boundary.
3) All other pixels within the moving window with source strength greater than 0 are identified and set as potential movement targets that the fauna can reach.
4) A current is injected into all pixels identified in 3. The injected current is equivalent to the source strength of the central pixel and divided proportionally based on source strength of the identified pixels in 3.
5) The current is measured from each of the pixels in 3 to the central pixels, across all possible resistance paths.
6) These steps are repeated for all pixels with a source strength greater than 0 and the current flows are summed to get a map of cumulative current flow.

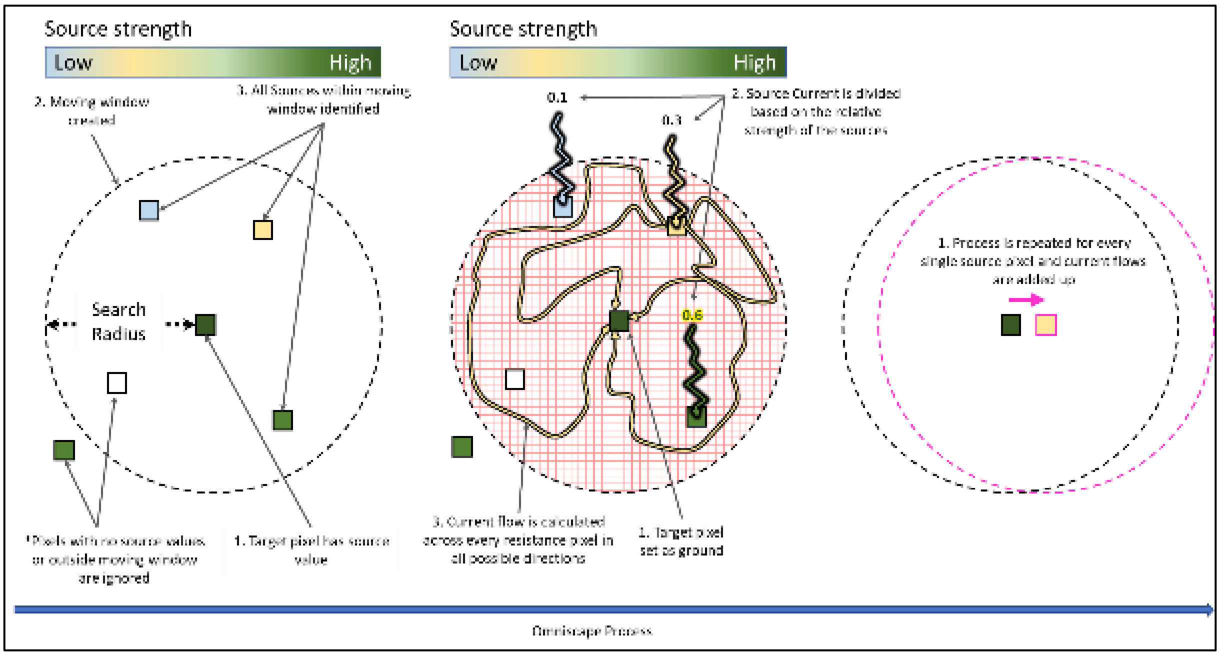


Figure 5: The Omniscape moving window (Landau et al., 2021) designates a radius which movement is calculated, centred around each selected pixel. The window is then moved to the next pixel and the assessment is repeated. Setting the moving window mimics the maximum movement of each species from a selected species and eliminates the need to designate an end and start point.

In this study, the moving window is set as the maximum known distance of fauna movement to represent the realistic expectation of an animal in traversing a landscape.

2.2.1 Omniscape outputs: Predicted and Normalized Connectivity Maps

The Omniscape modelling produces three maps for interpreting species connectivity: Predicted, Flow Potential and Normalized Connectivity Maps. The Predicted Connectivity maps show the summed probability of species movement through the resistance landscape, areas of high and no predicted movements are highlighted in yellow and blue, respectively.

While the predicted connectivity map shows existing movements, it does not reflect how the landscape is expected to affect the movement. This impact can be observed by normalizing the Predicted Flow over the Flow Potential, allowing us to understand if the landscape is currently carrying more flow than expected. The Flow Potential can be viewed as the maximum capacity of the landscape when all resistances are set to the lowest value of 1.

Highly values of normalized flow indicate Channelled flow, where existing landscape obstructions funnel movements through a singular corridor. Areas with highly channelized flows are critical to conserve or excellent candidates for improvements as they are pinch points, and its disruption could fragment habitats. The rest of the normalized flows are categorized into Intensified, Diffused or Impeded flow, and teases out how existing landscapes guide movement patterns (Belote et al., 2022; B. McRae et al., 2016).

2.3 Supervised Landscape Classification of Planet SkySat Imagery

The initial step to modeling in Omniscape involves classifying the Planet SkySat raster into landscape classes. Four classes in Table 3 were adopted as they were distinguishable through the available spectral bands (Szabó et al., 2021).

Supervised classification using Random Forest (RF) (Liaw & Wiener, 2002) was carried out in R using the Random Forest package (Cutler & Wiener, 2022). The RF classifier employs a decision tree algorithm which randomly selects variables for model training. The majority of the votes from outputs of decision trees are taken as the correct landscape classification. Generally, RF classifiers are known to achieve higher accuracies in landscape classification (Adam et al., 2014). Polygons representing the four classes were manually drawn in ArcGIS Pro v3.2.2. The model was trained using 10,000 pixels per class and 401 trees, and an independent validation dataset was used to validate the classified landscape. A LiDAR derived Canopy Height Model was added into the classifier to improve training and identification of trees (Hemingway & Opalach, 2024).

Table 3: Classification Classes used for classifying the landscape, four classes are selected as the 4 bands limits the type of features which can be distinguished.

No.	Classes	Training pixels	Validation pixels
1	Deciduous Forest	10,000	33,758
2	Coniferous Forest	10,000	66,143
3	Grass	10,000	40,372
4	Roads/Buildings	10,000	40,325

2.4 Deriving slopes and streams from LiDAR, Digital Terrain Model (DTM)

Streams are modelled from the LiDAR derived DTM. This is required as the SkySat imagery lacks Short-wave infrared band which is more suited for water detection (*Land And Water*

Bands Usage In The Satellite Imagery, 2021). Furthermore, the lack of visible waterbodies within the satellite imagery of PSRP suggests that the streams are either hidden under forest cover or too small to be detected.

The DTM was generated through the lidR package in R (Roussel et al., 2024). The British Columbia (BC) 2022 Provincial LiDAR dataset was used, and the Kriging interpolation was applied on the ground points to derive the DTM in Figure 6. Kriging interpolation was selected for its accuracy compared to other interpolation methods as it minimizes error variance and accounts for spatial autocorrelations which drops as distance increases (Meng et al., 2013).

Slope, Flow Accumulation, Flow Direction, Stream Orders Geoprocessing Tools in ArcGIS Pro v3.2.2 were used to generate slope and streams. A flow accumulation threshold of 3000 was applied to remove noise and small streams which were determined to be run-offs were manually removed.

Majority of the streams are modelled to be within forested areas of the Pacific Spirit Regional Park, shown in Figure 6 and Figure 9. The DTM was also used to derive slopes, which is added into the resistance layer to represent the difficulty to traverse elevations in Section 2.7.

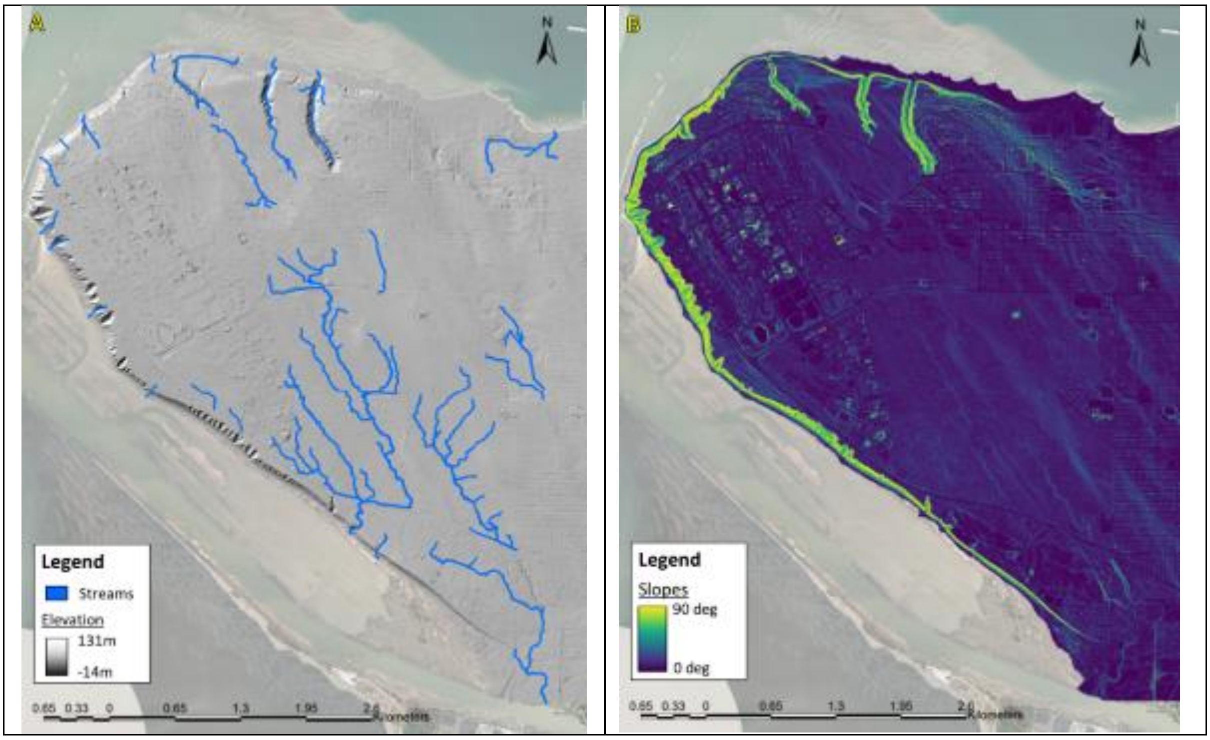


Figure 6–A: LiDAR ground points are used to create a DTM which is subsequently used to model slope and stream network. High resolution of the LiDAR dataset and DTM resulted in high noise during stream creation. These were filtered out to retain only more major streams of order S3 and above. Figure 9-B shows a slope derived from the DTM, steep slopes are observed nearer to the coast and buildings due to the rapid change in heights. Slope data is used as a resistance input to the resistance layers mentioned in Section 2.7.

2.5 Setting Riparian Areas

Riparian areas are a critical part of the stream ecosystems (Gomi et al., 2006; Park et al., 2021). Because the streams are too small to classify in accordance to the BC Riparian standards (Ministry of Forests, 2024), conservative riparian buffers in Table 4 are applied to the identified streams.

Table 4: Riparian Zone Width, conservative buffers are set in a lack of matching guidelines.

Stream Order	Riparian Zone Width
3	4m
4	6m
5	10m
6	20m

2.6 Source Raster from Observations

The source raster for each species was developed based on their observational recording and their known movement ranges. For example, a 250m buffer is applied to each Pacific Tree Frog observation point to mimic their known travel ranges (Green et al., 2021). Overlapping buffers were combined into clusters to establish the maximum boundary of potential source habitats. Next, observations within each cluster were counted and the total observations are split into four quantiles assuming a normal distribution. Each cluster was next assigned a source strength of 0.25, 0.5, 0.75 and 1, based on the quantiles (Figure 7). This ensured that areas with higher number of overlapping observations are assigned greater importance as sources. In cases where a quantile could not be clearly defined, all observation buffers were assigned a value of 1. The source raster for each species is shown in Figure 8.

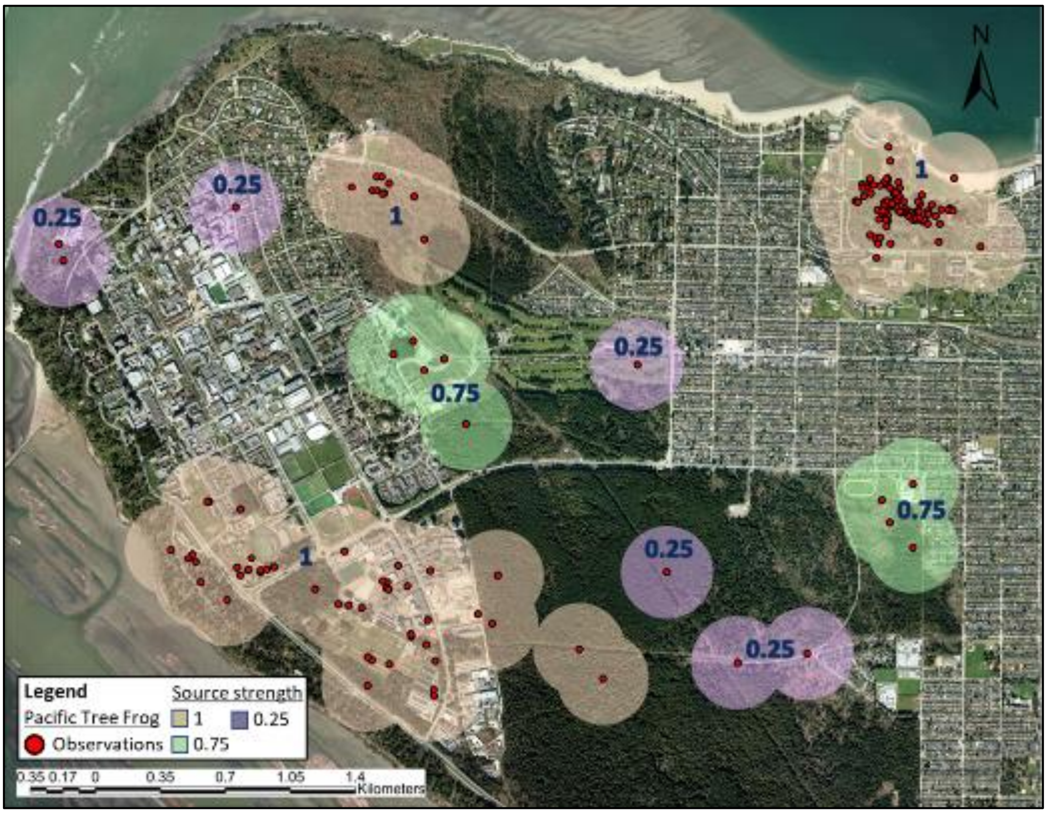


Figure 7: The Pacific Tree Frog observed points are buffered based on their known travel range and clustered. A cluster with more points is weighted higher as sources.


B
Legend
Salamander
Observations
Source strength
1
C
Legend
Bees
Observations
Source strength
1
D
Legend
Killdeer
Observations
Source strength
1
E
Legend
Banded-Tail Pigeon
Observations
Source strength
1

Figure 8: Shows the observations of the selected keystone species and their source strength, based on their known movement radius. Species are presented in the following order: B – Salamander, C – Bees, D – Killdeer, E – Banded-Tailed Pigeon, F – Douglas Squirrel, G – Coyote. For B, the source strength buffer is the same size as the observation points due to representation. It should be noted that aside from the Pacific Tree Frog, all other species were only assigned a source strength of 1 as the observations and their intersects were not sufficiently distributed to obtain a meaningful quantile split.

2.7 Assigning Resistance Values to Classified Landscape, Slope and Riparian

Resistance weighted raster is developed for each keystone species to indicate how difficult it is expected for the keystone species to move across the landscape. A resistance value of 100 is the highest (impassable) and 1 is the lowest (no resistance). Influences of Slope and Riparian areas are added as an overall weighted influence to the resistance. An example of combining the resistance values for the Pacific Tree Frog is shown in Table 5 and Table 6. The full resistance and source weights for each species is listed in Table 7.

Table 5: Resistance values assigned to each Classified Landscape class for each species, determined through literature review, expert and client agreement.

Species/ Resistance values of Classified Landscape	Broadleaf	Coniferous	Grass	Roads/Buildings
	Higher = Greater resistance to movement			
Pacific Tree Frog	20	20	40	90

Table 6: Combined Resistance example for Pacific Tree Frog, it is expected that the landscape class has an overall 70% influence, the Slope will present a 30% resistance and Riparian will be 0% (assuming that frogs travel freely near waterbodies)

	Weight	Parameter	Weight	Parameter	Weight	Parameter
Pacific Tree Frog	1	Resistance	0.3	Slope	0	Riparian
Total Resistance	(1 * Resistance) + (0.3 * Slope) + (0 * Riparian)					

Table 7: Resistance, Source weights of each identified keystone species. Some species under the same Taxon, which have similar habitat and movement requirements (e.g. Bumblebees) are aggregated to increase observations for a better model output.

Taxon	Species	Status	Range (m)	Resistance						Source				
				Higher = More Cost to move						Higher = Higher potential to use as source				
				Broadleaf	Coniferous	Grass	Roads/ Buildings	Slope	Riparian	Broadleaf	Coniferous	Grass	Roads/ Buildings	Riparian
Amphibian	Pacific Tree Frog	Yellow	250	20%	20%	40%	90%	30%	0%	25%	25%	0%	0%	100%
Amphibian	Ensatina, Western Red-Backed Salamander	Yellow	20	20%	20%	0%	100%	60%	0%	75%	75%	25%	0%	100%
Insect	Bees/Pollinators	Blue/Yellow	3000	0%	0%	40%	70%	0%	0%	75%	75%	0%	0%	0%
Bird	Killdeer	Blue	5000	0%	0%	0%	0%	0%	0%	0%	0%	50%	50%	50%
Bird	Band-tailed Pigeon	Blue	10000	0%	0%	0%	40%	0%	0%	75%	75%	25%	0%	25%
Mammal	Douglas's Squirrel	Yellow	2000	10%	0%	40%	80%	20%	80%	0%	100%	0%	0%	0%
Mammal	Coyote	Yellow	80000	20%	20%	10%	50%	40%	40%	25%	25%	25%	0%	0%

Results

3.1 Landscape Classification

Overall accuracy of the trained Random Forest (RF) model was observed at 99.12%. The RF model was then used to predict classifications for the entire Planet Satellite raster, and the model was validated with an independent set of user defined data. Results from the supervised Random Forest Classifier are shown in Figure 9. A high accuracy of the classified raster was observed at 97.81%, and the breakdown is detailed in Table 8.

Figure 9: Map showing classified habitats using random forest classifier using Red, Green, Blue, Near-Infrared Planet Satellite Bands and Canopy Height Model derived from BC LiDAR 2022. Landscape was classified with 97.81% accuracy with large patches of coniferous and deciduous forests located within PSRP and small corridors of greenery within residential estates.

Table 8: Error matrix of land cover classification, a higher level of accuracy was obtained by using supervised random forest classifier with addition of canopy height model.

		Reference (Valdiation Data)				User's Accuracy (%)	Commision (%)
		Coniferous	Deciduous	Grass	Roads/Buildings		
Prediction (Classified Raster)	Coniferous	63644	1345	0	0	97.93%	2.07%
	Deciduous	2445	32285	1	0	92.96%	7.04%
	Grass	0	120	40422	44	99.60%	0.40%
	Roads/Buildings	3	0	0	40277	99.99%	0.01%
	Producer's Accuracy (%)	96.30%	95.66%	100.00%	99.89%	Overall Accuracy	97.81%
	Omission (%)	3.70%	4.34%	0.00%	0.11%	Kappa Coefficient	97.01%

3.2 Omniscape Connectivity Models

Habitats and connectivity for the seven keystone species were modelled: Pacific Tree Frog (*Pseudacris regilla*), Salamanders (*Ensatina spp*), Bumblebees (*Bombus spp*), Killdeer (*Charadrius vociferus*), Band-tailed Pigeon (*Patagioenas fasciata*), Douglas's Squirrel (*Tamiasciurus douglasii*) and Coyote (*Canis latrans*). Connectivity for each keystone species was modelled using species-specific source and resistance layers, as detailed in Table 7. Additionally, a combined predicted connectivity and normalized connectivity map was produced (Figure 10), which aggregates the flows of all species. It is important to note that the connectivity values for the Killdeer were excluded from the combined maps due to the unexpected results which may skew the output.

The Omniscape models in the following section will be shown in the following order:

Top Left – Predicted Connectivity,

Top Right – Predicted Connectivity focused on UBC,

Bottom Left – Normalized Connectivity,

Bottom Right – Normalized Connectivity focused on UBC.

3.2.1 Combined Predicted Connectivity and Normalized Connectivity

We observe that the Overall Predicted Connectivity in Figure 10 – A1 has high connectivity originating from the southeastern segment of Pacific Spirit Regional Park (PSRP), extending towards the northwestern part of PSRP. Connectivity through the UBC campus is high on the southern segment of UBC campus near to the UBC Farms and Botanical Gardens, with additional areas of high flow within Main Mall. Conversely, predicted connectivity is generally low across the northern side of the campus in Figure 10 – A2. It is also observed that the streams, along with a few circular spots within PSRP were identified with high connectivity. Urban areas display limited connectivity, with species utilizing the landscape between buildings for movement.

In the normalized connectivity model Figure 10 – B1, connectivity throughout most parts of the eastern PSRP appears intensified, with connectivity in the western part being channelized. Within the UBC campus, normalized connectivity is highly channelized, predominantly through Main Mall.

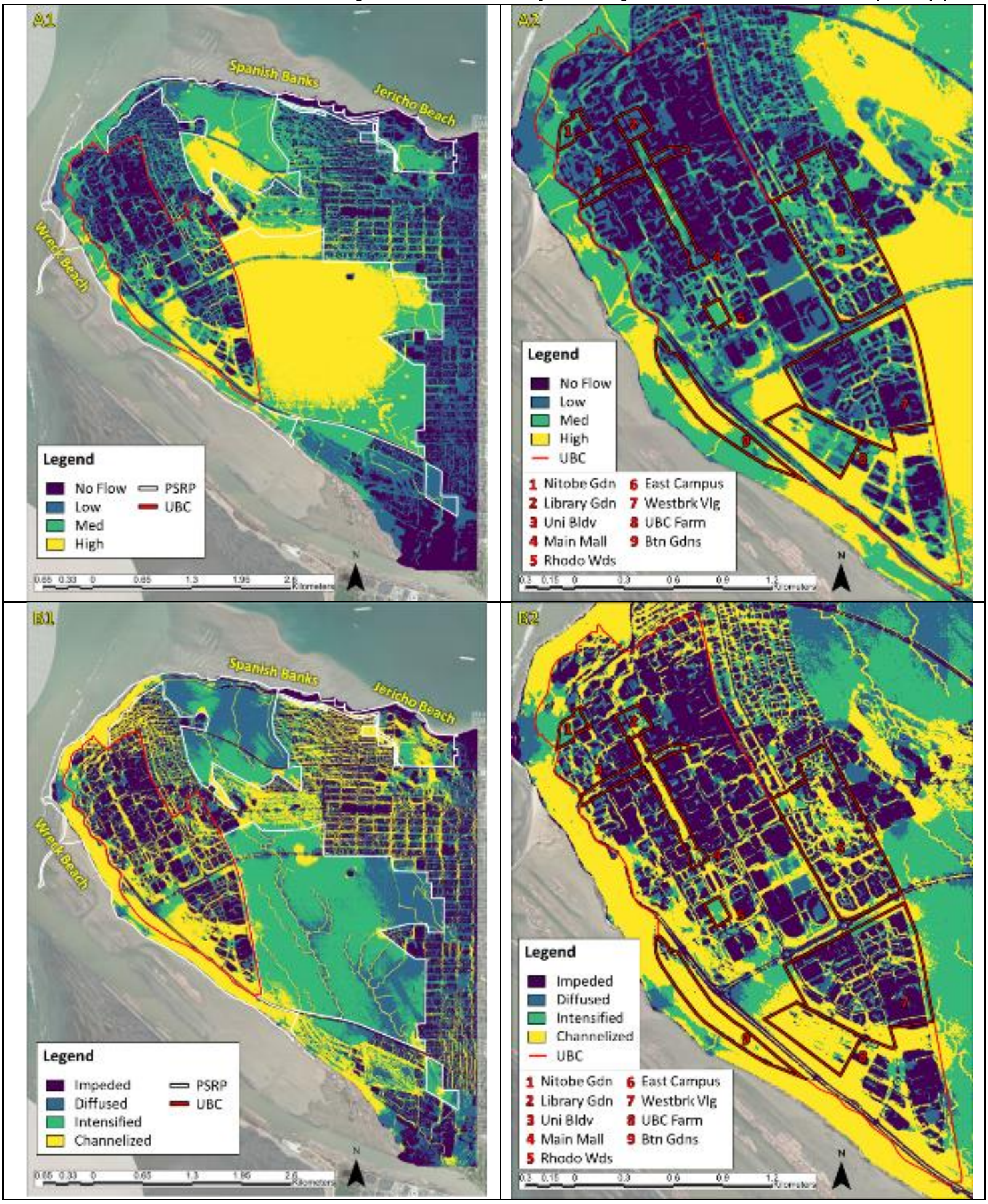
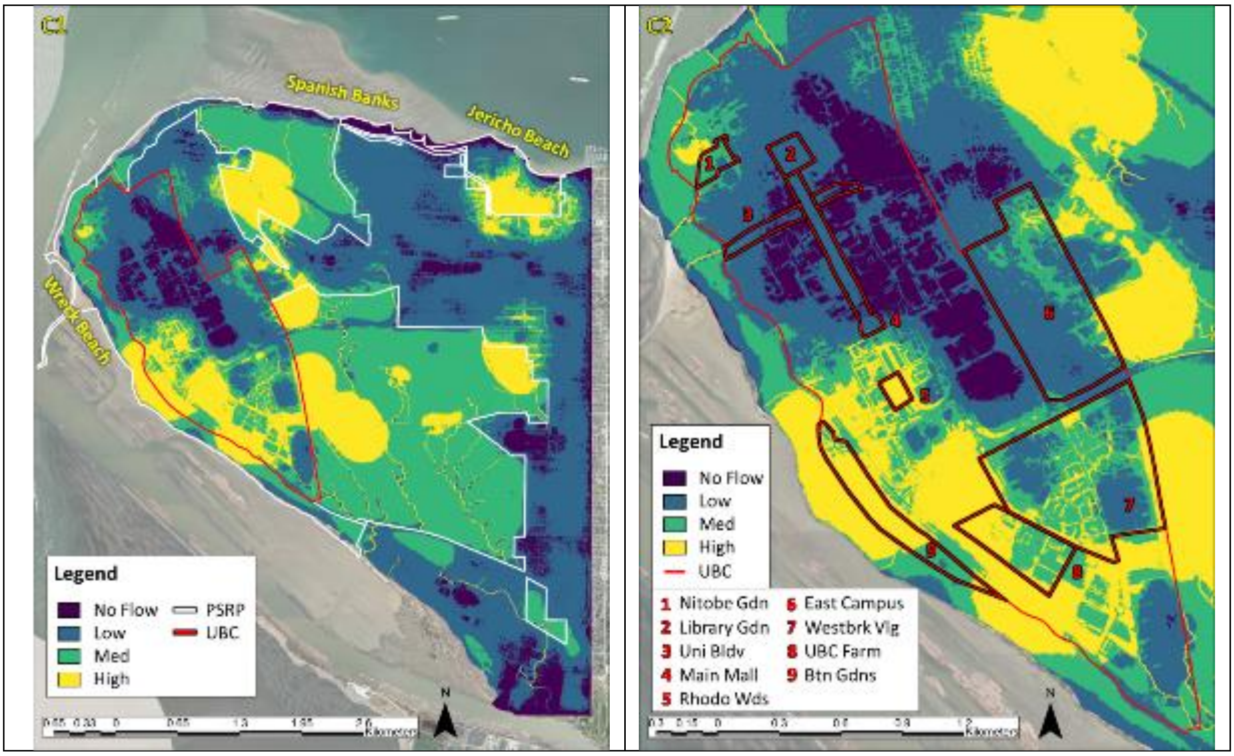


Figure 10: Overall predicted and normalized connectivity derived from adding all connectivity from the 7 modelled species. A1 and A2 represents predicted connectivity and B1 and B2 represents the normalized connectivity. It is observed that most of the predicted connectivity originates from the southeast of Pacific Spirit Regional Park and radiates northwards. Connectivity through UBC is predicted to be low, with areas of medium connectivity in densely green areas such as Botanical Gardens and UBC Farm. In the normalized model, we observe that UBC campus is largely channelized flow, suggesting that the predicted connectivity is higher than the capacity of the landscape. I.e., animals are funnelled to move through specific corridors.

3.2.2 Pacific Tree Frog

A 250m moving window was applied for the Pacific Tree Frog's model, areas of high predicted connectivity are observed near Jericho Beach, riparian areas, and the southern regions of UBC, particularly near to the West Book Village, UBC Farm and Botanical Gardens. High connectivity is also noted to the east of the East Campus area, which decreases towards the Arcadia Residences area, as shown in Figure 11 – C1. Furthermore, connectivity through the UBC transitions from high to medium to low as it progresses from south to the north, as shown in Figure 11 – C2.

In the normalized connectivity model (Figure 11 – D1), flows are seen to be highly channelized within the eastern housing estate, between Jericho Beach and PSRP. Similar Channelized flows are observed within the housing estate located between PSRP and UBC and within UBC itself. Specifically, within UBC, channelize flows are concentrated around the areas labelled 2,3,4,5 in Figure 11 – D2.



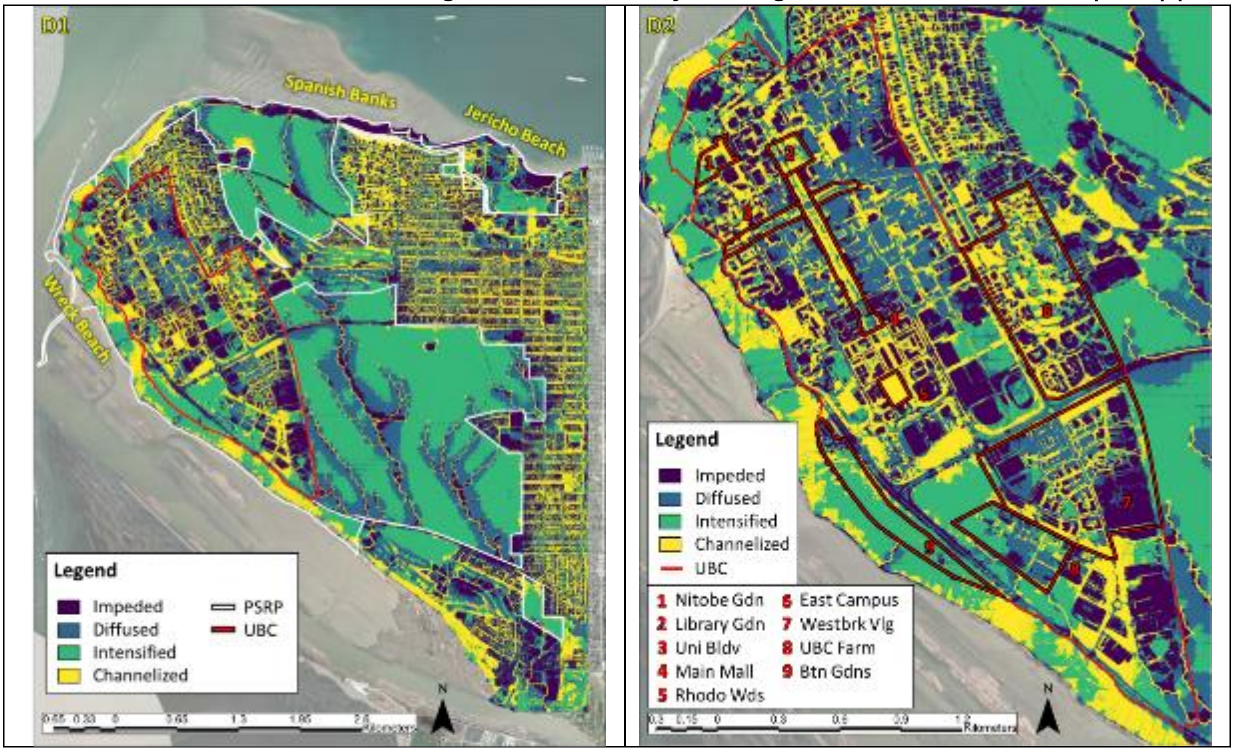


Figure 11: Omniscape model for Pacific Tree Frogs conducted with a moving window of 250m. Predicted flows are seen near to the sources radius outwards and diminishing across the landscape. High flows are predicted to be at Jericho Beach, Western edge of the PSRP and Southern regions of PSRP and UBC Campus in C1 and C2. In the normalized flow, we observe that flows are highly channelized though the landscape between urban structures in general. Within UBC, these flows are highly channelized within points 2,3,4,5.

3.2.3 <u>Salamanders</u>

A moving window of 20m is applied to represent the Salamander's limited movement range. The model predicted high movement throughout most of the green spaces within PSRP and UBC in Figure 12 – E1 and E2. Likewise, the normalized flow shows highly channelized connections through the entire landscape where conifer and deciduous forests are available.

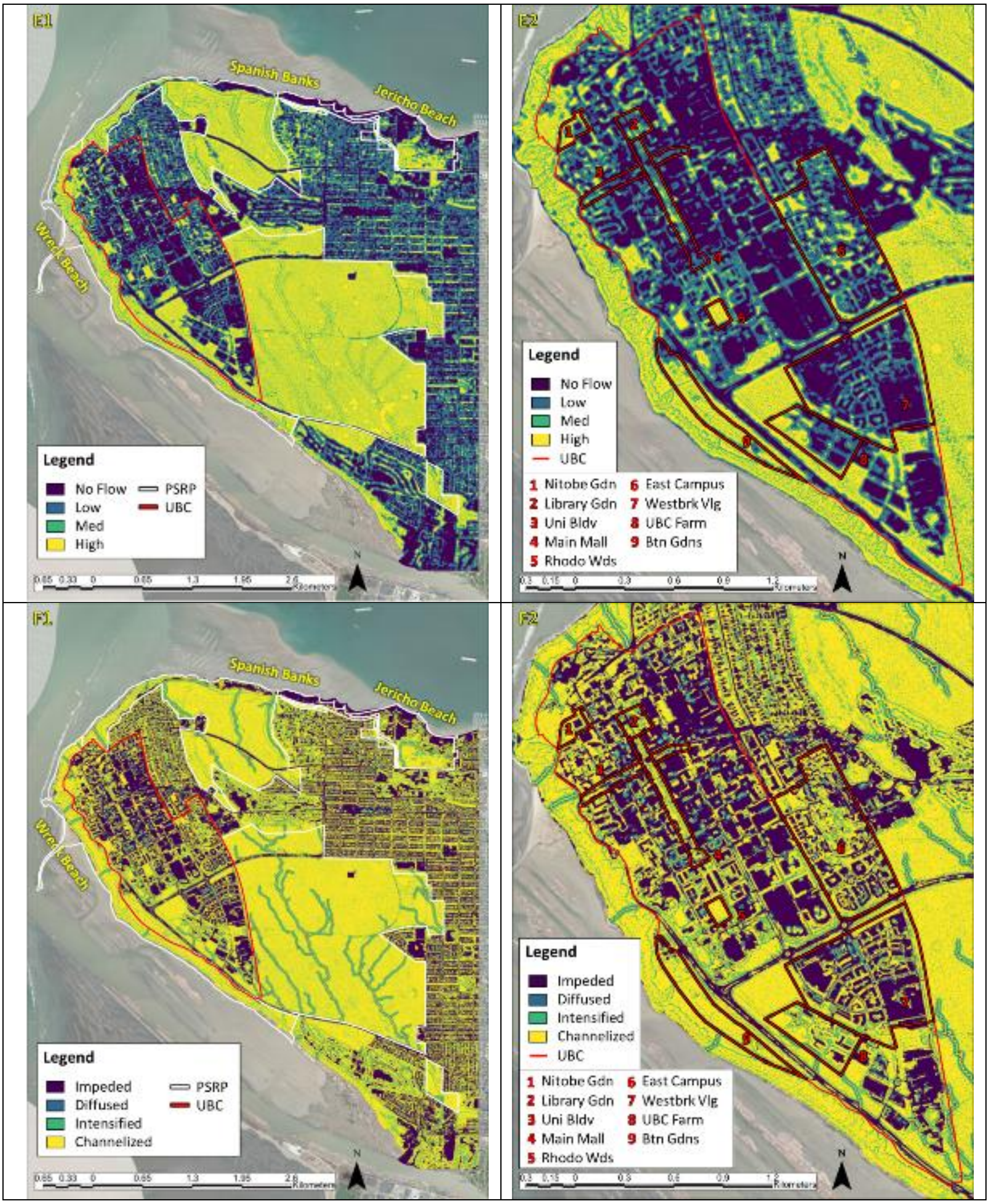
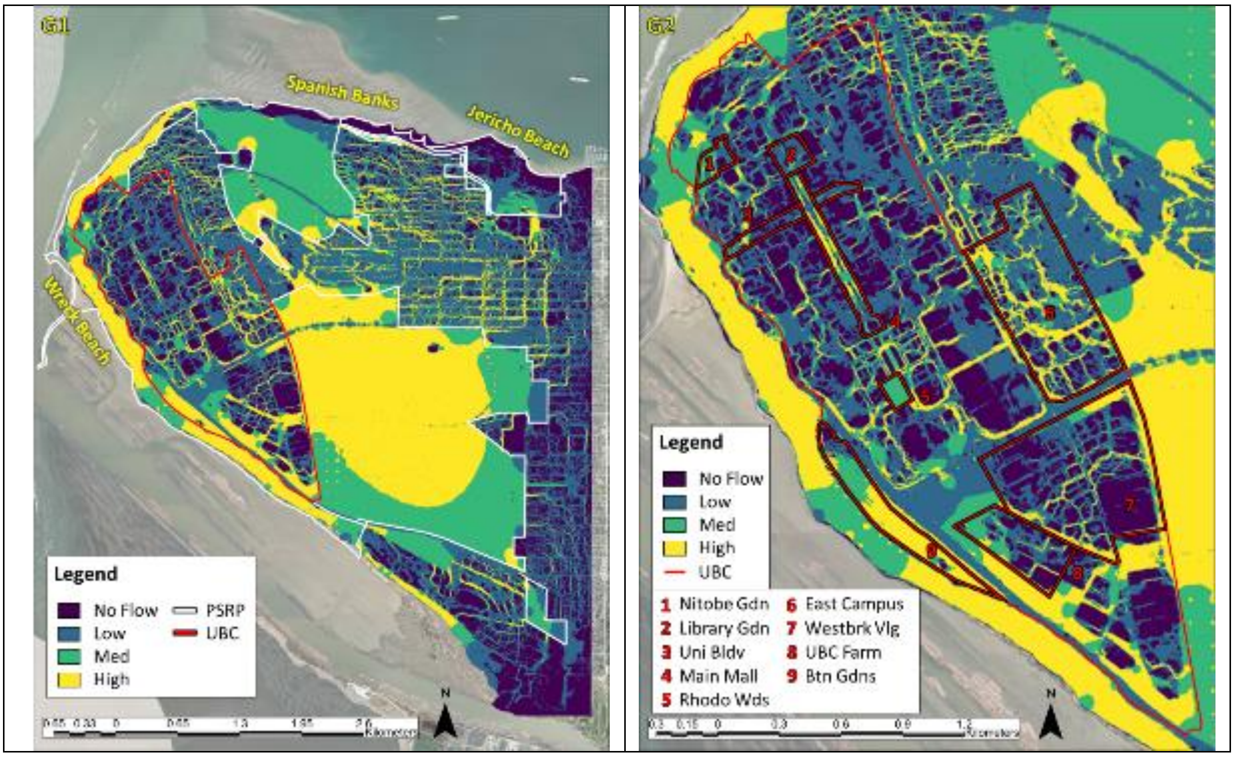


Figure 12: Model of Salamanders, showing high predicted connectivity and channelized flow throughout the landscape where conifers and deciduous forests are present.

3.2.4 Bumblebees

Bumblebees are modelled with a predicted movement range of 3000m. High connectivity is observed at the southeast of PSRP, extending towards the north, west and eastern segments (Figure 13 – G1), moving through landscapes that are interspersed between buildings. Within UBC (Figure 13 – G2), high connectivity is predicted on the south and eastern fringes, with movement percolating through landscapes at Label 5, 6, 7, 8, 9 and concentrating within north-south Main Mall corridor. Low flows over buildings are also observed.

Normalized flows in Figure 13 – K1 shows highly channelized flows between Jericho Beach, the Point Grey housing estate, and the western edge of PSRP. These channelized flows further percolate into UBC campus, between the buildings and within Main Mall in Figure 13 – K2.



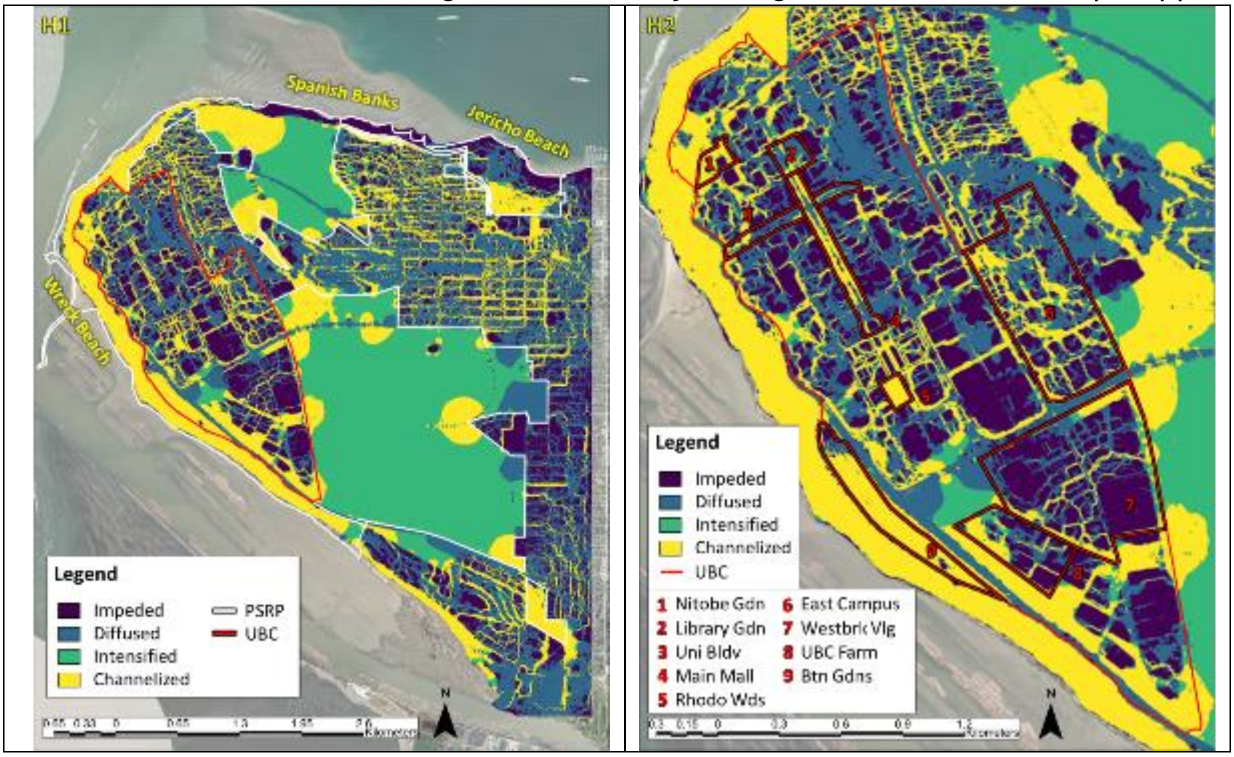


Figure 13: Bumblebees are modelled with a 3000m movement range. Although they can move up to 12000m, 75% of their movements are within a 3000m range. High flows are predicted within the southern areas of PSRP and within corridors of landscape (5,6,7,8,9) within UBC Campus. In the normalized flow diagram, it can be observed that landscapes between urban areas form highly channelize corridors. Landscape within UBC is also form highly channelized flows suggesting their importance in their connectivity.

3.2.5 Killdeer

A model for Killdeer was run with a moving window of 5000m and all resistance set to zero, reflecting the assumption that they are able to fly over obstacles and landscapes. The output for both predicted and normalized connectivity were unexpected. A high predicted flow is observed at the centre of PSRP, radiating outwards and diminishing with distance from PSRP in Figure 14 – I1, I2.

For normalized flows, as shown in Figure 14 – J1, J2, the channelized flows, intensified flow, and diffused flows are largely distributed across large expanses of the landscape.

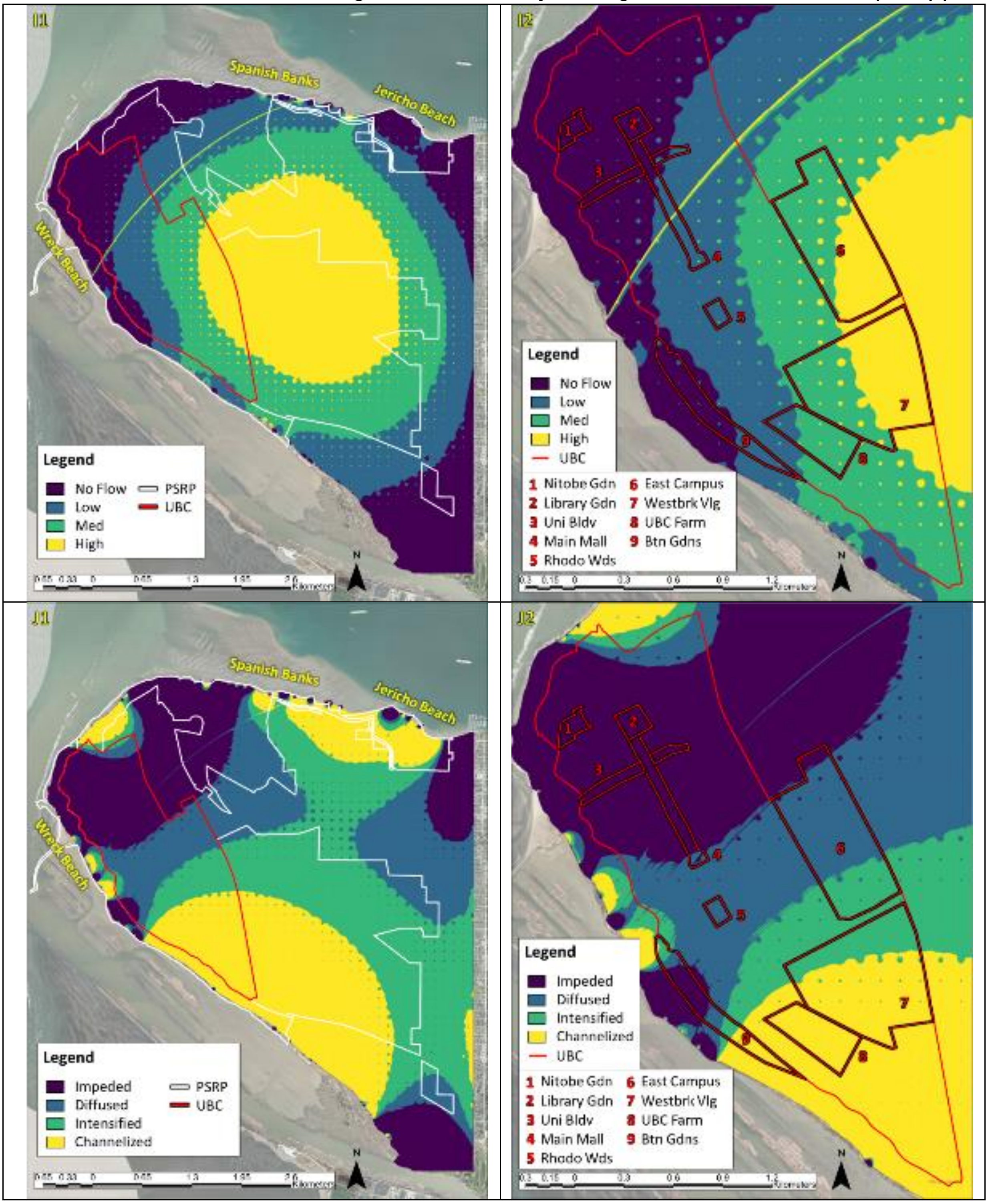


Figure 14: The Killdeer model produced unexpected results, showing a large span and distributed high to low flow across the whole landscape in I1 and I2. Normalised flow produced similarly distributed flows across the landscape.

3.2.6 <u>Banded Tailed Pigeon</u>

Modelled with a moving radius of 10,000m, the Banded Tailed Pigeon showed high predicted flow in the middle and southeastern segment of PSRP. High connectivity extends westward towards UBC Farms and parts of the Botanical Gardens before transitioning to medium connectivity, northwards into the rest of the UBC campus in Figure 15 – K1, K2. High connectivity was also predicted within Main Mall and Wreck Beach, while most of the buildings had no connectivity.

Channelized connectivity is observed between Jericho Beach, the middle of PSRP, throughout the landscape of the entire UBC campus and the Wreck Beach area as seen in Figure 15 – L1, L2.

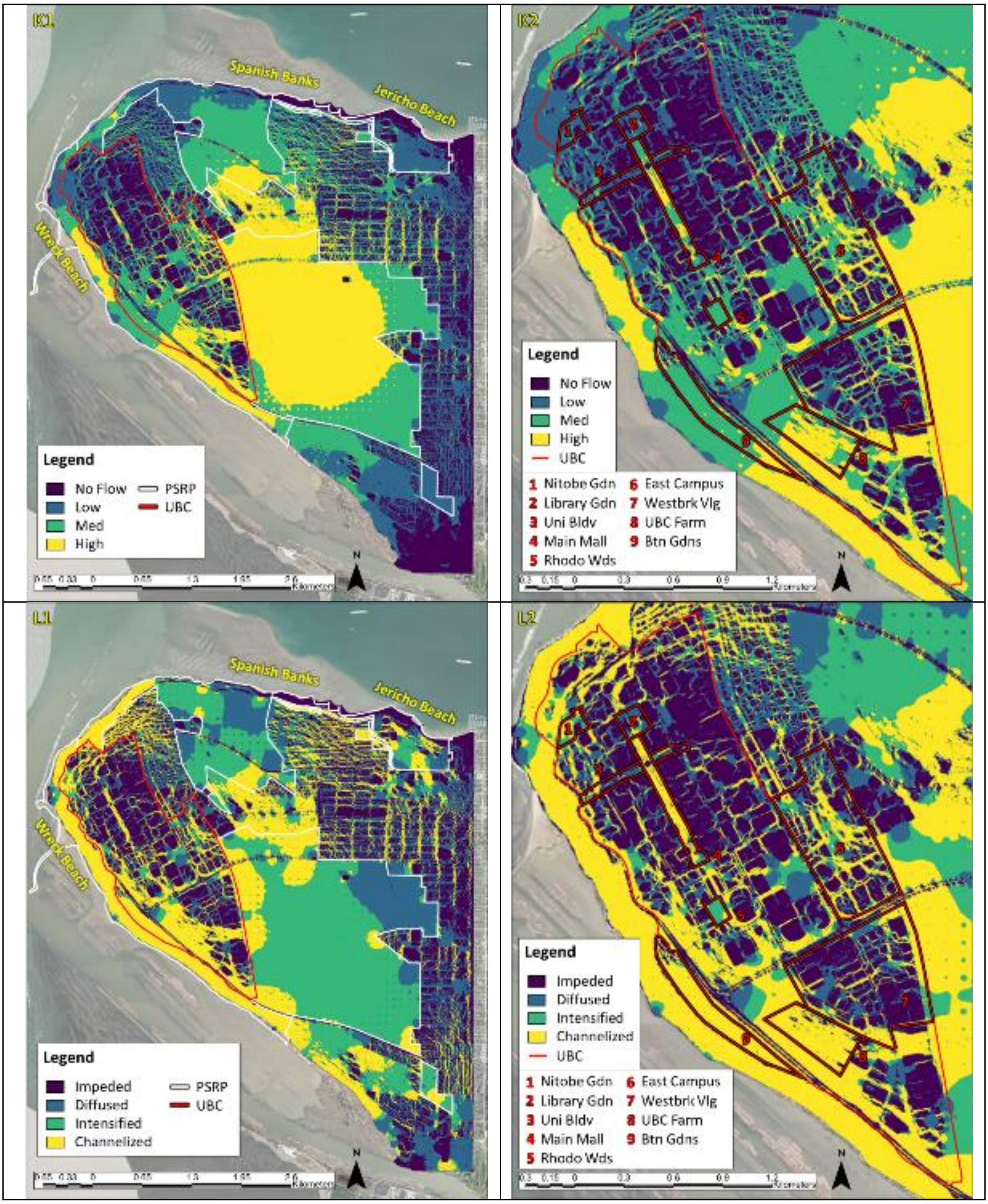


Figure 15: Banded Tailed Pigeons are expected to have high connectivity within the middle of PSRP, UBC Farms and Botanical Gardens. Within UBC they are predicted to move through Main Mall. Channelized flows are expected between Jericho Beach, the middle of PSRP, UBC and Wreck Beach.

3.2.7 Douglas Squirrel

Moving window of 2000m was adopted for the Douglas Squirrel. Similar to other models, areas of high predicted flow are located on the southern side of PSRP, where large patches of coniferous trees are present as shown in Figure 16 – M1. The model also predicts connectivity through the campus, with medium flows where deciduous trees are present as shown in Figure 16 – M2.

Similarly, the normalised flow shows highly channelized mostly within the UBC campus, showing predicted high usage of existing landscape in Figure 16 – N1, N2.

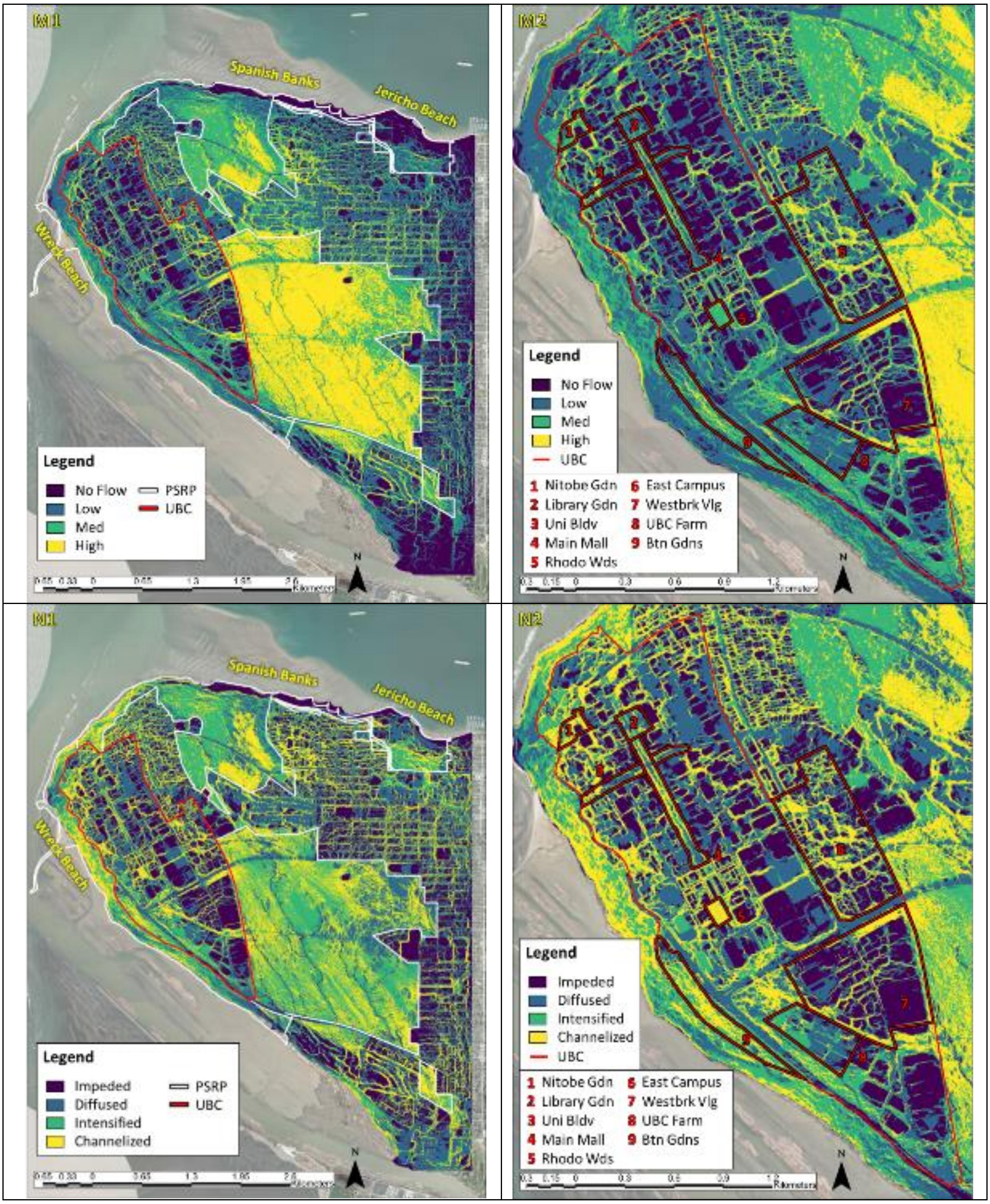
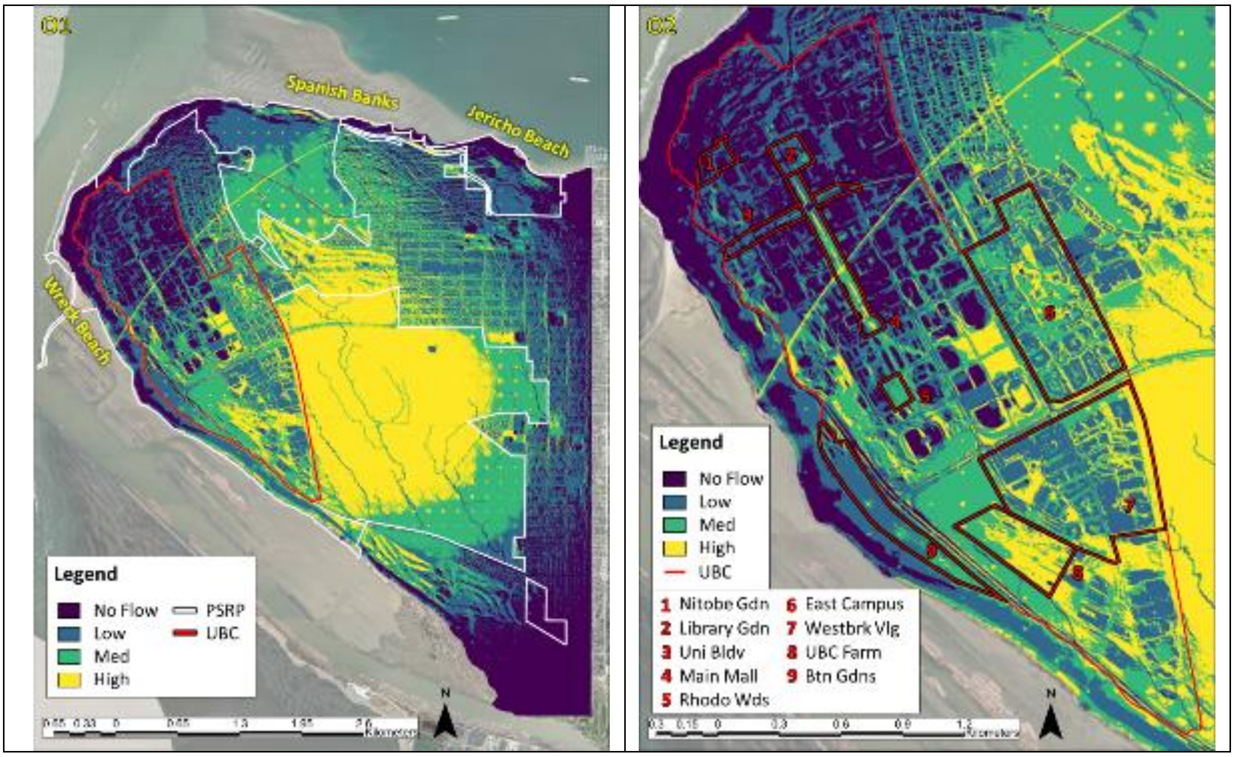


Figure 16: Douglas Squirrels have a specific habitat requirement, exclusively using coniferous trees for nesting. The predicted to mainly move within PSRP and medium/high flow within the UBC campus. In the normalized flow model, the PSRP is observed to have a mix of channelised and intensified connectivity. Within UBC campus, Channelised flow is spread across 2,3,4,5.

3.2.8 Coyote

The Coyote model predicts high connectivity beginning from southern PSRP, extending through the northern side of PSRP and westward through UBC Farms and Main Mall. Predicted movements taper off northwards and southwards of PSRP as shown in Figure 17 – O1, O2.

Normalized flows are channelized within the southwestern side of the PSRP. In UBC campus, channelized flows are observed on the south through main mall to the north of the campus.



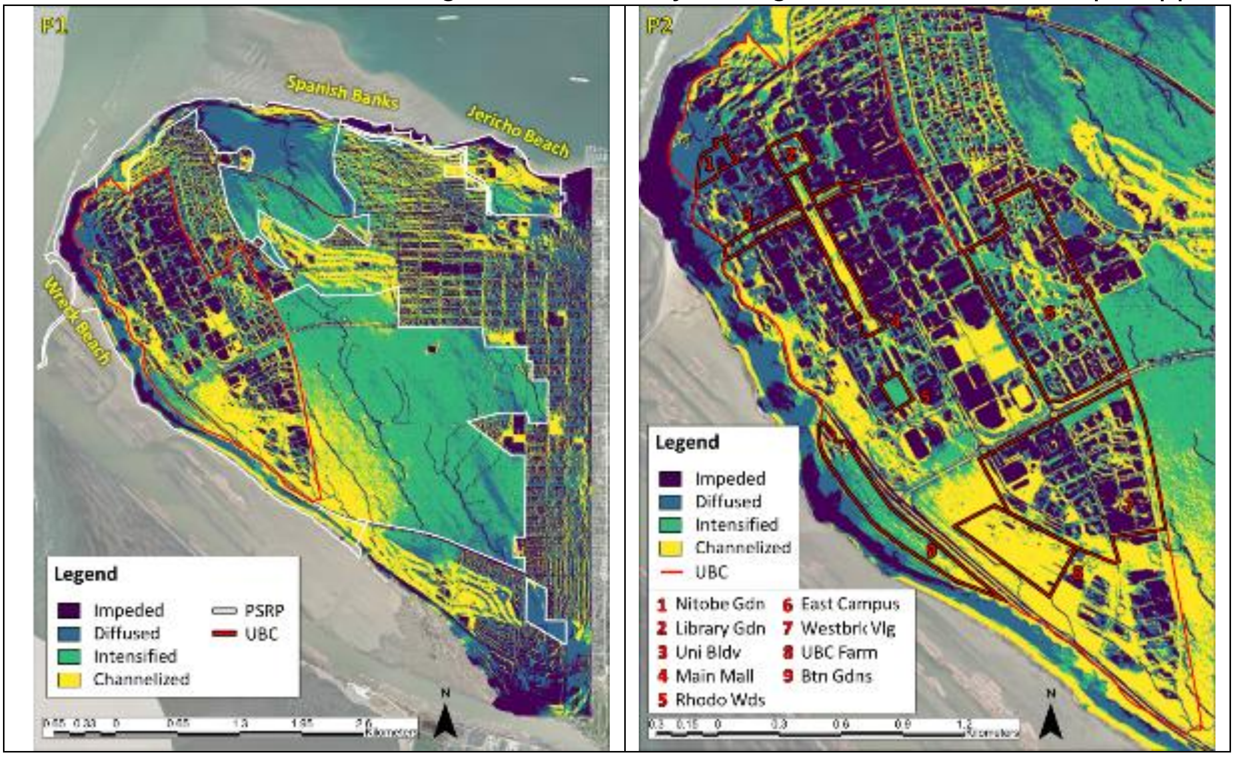


Figure 17: Model of Coyote movements, high flows are within south PSRP with some movement westward within UBC Farms and Main Mall. Normalize flow shows highly channelize flow within the UBC campus.

Discussion

In this study, we explored existing habitats surrounding UBC and UBC's role in facilitating habitat connecting through its urban campus. The results through Omniscape modelling of the seven keystone species allowed us to determine connectivity through the UBC campus and determine critical habits for conservation. The connectivity identified similar areas of importance to two previous studies done for the UBC campus (Mantegna, 2021; Nduna, 2023).

4.1 Overall observations

The Overall Predicted Connectivity aligns with the general observations of the other species. High flows within streams and specific spots are likely a result of the Amphibian's models, which placed a significantly high value on the streams and observations as sources. Excluding Amphibians, other species were observed to have similar predicted connectivity models, with generally high flows within the southern to northwestern part of Pacific Spirit Regional Park. Within UBC, the southern campus areas are predicted with high flows (Figure 10) including UBC Farm, UBC Botanical Gardens and parts of Wesbrook and East Campus. The flows diminishes as it progresses towards the northern part of the UBC campus, with only Main Mall and University Boulevard recording high to medium flows. This pattern is likely due to the increasing distance from the main sources and increasing resistance to travel through the landscape though more urbanized areas.

Based on the predicted flow, we can conclude that PSRP remains the largest habitat source for all the seven species modelled. Within UBC, potential habitats include UBC Farm, Botanical Gardens and the forested patches at the south which can be seen in Figure 10.

Connectivity within existing landscape of the UBC campus are all highly channelized, which underscores the need for conservation efforts and improvements to enhance the resiliency of the landscape. This is particularly true for Main Mall, a highly channelized corridor connecting habitats in the southern UBC to the northern part of PSRP and Wreck Beach.

4.2 Individual Species Model and Potential Interventions

4.2.1 Pacific Tree Frog

The absence of the Pacific Tree Frog from the central area of the UBC campus is likely attributed to their limited movement range and a strong preference for riparian habitats. This hypothesis is supported by the proximity of their observations and high predicted connectivity near riparian and waterbodies shown in Figure 6 and Figure 7. Interestingly, two isolated high connectivity areas were identified at Jericho Beach and the northwestern corner of Wreck Beach, both sites with observational sightings of tree frogs. While the means of their appearance at these locations or originating source remains uncertain, the presence of isolated patches suggests that some frogs might have travelled through low connectivity areas to discover and settle in new, suitable habitats. This indicates that the areas of low connectivity could hold potential in establishing connectivity.

Highly channelized connectivity within Urban Areas, including housing estates and the UBC campus could be enhanced by creating additional waterbodies or riparian areas within 250m radius of known sources. These enhancements would serve as stepping stones and refuges to encourage frog movement (Rannap et al., 2009). The selection of locations for new enhancements should be carefully studied with the aim of creating a diffused normalized flow that builds network resiliency.

4.2.2 Salamanders
The high predicted movement of the Salamanders shown in Figure 12 – E1, E2 was unexpected given their small travel range of 20m (Fang et al., n.d.; Ovaska', 2024) and the model's assignment of 100% resistance to roads/buildings. In reality, we would expect the Salamanders to stay within a landscape which are bounded by roads or pavements unless connections such as culverts or under-road streams exists to facilitate their crossing (Matos et al., 2017; Patrick et al., 2010). Several factors could explain the unexpected predictions: Firstly, road widths might be less than 20m, allowing the Omniscape moving window to consider source pixels from across the road for modelling. Secondly, plantings in the middle of the roads could fall within the 20m moving window, enabling the model to use these as stepping stones to cross the obstruction. Thirdly, the high source weightage assigned to Deciduous, Coniferous, and Riparian areas (Table 5) might have led the model to predict extremely high connectivity through any available green landscapes. Fourth, the classified landscape in Figure 9 includes tree crowns, the wide coverage from the top may not accurately reflect available habitats for Salamanders, who primarily move through leaf litter and moist soil.

It is suggested for future models for salamanders to adopt a smaller moving window size to realistically reflect the restriction of known obstructions such as roads. In addition, ground-level terrestrial data such as soil, shrubs should be included to improve the accuracy of landscape availability.

4.2.3 Bumblebees
The observed low predicted flows over buildings, attributed to bee's large movement radius and their presumed ability to fly over obstacles contrasts with the high flows detected between built environments. This suggests that landscaping plays a key role in encouraging movements of bees through the urban fabric. When analysed in conjunction with the classified landscape in Figure 9, it is evident that areas of higher connectivity correspond to more densely spaced landscapes, such as those within the residential areas in East Campus and the landscapes in Figure 13 – G2, Labels 5, 6, 7, 8, 9. Conversely, further spaced landscapes in the other parts of UBC correspond to lower flows suggesting that landscape spacing places an important role in influencing connectivity. It would be interesting if building heights could be included in future studies to model resistance of different building heights.

4.2.4 Killdeer
Similar to the model for salamanders, the Killdeer model produced an unexpected result. Both the predicted and normalized connectivity did not exhibit any discernible patterns. It was anticipated that Killdeers would avoid forests and show high connectivity along roads/buildings and grass class, as they are coastal birds that prefer gravel roads and open grass for nesting (*Killdeer_BC_Data_Centre*, n.d.). This discrepancy may stem from setting all resistances to zero and using a 5000m moving window, which likely caused the model to overly represent the source pixels.

Interestingly, the Banded-Tailed Pigeon's model showed the expected predicted connectivity, despite utilizing a larger moving window of 10000m. The only notable difference being an assignment of resistance values to one class. This suggests that the model requires at least one resistance parameter to accurately predict connectivity.

4.2.5 Banded-Tailed Pigeon

The Banded-Tailed Pigeon model performed as anticipated, largely avoiding urban areas while extensively utilizing trees as corridors, with highly channelized flows. Enhancing connectivity could involve planting trees in closer proximity to establish continuous canopy cover (Fernández-Juricic, 2000). Additionally, introduction of fruiting trees and shrubs would expand habitat areas and provide refuge for the species.

4.2.6 Douglas's Squirrel

The large connectivity within the south side of the PSRP where large number of coniferous trees are found is generally aligned with known behaviour of Douglas Squirrels (Carey, 1991). Connectivity can be enhanced through the introduction of vertical and rooftop gardens on buildings, or the planting of trees with overlapping crowns across roads. Additionally, planting coniferous tree stands or adopting a mixed-forest street planting approach could be explored. This would allow creation of more nesting habitats whilst leveraging on the extensive crown spreads of deciduous trees for arboreal connectivity.

4.2.7 Coyote

Interestingly, the observations of the coyote differ from the recorded observations, which are predominantly clustered to the western side of UBC. This could be attributed to the large movement range (moving window) specified for the model and assignment of a value 1 for source weight due to the inability to define a meaningful quantile range. This produced a more balanced source weightage and less skewed results. One interpretation we could make that the coyotes could still mainly prefer the south of PSRP, but commonly travel to urban areas to forage for food. The increased sightings could be a function of happenstance observations or multiple records by similar users, further described in Section 5.2.2. Given the coyote's adaptability to urban environments, the enhancements proposed for other species would likely benefit the coyote as well.

4.3 Agreement of critical habitats with past studies

The results in Section 3.2 were compared with two previous studies conducted on habitat and species connectivity in UBC: (Mantegna, 2021) and (Nduna, 2023). Mantegna applied a network analysis approach to denote landscape resiliency based on their modularity and linkages to other nodes. Conversely, Nduna employed Graph Theory to study landscape connectivity of two distinct species – the urban-adapted coyote and the forest-dwelling brown creeper.

The high predicted connectivity identified in our Omniscape model (Figure 10 A2-Labels 1 through 9) demonstrates substantial overlap with important nodes highlighted in Mantegna's study. This suggests a high correlation between connectivity and landscape resilience, suggesting certain areas play a critical role in maintaining ecological networks.

Similarly, our results on the coyotes (Figure 17-O2) and banded-tailed pigeon (Figure 15-K2) connectivity closely aligns with importance landscape pssatches identified in Nduna's study.

The consensus among these three studies highlights importance to conserve all the identified greenery in Figure 10 A2-Labels 1 through 9. The overlay the three studies is shown in Figure 18

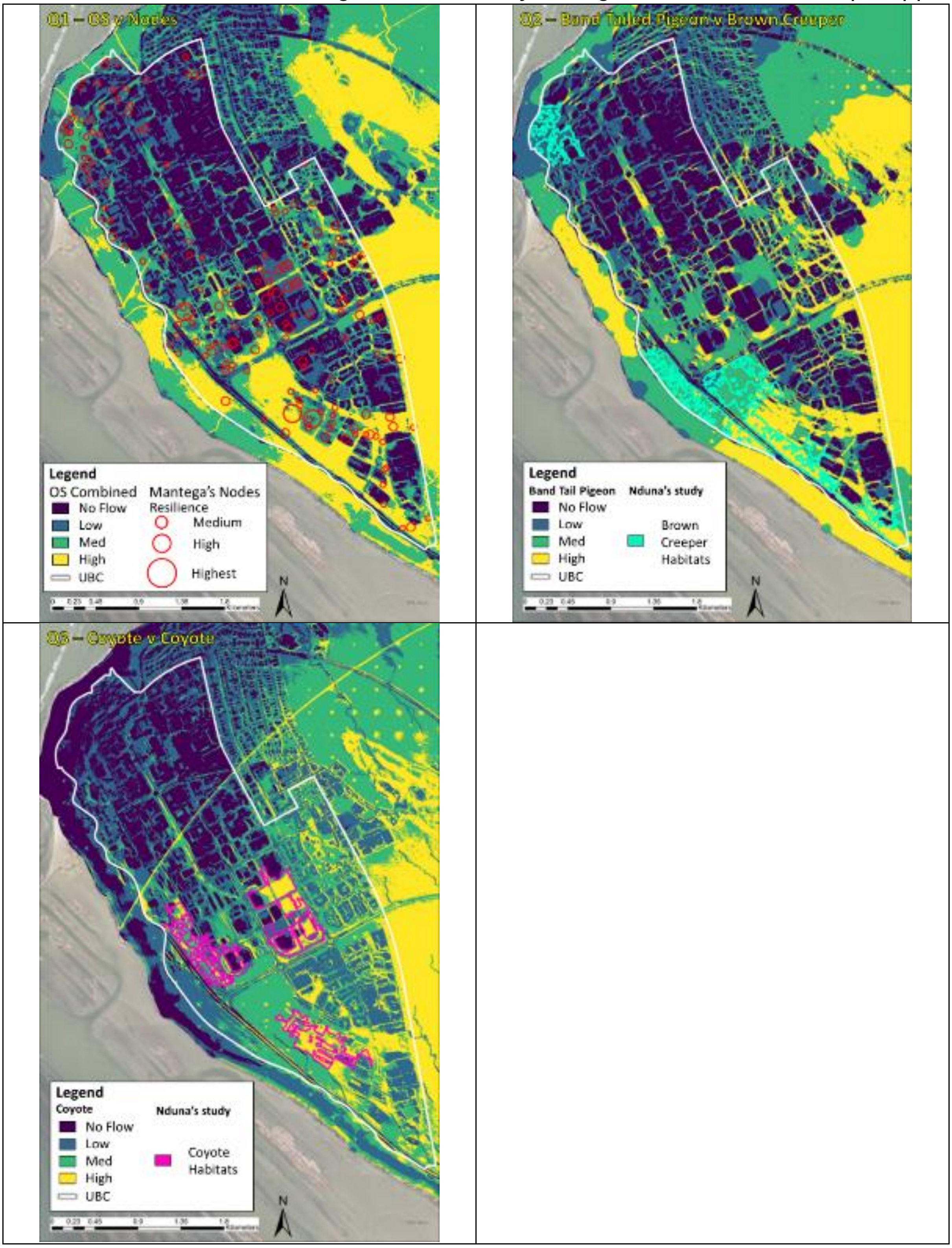


Figure 18: Overlap of Omniscape predict flow, Network Analysis Model and Graph Theory modelling highlights the critical landscapes within UBC which had significant value as habitat and nodes for ecological connectivity. Q1 compares Omniscape combined connectivity and (Mantegna, 2021) node resiliency, Q2 compares Band Tailed Pigeon connectivity and (Nduna, 2023) Brown Creeper habitats and Q3 compares Coyote connectivity and (Nduna, 2023) Coyote habitats.

Limitations

5.1 Subjectivity of model parameters

Deciding resistance and source values for individual species was a highly subjective exercise. Existing literature provided description on species preferred habitats and range but avoided quantifying a value. This meant that clients and subject experts had to sit down to fix an arbitrary value for these. For example, in literature, Bumblebees are known to have a maximum travel range of 12km, though 75% for these activities happened within 3km of the nest. Though some experts argued that the range was likely to be within a few hundred meters.

Likewise, Bumblebees are modelled with a grass resistance value of 50%, and 0% for both Forest types (Table 5). Though some stakeholders felt that it was harder for them to fly through forests as opposed to open grass fields, despite higher potential of predation.

Species behaviours are also not captured in this modelling, such as Coyotes potential to use urban environments as sources due to potential to access richer food sources (human refuse). Bumblebees have also shown to use linear landscapes, such as pathways, roads, hedges to orientate and optimize travelling(Brebner et al., 2021; Osborne et al., 2008).

5.2 Dataset

5.2.1 Nature of satellite imagery

The limited range of spectral bands in the Planet SkySat imagery outlined in Table 1, constrained the variety of classification classes that could be derived. For example, the availability of Short-Wave Infrared (SWIR) spectral imagery would enable the detection of ponds and beaches. The amalgamation of roads and buildings into a single classification also restricted the finer differentiation which would improve connectivity modelling. For example, a bee could easily cross a road, but not a building.

Inclusion of additional landscape classes such as ponds, shrubs, gravel, roads and buildings would improve the model's accuracy and might increase the prediction of species within UBC. For example, the inclusion of shrubs would increase the source habitats available for modelling, mimicking increased foraging options, hiding spaces when moving between habitats and potential habitats.

Separating the roads, buildings and gravel into different classifications would allow us to parameterize gravel, sand and grass as sources and roads and buildings as potential barriers. This will allow us to correct the model for Killdeer, placing gravel, sand and grass as potential habitats and varying building heights as obstructions.

In addition, other physical barriers such as fences should be considered. For example, fences around the Botanical Gardens will significantly restrict the connectivity of terrestrial animals such as Coyotes while allowing still allowing birds to pass through.

5.2.2 Nature of observation data

The data for fauna observations consisted mainly of research grade Citizen Science records supplemented by some research papers. This presented inherent biases, as the data quality is influenced by observer's expertise, the frequency of Citizen Science user visits (areas of higher footfall naturally yields more observations), and the accessibility of observation sites along paths or trails. This bias is notably evident in the Pacific Spirit Regional Park, where observations are clustered around official trails and observations beyond the trails are scarce. Property boundaries such as fenced UBC Botanical Gardens or private properties, also limit data collection through Citizen Science.

Given the study's limited duration, comprehensive site verification to validate both the base datasets and the model predictions were not carried out. Accuracy of the models can be improved by conducting site visits to verify landscape classifications such as streams, riparian areas. In addition, proper site transects can also be carried out to verify the model's prediction accuracy for individual species.

5.2.3 Model computational requirements

The project aimed to use 0.5m spatial resolution to capture fine details, such as pavements and grass strips, essential for modelling localize connectivity. Moving window sizes were set to represent movement ranges for each species.

However, this presented an extremely heavy demand on computation. For example, a moving window of 250m for the Pacific Tree Frog resulted in a modelling of 785500 pixels per moving window simulation, requiring 25 GB of Random-Access Memory (RAM) using 8 processor threads. Resulting in an initial projected completion date of 336 days for 145 million pixels. Increasing the moving window to 3,000m increased the RAM requirement to 43435 GB, repeatedly causing the model to fail with an "out of memory" error.

Computational requirements were managed by increasing the "block size" and also resampling of the source and resistance rasters to 3 or 5m. A block size of 3 aggregated 9 pixels by averaging their values, effectively reduced processed pixels by a third (B. McRae et al., 2016). Although other studies adopted a 1:10 ratio for balancing results and computation needs, (Belote et al., 2022), our studies could only adopt a ratio of between 1:2.5 to 1:153 due to computation limitations. This compromise resulted in visible artifacts in the model's output, where a centralized pixel exhibited disproportionately high flow strength due to the aggregation of source values over a large area. An example can be seen in the top right corner of Figure 17-O2.

Despite less-than-optimal modelling parameters, the models largely produced expected results, likely due to the multiple close overlaps of the moving windows and the additive nature of the cumulative flows. A more in-depth assessment is needed to verify the accuracy of the model. Successful runs are included in the Appendix A for future reference.

It is recommended for an enterprise level workstation with high RAM be used for future modelling. A lower resolution satellite imagery could also be used to manage the number of pixels to process.

Recommendations

The Omniscape results in Figure 10 highlights the overall connectivity for the seven keystone species modelled. Generally, the goal is to leverage these models to guide intensification of tree and landscaping, thereby increasing available habitats within the UBC urban campus. This approach aims to increase the number of habitat sources and reduce resistance of moving through urban landscapes, especially for the less mobile fauna.

6.1 Broad-level habitat conservation and enhancement

6.1.1 Conserving Existing Habitats

The results show that all existing greenery is critical for connectivity. A comparison with two previously completed studies (Figure 18) has highlighted the key areas of conservation, which include the forests within the southern campus (including UBC Farms and Botanical Gardens), Main Mall, east campus and a patch of forest at Nitobe Gardens. It should be noted that although Main Mall was not predicted to have the highest connectivity, it consistently appears as the main connection between the southern and northern parts of the UBC campus, making it a critical connectivity to be safeguarded and enhanced.

6.1.2 Increasing Connectivity and Carrying Capacity through Structured Planting

Habitat enhancement can be achieved by adopting a multi-tiered tree planting to mimic natural forest structures, introducing vertical greenery and or roof top greenery (Bierwagen, 2007; Fernández-Juricic, 2000; Öckinger et al., 2012). Initiatives should start at areas with low connectivity, with the goal of connecting them to areas with high connectivity such as UBC Farm, Botanical Gardens, south and eastern campus. These initiatives would increase both connectivity between landscape patches and the carrying capacity of the landscape, thus increasing connectivity resilience.

New ecological corridors can also be created through these greenery initiatives. The current connectivity map shows a lack of an east to west connection, and one potential corridor can be established along University Boulevard.

6.1.3 Integrating Green Infrastructure into Urban Planning

In the longer term, connectivity and carrying capacity can be further enhanced by integrating greenery into built infrastructure. Integrating green roofs and living walls can provide new habitats and stepping stones, reducing the resistance to move across buildings.

6.2 Species Specific Recommendations

Each model (Figure 11 to Figure 17) highlights distinct requirements of each species regarding habitats, existing movement patterns within and beyond UBC, and the degree of channelized connectivity. General recommendations are summarized in the section below; however, it should be noted that detailed implementation remains a multi-factor decision and needs to consider urban planning considerations aspects, such as development of educational facilities, social enhancement goals and funding availability. Human-wildlife interactions and exotic fauna management would also require further consideration, as generalist and exotic faunas are usually more successful than native counterparts.

6.2.1 Pacific Tree Frogs

Water bodies and wetlands can be strategically implemented within the areas of low connectivity. These should be located within 250m of known observations or areas of medium to high connectivity with minimal amount of road crossings, to ensure higher success rates.

6.2.2 Salamanders

Existing infrastructure can be modified to include wildlife-friendly underpasses or culverts at key road crossings to enable safe crossing salamanders. These should be designed to accommodate their small movement ranges (20m) and their need to remain within moist, vegetated undergrowth.

6.2.3 Bumblebees

Flowering trees, shrubs and ground cover can be planted throughout the campus to increase flower density. This will provide larger food source and facilitate movement across urban areas.

6.2.4 Douglas Squirrel

Movement for the squirrels can be improved by enhancing arboreal connectivity. Trees should be planted with overlapping crowns, over roads and between buildings, to allow squirrels to move above ground and avoid ground-level hazards.

6.2.5 Killdeer

Open grassy areas and gravel paths in the less forested areas of the campus should be retained to provide suitable nesting sites for the Killdeer. Gravel areas can also be installed on building roof tops which would provide Killdeers with a safe and undisturbed nesting site.

6.2.6 Banded-Tailed Pigeon

Fruit-bearing trees and shrubs can be planted to create canopy corridors that facilitate movement and foraging. As a forest species, a multi-tiered planting (section 6.1.2) would be more effective in promoting connectivity.

6.2.7 Coyote

As a generalist, the coyote will naturally benefit from all the enhancements mentioned above, potentially leading to increased human-wildlife conflict. A comprehensive urban wildlife management strategy, such as managing urban food source, installing coyote barriers and implementing hazing may need to be adopted to redirect the coyote towards the landscape at the fringe of the UBC campus.

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Appendices

Appendix A

Ominscape modelling runs, spatial resolution, moving windows and time taken for processing.

Omniscape Runs	Spatial Resolution	Number of pixels in landscape after resampling	Moving Window size (m)	Moving Window Size (pixels)	Number of pixels resistance per moving window	Block Size	Block Size in Length	Moving window to block ratio	Number of pixels source per moving window	Total number of pixels processed	Time in hrs
Banded Pigeon R2	5	5,811,853	10,000	2,000	12,566,371	45	225	44	2,870	36,074,362,020	5
Banded Pigeon R3	5	5,811,853	10,000	2,000	12,566,371	11	55	182	48,032	605,893,031,544	35
Banded Pigeon R4	5	5,811,853	10,000	2,000	12,566,371	21	105	95	13,179	165,783,437,780	12
Bees R3	10	1,452,963	10,000	300	3,141,593	3	30	333	161,440	533,242,873,451	6
Bees R5	3	16,144,037	3,000	1,000	3,141,593	37	111	27	11,793	37,186,536,032	12
Pacific Tree frog R1	0.5	145,296,333	63	125	49,087	3	2	42	16,144,037	261,422,399,220,470	144
Pacific Tree frog R9	0.5	145,296,333	250	500	785,398	111	56	5	11,793	9,400,932,650	24
Douglas Squrriel R1	1	145,296,333	2,000	2,000	12,566,371	21	21	95	329,470	4,248,794,496,543	5,304
Douglas Squrriel R2	3	16,144,037	2,000	666	1,396,263	21	63	32	36,608	52,454,253,044	30
Killdeer R1	0.5	145,296,333	5,000	10,000	314,159,265	111	56	90	11,793	3,704,886,182,350	Failed
Killdeer R2	3	145,296,333	5,000	1,667	8,726,646	21	63	79	329,470	2,983,719,964,971	65
Killdeer R3	3	145,296,333	5,000	1,667	8,726,646	31	93	54	151,193	1,342,265,835,869	50
Coyote R1	3	16,144,037	5,000	1,667	8,726,646	41	123	41	9,604	83,901,454,302	50
Coyote R2	3	16,144,037	5,000	1,667	8,726,646	51	153	33	6,207	54,203,577,027	24
Salamander R1	0.5	145,296,333	20	40	5,027	1	1	40	145,296,333	21,111,754,722,274,600	312
Salamander R2	0.5	145,296,333	20	40	5,027	5	3	8	5,811,853	33,806,852,574,305	50

Final runs that were used in report