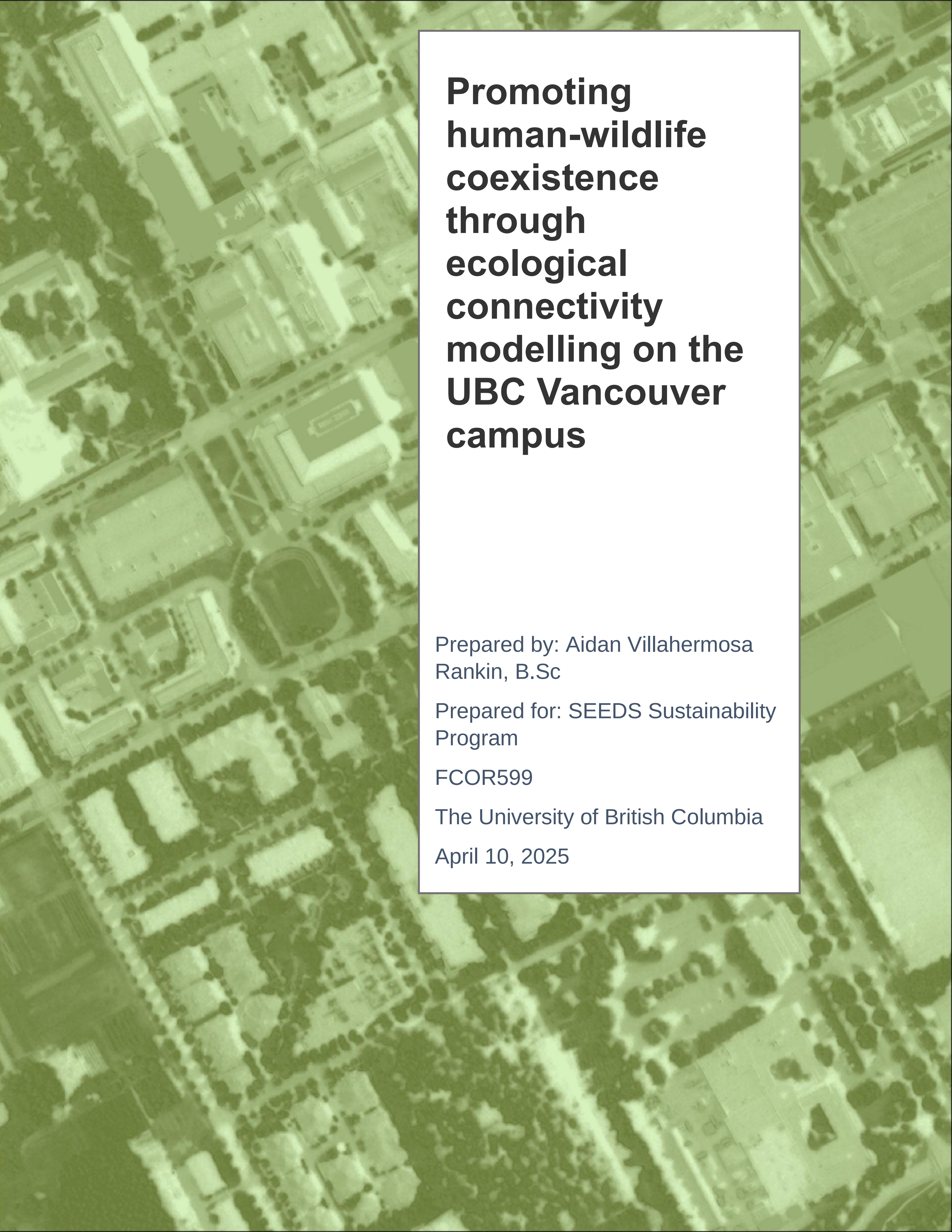

Promoting human-wildlife coexistence through ecological connectivity modelling on the UBC Vancouver campus

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The UBC Vancouver campus is situated within the traditional, ancestral, and unceded territory of the xʷməθkʷəy̓əm (Musqueam). We acknowledge the culture, history, and traditions of the Musqueam and other Indigenous Peoples who have stewarded this land and its forests for millennia.

Executive summary

Urban landscape networks of connected habitat nodes are expanding and play an important role in shaping the biosphere. Within these networks, humans and wildlife coexist, living and moving in close proximity with the potential for conflict. Remotely sensed data provides accurate knowledge of landscape cover. Circuit-based ecological connectivity models can simulate the movement of wildlife across complex urban landscapes. The resistance surfaces needed to perform this modelling were derived using random forest machine learning land cover classification on combined Planet SkySat multispectral satellite imagery and LiDAR-derived digital surface model datasets with 78.2% overall accuracy. By comparing movement models for wildlife species and humans, sites of overlapping movement were identified primarily along roads and between forested patches in the south of campus. Areas of particular interest were located at intersections where vehicle and pedestrian traffic is high, and at active construction sites both near the Museum of Anthropology and in Wesbrook Village. These findings are consistent with previous projects studying ecological connectivity on campus. Recommendations involve monitoring construction projects, roads, and neighbourhoods. These results support Campus Vision 2050 initiatives to increase green space to improve ecological connectivity in the centre of campus, design protected connectivity corridors, and discourage unnecessary single-passenger vehicle traffic. Future research may incorporate object-based classification, or consider timing in human and animal movement patterns.

Tags: **coexistence of species, campus planning, land cover, corridors (ecology), urban ecological design, biodiversity conservation**

Contents

A cyborg world might be about lived social and bodily realities in which people are not afraid of their joint kinship with animals and machines, not afraid of permanently partial identities and contradictory standpoints.

– Donna Haraway

The map does not reproduce an unconscious closed in upon itself; it constructs the unconscious. It fosters connections between fields, the removal of blockages on bodies without organs, the maximum opening of bodies without organs onto a plane of consistency. It is itself a part of the rhizome. The map is open and connectable in all of its dimensions; it is detachable, reversible, susceptible to constant modification. It can be torn, reversed, adapted to any kind of mounting, reworked by an individual, group, or social formation.

– Gilles Deleuze, Félix Guattari

Introduction

Urban areas play a significant role in shaping the biosphere (Elmqvist et al., 2019). Urban landscapes are fragmented networks of nodes that serve as suitable wildlife habitat, isolated from each other but potentially connected by corridors. Fragmentation of these nodes leads to habitat loss and has consistent negative effects on biodiversity (Fahrig, 2003). Within fragmented urban landscapes, humans and wildlife living in close proximity can lead to conflict such as direct aggression and injury, nuisance and property damage, and disease (Soulsbury and White, 2014). The University of British Columbia (UBC) Vancouver campus, located on the Point Grey Peninsula on the traditional, ancestral, and unceded territory of the Musqueam, is an example of an urban environment where wildlife such as birds, amphibians, and mammals are in close proximity to humans. Understanding the composition of the campus landscape through the use of broad-scale remotely sensed data and modelling movement across it can identify sites of overlap in human and wildlife movement patterns. Promoting coexistence and minimizing conflict for the good of both human and wildlife populations is an important goal of urban ecology and of the University.

Understanding how humans and animals move across campus first requires understanding the land cover structure of the complex urban landscape. Remotely sensed data is well-suited for use in land cover classification, and a combination of multispectral satellite imagery and light detection and ranging (LiDAR) data provides more accurate land cover classes than using either alone (Jin & Mountrakis, 2022). Land-use and land cover classification relies on current, accurate, and reliable sources of data, and remotely sensed data is available at the necessary high spatial and temporal scales (Gudmann et al., 2020). LiDAR data in particular allows for fine-scale analysis needed for analyzing urban landscapes (Yan et al., 2015). LiDAR derived products like canopy height models can be incorporated into classification models to improve training and identification (Hemingway and Opalach, 2024).

Circuit-based connectivity modelling has proven effective in modelling animal movement, and circuit-based models of connectivity in novel landscapes have been empirically verified (McClure et al., 2016). This type of modelling improves over alternative ecological connectivity models like least-cost path approaches by generating a continuous metric of connectivity for the entire study area and by incorporating multiple pathways rather than one best path from source to destination (McRae et al., 2008). This project develops on prior research into ecological connectivity on campus carried out through the SEEDS Sustainability Program. A 2023 study by Nduna examined connectivity using coyotes and brown creepers as model species. This study used a combination of Metro Vancouver land cover data and UBC green space and UBC green space and building outlines as input for connectivity modelling (Nduna, 2023). Patches and corridors were identified, though the study recognized the limitations of not incorporating human-built features like roads and other human disturbances into the connectivity model (Nduna, 2023). Goh (2024) carried out a more thorough ecological connectivity modelling project, modelling omnidirectional circuit-based connectivity in Omniscape. This project fill gaps related to human presence and movement, analyzing where wildlife and humans are frequently moving, where these paths and corridors overlap, and where there is potential for conflict.

Study area summary

Figure 1. UBC campus study site location within Vancouver, and within British Columbia. Base satellite imagery from Esri.

The study site of this project is the University of British Columbia's Vancouver campus, located on the West Point Grey peninsula in British Columbia, Canada. The campus is located on the traditional, ancestral, and unceded territory of the Musqueam. Of the 400 hectares the campus encompasses, 160 hectares are built-up land cover. Much of the rest of the campus area is vegetated space, including an urban forest comprised of more than 10,000 native trees. (UBC Planning). It is a large urban green environment in its own right, and is also located around, within or adjacent to several areas of ecological importance. Within the campus there are the UBC Botanical Gardens and the Nitobe Memorial Garden. Pacific Spirit Park, a large 90-hectare urban park, surrounds the campus, and the Pacific Flyway bird migration route passes through.

The campus is also a busy site for students, faculty, staff, and many people unaffiliated with the University who live and working here. Approximately 80,000 people use the campus during the day, 55,000 of whom are students and 15,000 workers. Student housing has a maximum capacity of 12,000, and campus residential neighbourhoods house another 12,500 people (UBC Planning). These people travel to and from campus and within the campus using many forms of transportation. The Vancouver campus plan has promoted pedestrian and cyclist access and ease of movement across the campus and deemphasized single-occupant car traffic (UBC Vancouver Campus Plan). Over the next decades, Campus and Community Planning's Campus Vision 2050 plan outlines potential increased transit capacity, including SkyTrain access, bus and shuttle expansion, and further promotes non-automobile transportation methods (Campus Vision 2050).

Data summary

Multispectral satellite imagery

Planet SkySat multispectral satellite imagery is available from Planet directly, accessed through the UBC license for research. Planet provides very high spatial resolution imagery of the study area, collected at a high temporal resolution. Previous studies on ecological connectivity on campus have used imagery collected by Landsat and by Planet, but the 30-metre spatial resolution of Landsat imagery is a drawback in classifying complex landscapes and misses some of the small details of the UBC campus, already a small study area to begin with. Planet imagery has been used successfully in a later study to classify campus land cover for ecological connectivity modelling purposes (Goh, 2024), and newer Planet imagery will be used again in this study for that reason. The imagery used in this project was collected July 27, 2023, a date where there was minimal cloud cover over the study area and high amounts of vegetation. It has a spatial resolution of 0.5 metres. The image is comprised of four spectral bands in visible red, green, and blue and near-infrared. The Planet Ortho Scene has been orthorectified, radiometrically and geometrically corrected, and is projected in the Universal Transverse Mercator (UTM) coordinate system.

LiDAR

LiDAR data covering the UBC Vancouver campus is available from the City of Vancouver open data portal. This is the most cohesive and up-to-date LiDAR dataset available for the City of Vancouver and UBC Endowment lands. The most current aerial LiDAR dataset was collected September 7 and 9, 2022. The data has a mean density of approximately 49 points per square metre, vertical accuracy of 0.081 metre at a 95% confidence level. Six land cover classes have been preclassified, representing bare earth and low grass, vegetation with a height less than 2 metres, vegetation over 2 metres, water, and buildings, and remaining unidentified points are classified as noise, other land cover types, and unclassified points.

Figure 2. Mosaic of multispectral Planet imagery across extent of the study site, visualized in RGB true colour.

Methods

This study investigates sites of overlap between human and wildlife movement across the UBC Vancouver campus to identify and avoid human-wildlife conflict. First, Planet SkySat satellite imagery and public LiDAR data are utilized to create classified land cover maps of the campus. These classified land cover rasters are then used as resistance surfaces for omnidirectional connectivity modelling to understand how humans and wildlife move across campus. Finally, human and wildlife connectivity are compared to identify sites of overlap. Core study stages are summarized in Figure 3 and further described below.

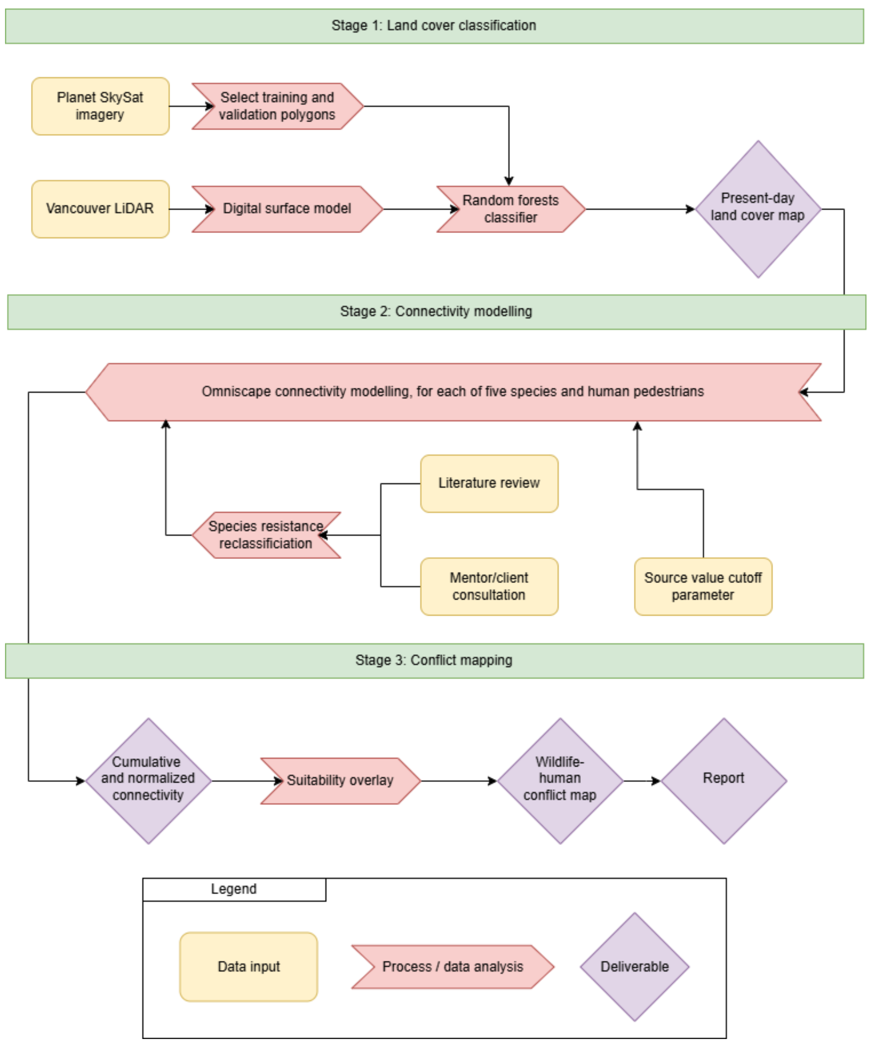

Figure 3. Workflow diagram depicting three substages of the study. Data inputs, data processing or analysis, and deliverable products are colour-coded as shown in legend.

Stage 1: Land cover classification.

This study first created fine-grain land cover classification maps of the UBC campus at present. Supervised land cover classification was carried out using the random forest classifier from the scikit learn package in Python (Pedregosa et al., 2011). Random forest is a decision tree algorithm used for classification that is commonly and successfully used in land cover classification (Gislason et al., 2006), and provides accurate land cover maps from satellite imagery (Tikuye et al., 2023). Compared to other common classification methods, random forest is equally accurate, does not overfit, and is faster and less computationally intensive (Gislason et al., 2006).

Classes were defined based on spectral signatures from the Planet SkySat satellite imagery and height from a LiDAR-derived digital surface model. The four existing Planet bands in the red, blue, green, and near-infrared bands were used. A normalized difference vegetation index was calculated from the red and near-infrared bands, which has been used in land cover classification to better distinguish between vegetation types (Defries and Townshend, 1994). A digital surface model was produced from LiDAR and incorporated into the classifier to distinguish between buildings and paved surfaces by including height data (Salehi et al., 2012). Polygons representing nine classes were manually delineated from the imagery and divided into training and validation groups for the classifier, which comprised 70% and 30% of the total pixels respectively. Identified land cover classes represented on the UBC campus were forest, low vegetation, grass, barren land, water, artificial turf, asphalt pavement, and buildings. Despite not being a land cover type, a ninth class, shadow, was included in the training data to account for shadows in the satellite imagery. Post-classification, erroneously classified pixels were cleaned using a low-pass filter and manually cleaned using ground truth data.

Stage 2: Connectivity modelling.

Classified land cover rasters were then used as resistance matrix inputs for ecological connectivity modelling. Each land cover class was reclassified to represent the resistance to movement through a given cell of that land cover type. This reclassification was performed six times, representing specific landscape resistances for six species found on the UBC campus, and human pedestrians. Resistance values were adapted from a previous study modelling connectivity on campus (Goh, 2024), determined from literature review, and from consultation with this study’s client and mentor. Values were derived for *Hyla regilla* (Pacific treefrogs) (BC Frogwatch, n.d.), for *Myotis lucifugus* (little brown bats) (Hepburn, 2024), for *Patagioenas fasciata* (band-tailed pigeons) (Neff, 1947), for *Sciurus carolinensis* (grey squirrels) (Gonzales, 2005), and for *Canis latrans* (coyotes) (Grinder and Krausman, 2001). These species were chosen for their presence in the study site, and as representatives of diverse urban-adapted functional groups.

Table 1. Species-specific reclassified resistance values per land cover class. Values represent the difficulty an individual faces in crossing a landscape cell of the given cover type. Shadows in the satellite imagery were observed most frequently cast on pavement and buildings and so have been assigned a placeholder value of the average of those two classes.

Species	Forest	Low veg	Turf grass	Barren	Water	Artif. turf	Asphalt	Building	Shadow
Human pedestrian	70	60	10	10	100	30	10	20	10
Pacific treefrog	10	10	30	30	1	50	70	100	85
Little brown bat	1	1	10	1	1	60	80	60	70
Band-tailed pigeon	1	1	1	1	1	30	30	80	55
Grey squirrel	1	10	10	10	100	30	50	90	70
Coyote	20	20	10	10	100	20	10	100	50

Connectivity modelling was then carried out using the Omniscape software package for Julia, an omnidirectional circuit-based connectivity model developed from the Circuitscape model (Anantharaman et al., 2020). Omnidirectional circuit-based connectivity modelling better simulates movement of multiple species and does not make assumptions about the source or destination of movement, important when considering continuously distributed species in this small study site (Phillips et al., 2021), Omniscape has been successfully used in connectivity modelling within complex urban landscapes (Kwon et al., 2021).

The Omniscape model uses an algorithm described by Landau et al., 2021. A moving window is applied to the landscape with a radius equal in this study to the typical maximum distance a given species or mode of human transportation travels. The window centers on a target pixel in the source strength surface that has a source strength greater than zero. The source strength and resistance rasters are clipped to the circular window, and every source pixel within the search radius that also has a source strength greater than zero are identified as source pixels. The circuit-based connectivity model is run using the clipped resistance raster using the target pixel as the circuit's ground, and the source pixels as current sources. The level of current injected is based on the strength of the target pixel and proportionally divided among all the source pixels by their source strengths. These steps then repeat for every potential target pixel of the source raster. The methodological advantage of omnidirectional circuit-based connectivity modelling over other forms of connectivity modelling is that it eliminates the requirement for start and endpoints, representing the reality that an individual organism might move through space without a fixed destination. Instead, connectivity is summed across the entire resistance surface.

Source strengths for each species were derived from the resistance surface. Estimates of observation locations and numbers for each species as recorded through citizen science platforms were consulted, but as the study area is quite small and the known range of each species is quite large, source strength was considered to be equivalent to the inverse of each cell's resistance value. The cutoff for a pixel to be considered a source was set at a resistance value of 30. Lastly, the same process was followed to model human pedestrian connectivity.

Stage 3: Conflict mapping.

In the final stage of the study, the connectivity maps for each species were normalized and averaged to create a map of mean connectivity across all representative functional wildlife groups on the UBC campus. A vehicle traffic map was created from traffic monitoring data collected at street intersections on campus and generalized to all streets by street type attributes. Ecological connectivity was then overlaid against the human pedestrian connectivity map and the vehicle traffic volume map to identify sites with the highest potential for conflict.

Results

Stage 1. Land cover classification

Figure 4. Classified map of UBC campus. Nine classes were identified with reasonable accuracy. Forest canopy and buildings make up the majority of the landscape. Base satellite imagery from Esri.

Supervised classification was performed using a random forest with 100 trees. Distinct classes representing the diversity of land cover types making up the campus landscape are identifiable. Incorporating an imagery-derived normalized difference vegetation index and a digital surface model derived from LiDAR data were the most important features in distinguishing between classes with similar spectral signatures (Figure 3.), primarily vegetation classes and built-up classes. Overall accuracy value was 78.2%, with a high degree of variation in user's and producer's accuracy between classes (Table 2.).

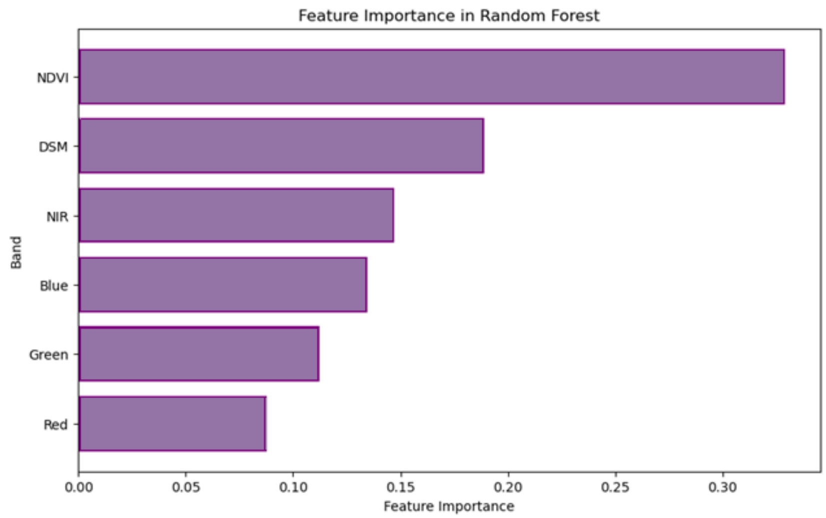

Figure 5. Relative importance of each band used in model training. The imagery-derived vegetation index and the LiDAR-derived surface model were found to be most important.

Table 2. Accuracy matrix for random forests classification model. User's and producer's accuracy between classes was variable, with water displaying poor user's accuracy, and artificial turf displaying poor overall accuracy.

Predicted	**1 Forest**	**2 Low veg**	**3 Turf grass**	**4 Barren**	**5 Water**	**6 Artificial**	**7 Asphalt**	**8 Building**	**9 Shadow**	**User's Accuracy**
1 Forest	52907	13282	5051	0	0	0	0	0	285	73.97
2 Low veg	975	7401	944	8	0	0	0	0	0	79.34
3 Turf grass	0	0	21682	0	0	0	0	0	0	100
4 Barren	0	0	2	11591	0	0	0	0	0	99.98
5 Water	0	0	0	0	1199	391	0	9	2837	27.03
6 Artificial turf	0	0	0	0	50	31	1	75	0	19.75
7 Asphalt	0	0	496	0	0	2686	4565	563	4	54.91
8 Building	0	0	49	1	7	12059	6986	70847	3	78.76
9 Shadow	0	0	0	0	74	1580	0	1	3493	67.85
Producer's Accuracy	98.19	35.783	76.821	99.922	90.15	0.185	39.517	99.094	52.748	

As most inaccuracies were constrained to artificial turf and water classes and these are relatively small land cover classes confined to known locations, many incorrectly classified pixels were able to be later corrected and overall applicability of the classified land cover raster for connectivity modelling is still high despite the low accuracy score.

Stage 2. Connectivity modelling

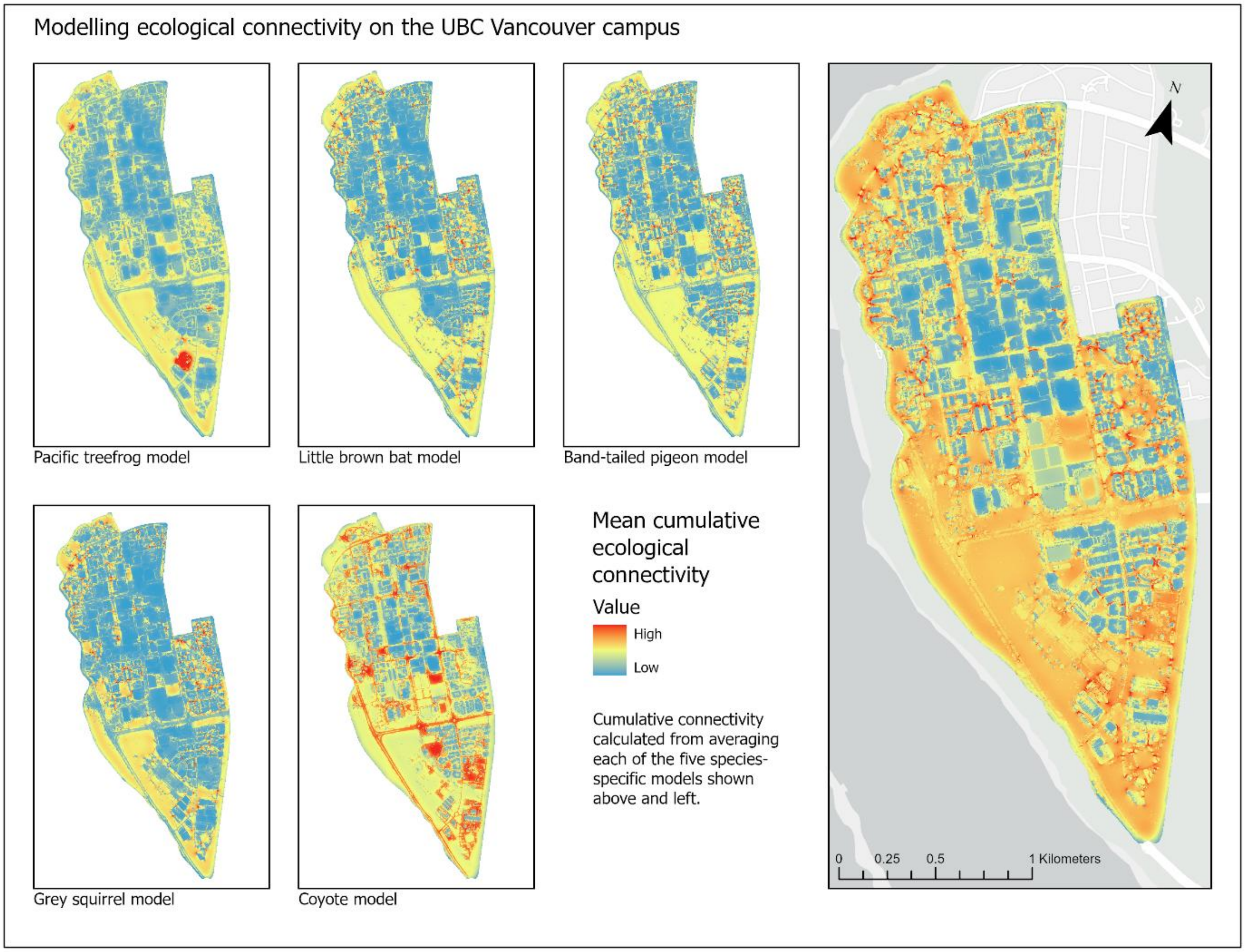

Figure 6. Each of five species-specific connectivity models and a combined cumulative connectivity map made from averaging the results of each species model. Connectivity for wildlife is highest in forest along the northwest and southwest edges of campus, and low between and around the buildings and paved surface in the northeast.

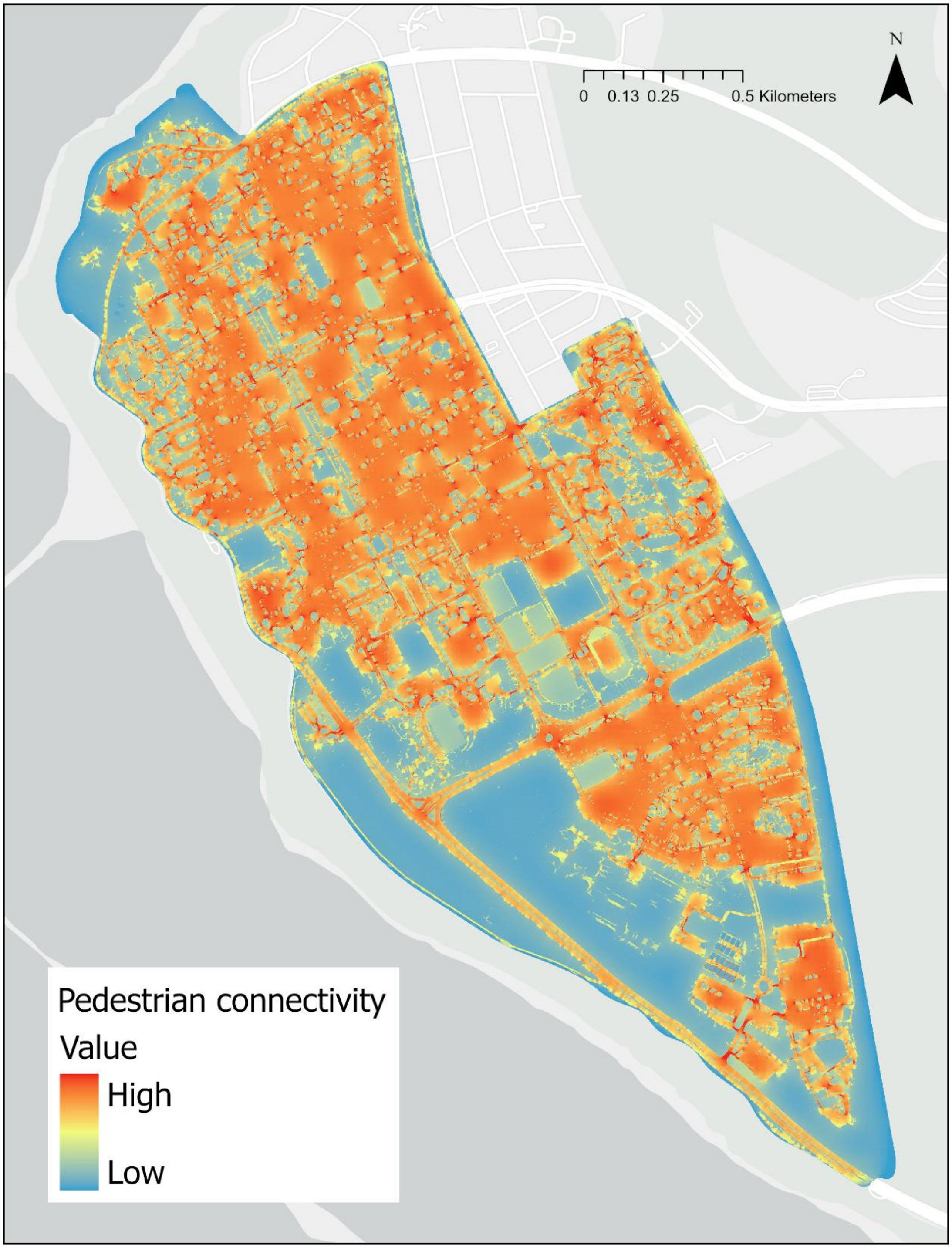

Figure 7. Pedestrian connectivity. Pedestrians prefer moving along paved paths or through buildings, and avoid dense forest canopy.

Connectivity differed between wildlife species (Figure 6). Frogs had high connectivity around water features and their surrounding forests. Bats and pigeons, as flying animals, had very similar connectivity results, but tended to avoid roads and buildings. Grey squirrels tend to prefer forest canopy and other vegetation types. Coyotes move across many land cover classes well, and can travel along roads. Overall, ecological connectivity is highest in natural land cover types and lowest among buildings and paved surfaces. In the animal species models, high-cost routes are between and along green space on campus, including forested area and areas of low vegetation. These land cover classes are suitable habitat for many of the species studied and are easier to cross than human-built land cover classes. Human connectivity rasters display an inverse pattern, as human pedestrian and vehicle traffic more easily moves through areas with sidewalks and other paved surfaces (Figure 7).

Stage 3: Conflict mapping

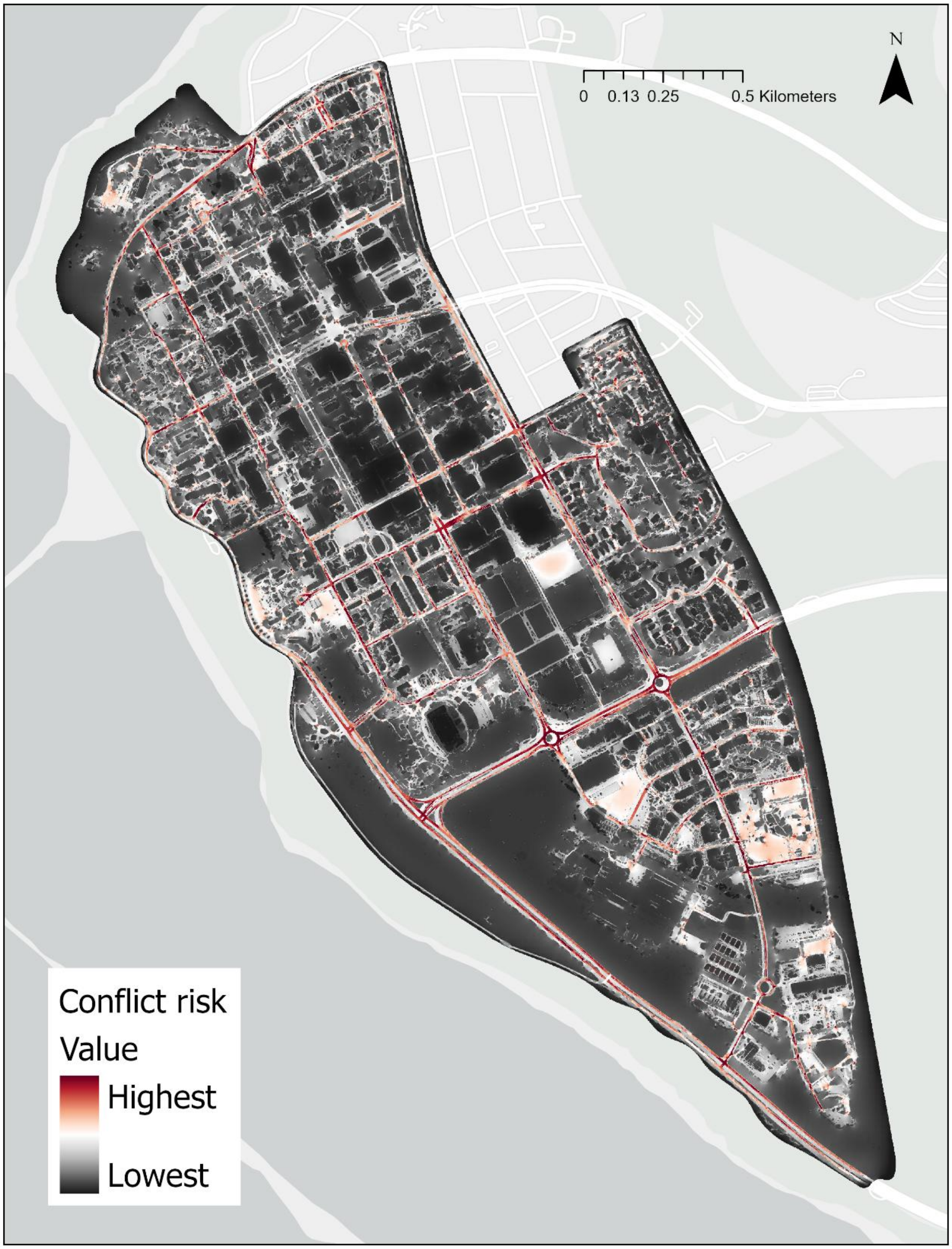

Figure 8. Conflict map displaying locations where combined species ecological connectivity and human pedestrian and traffic connectivity are all high. Sites of conflict are clustered around roads but evenly distributed throughout the UBC Vancouver campus.

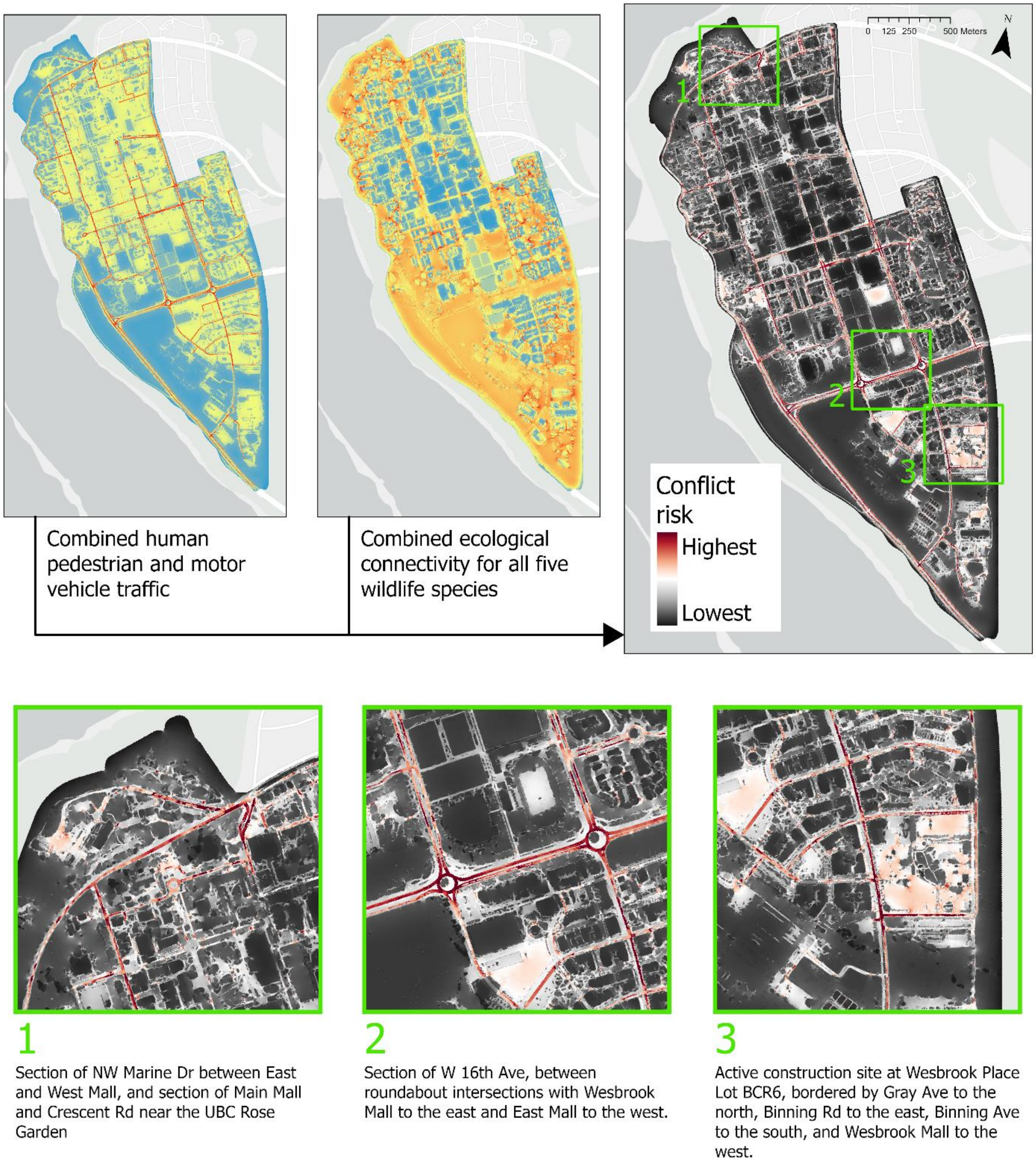

Figure 9. Models for animal and human movement were combined to predict conflict. Some sites of particular interest in the final conflict map are identified.

By overlaying connectivity models and incorporating other known conflict factors like traffic volume, it is possible to predict where human and wildlife movement currently overlaps. Species-specific conflict maps varied, with most following species-specific connectivity quite closely (Appendix A). Conflict between humans and wildlife follows closely the maps of human pedestrian and vehicle traffic volume, and the top sites of potential conflict are at the edges of campus green spaces and along roads where wildlife movement is forced across more costly land cover types that humans occupy.

Discussion

This study examined sites of overlap between wildlife and human movement on the UBC Vancouver campus, seeking promote human-wildlife coexistence by identifying locations where there exists a risk of human-wildlife conflict. Remotely sensed multispectral imagery and LiDAR data were used to produce a classified land cover map of campus in order to understand the composition of this complex urban landscape. This information was used in omnidirectional circuit-based connectivity modelling of animal species to identify wildlife movement routes, and modelling of human pedestrian movement. After combining pedestrian and traffic movement data, the human and wildlife movement maps were overlaid to determine where conflict risk is highest.

Connectivity for each wildlife species follows a general pattern of high flows through Pacific Spirit Park along the southern and western edges of campus. Notable hot spots include water features, most prominently areas surrounding the UBC Farm ponds and the Nitobe Memorial Garden pond, which were found to be extremely important in the Pacific treefrog model and likely amphibians more broadly. Human-modified land cover classes were found to be hot spots in the coyote model, reflecting the urban-adapted species' willingness to traverse streets and fields. The two species capable of flight, little brown bats and band-tailed pigeons, produced two connectivity maps that were very similar, and tended to display low flows around buildings and uniform flows through all other land cover types, reflecting that there are few barriers to aerial movement. Combined ecological connectivity follows a very broad pattern of low flows in the centre and north of campus, where buildings are more clustered, and high flows through the various types of vegetated land cover. Human connectivity was roughly the inverse of wildlife ecological connectivity, and was high through the centre of campus as well as the leləm̓ and Wesbrook Village neighbourhoods (Figure 7). After including vehicle traffic, hot spots were identified at the UBC Exchange on University Boulevard, along Thunderbird Boulevard, at the roundabout intersections of W 16th Avenue with Wesbrook Mall and East Mall, and along streets throughout Wesbrook Village.

The most prominent sites of overlap between human and wildlife movement are generally along streets and walkways in close proximity to tree canopy or open grass, where human pedestrian and motor vehicle traffic as well as ecological connectivity are both high. Some specific sites of interest are near the Museum of Anthropology on the northern edge of campus, intersections along W 16th avenue, and the active construction site at Wesbrook Place Lot BCR6. All of these sites are located along busy streets, with patches of forest and vegetation directly adjacent.

Previous research

The findings of this project align with research studying ecological connectivity on the UBC Vancouver campus both previously completed and ongoing. A previous study by Nduna, 2023, examined connectivity of two species, brown creepers and coyotes, on campus. Patches for brown creepers were located on the northern edge of campus and the most important habitat patches were in Pacific Spirit Park along SW Marine Drive, and this location was also found to have high combined ecological connectivity in this study. Coyote patches of importance were identified around athletic fields in the centre of campus, a result also displayed by the coyote connectivity model in this project. A later study by Goh, 2024, emphasized the importance of southern campus forest patches, the UBC Farm, and the UBC Botanical Gardens. These also appeared as high flow sites in this project (Figure 6). Coyotes were the common species through all three studies, and all emphasize the importance of grass athletic fields to coyote connectivity.

In contrast to the same existing research, Main Mall did not appear as a conflict risk in the final conflict map. Though it was identified as an important corridor for animal movement in both previous studies as well as in this study, this study did not find it to be the most important corridor for human movement. This is likely because the human movement model after incorporating vehicle traffic was biased to favour streets, and because of the heterogeneous land cover along Main Mall. The land cover structure of paved stone walkways between low grass and tree cover meant that the model did not accurately predict human movement as it happens in the real world.

Issues and limitations

This project faced some limitations. In the first stage of this project, land cover classification, inherent issues with data presented certain challenges. Planet SkySat scene imagery was chosen as the spectral satellite imagery from which land cover was classified, as it contained spectral bands in red, green, blue, and near-infrared ranges at the 0.5 metre resolution required for this project, however the fine resolution meant shadows in passively-sensed satellite imagery caused classification issues. To some degree, actively-remote sensed LiDAR data can help correct for this, but shadowed areas without surface reflectance in spectral bands remained an issue throughout classification (Figure 4). This leads into a set of broader issues with land cover classification as a preliminary stage in ecological connectivity modelling. Some of these issues are inherent to the method, as land cover classification from satellite imagery produces a landscape as it would be understood from a top-down, bird’s-eye view. This fails to capture vertical heterogeneity in the landscape that would be evidently clear to an animal or human moving through. Tree canopy viewed from above often extends over roads or pedestrian pathways, but this does not mean that the landscape at that location is impenetrable forest as the model assumes. A recommendation for future research is that projects incorporate to a greater extent any existing vector data on fixed, permanent campus features. On this project, incorporating rasterized building and street layers accessed through the Campus Planning geospatial database to correct the classified land cover raster significantly improved human pedestrian connectivity modelling. Furthermore, considering the fine spatial resolutions and small study area required for this project, object-based image analysis is much more theoretically applicable than the pixel-based classification that was performed.

Other issues were related to the accessibility or existence of potentially useful data that is either not collected or not aggregated and stored. This project would have benefitted from real presence data on the numbers and locations of both wildlife species of interest and human pedestrians. Understanding where people currently tend to gather and move on campus and understanding where wildlife moves would allow for a more precise model. Promising research on animal connectivity and urban wildlife conflict is being carried out at present through the Animal Behavior and Cognition lab, though data on animal movement and presence unfortunately did not yet exist at the time of this project. Several potential data sources regarding human presence were pursued but none were fruitful. There existed a pilot project tracking building daily capacities through WiFi connected personal devices, but this has been completed and the data if it exists is both unavailable and out of date. Alternatives such as estimating building capacity from fire code regulations also were not viable as there is no central readily-available source of building code capacities. In lieu of real human presence data, all building and paved pixels were treated as sources of human movement, but future projects may find a better proxy.

Recommendations

This project is informed by and aims to inform many principles and goals set out in UBC Campus and Community Planning's official guiding documents for the future of campus, primarily Campus Vision 2050 and the upcoming Biodiversity Plan. The recommendations of this project support the proposed changes made under Campus Vision 2050's goal of Restorative and Resilient Landscapes. In particular, sites of conflict identified by this project align with proposed ecological corridors: Main Mall, W 16th Avenue, East Mall, University Boulevard, and a diagonal connector between leləm̓, UBC, and Wreck Beach. Future directions for research can explore how to design these corridors to best accommodate their use by both humans and wildlife moving alongside each other.

Planning roads

One feature of interest is underground passages. Features like drainage culverts can be important passages for small mammals like squirrels (Clevenger et al., 2002). If these features exist and are being used, it might be important to construct more dedicated underpasses. However, this requires more monitoring of vehicle-wildlife conflict to identify ideal positions and without fencing at road edges directing wildlife to underpasses it is likely they will not serve their purpose (Mccollister and Van Manen, 2010). This again comes into conflict with human connectivity, as the campus is an urban area and constructing fencing to direct wildlife movement may unduly impact people. At higher levels of consideration, this project supports broad initiatives like Active Transportation Network concepts and Transit Network concepts described in Campus Vision 2050. Reducing unnecessary vehicle traffic along Marine Drive, Thunderbird Blvd, Wesbrook Mall and West Mall below Agronomy Rd would clearly benefit wildlife and humans. Promoting pedestrian and cyclist traffic reduces a large source of traffic and conflict.

Planning features

Differences in connectivity surrounding artificial and natural turf grass fields are of note, most evidently the athletic playing fields in the south centre of campus (Figure 6, Figure 9). The natural grass Wolfson East Field, Frank Buck Field, and Arthur Lord Field, are easily crossed by wildlife, and have appeared as important routes for coyotes in several ecological connectivity modelling projects. The nearby artificial turf Ken Woods Field, Harry Warren Field, Harold Wright Field, South Turf mini-fields, South Turf Field, Rasphal Dhillon Track and Field Oval, and the Tourmaline West Baseball Stadium likely barriers to connectivity for several wildlife species of interest, as they tend to be fenced off and brightly lit at night. Though this project did not identify these artificial turf sites as at high relative risk for conflict given that wildlife connectivity is low, any animal that is moving through the suitable natural grass fields may find itself routed through the narrow paths between nearby inaccessible artificial fields. It is recommended that alternative ecological corridors be constructed that avoid this central area.

Construction sites appear as a frequent site of potential conflict as they are commonly open areas easy to move through, and located adjacent to forest or other vegetated cover. The Museum of Anthropology and Wesbrook Place Lot BCR6 were specifically identified by this project as risk sites (Figure 9). Potential strategies to promote coexistence encourage wildlife to avoid construction, like pre-stressing by encouraging wildlife to avoid the site before construction begins, and proofing the site by avoiding obvious food, water, and shelter sources. Pre-stressing might look like increasing noise and installing preventative fencing early. Wildlife proofing might involve waste control to limit food sources, drainage strategies to remove standing water sources, and covering and securing loose material that small animals might nest or roost in (City of Ottawa, 2022).

Planning campus

Active adaptive wildlife management is the recommended approach to prevent conflict and promote coexistence. In active adaptive management, learning about the system is an objective in itself, different potential approaches are tested simultaneously, there is tolerance for imperfect management strategies implemented in order to learn more about the system (Richardson et al., 2020). Any recommendations that support increasing human movement and recommendations that support biodiversity and wildlife movement can potentially contradict each other, and it is difficult to know in depth what forms conflict might take or where it might exist without implementing these strategies.

A heavy emphasis must be placed on data collection and population monitoring to inform evidence-based management strategies. This means monitoring of wildlife populations through camera traps and direct trapping and monitoring of smaller species. Volunteer positions and undergraduate courses could support this goal. General, aggregated data on human movement through campus would also directly benefit future coexistence-oriented projects. Lastly, movement and capacity data are inherently temporal data, as patterns change with time of day, day of the week, and month of the year. Future research should take into account the changing patterns of wildlife movement with the seasons, changing patterns of pedestrian movement during school or work hours, changing traffic levels at different times of year, and other time-sensitive datasets. It is possible, for example, that reduced wildlife activity during fall and winter months reduces conflict with students through the majority of the school year, or that increased traffic at the beginning and end of school terms increases potential conflict.

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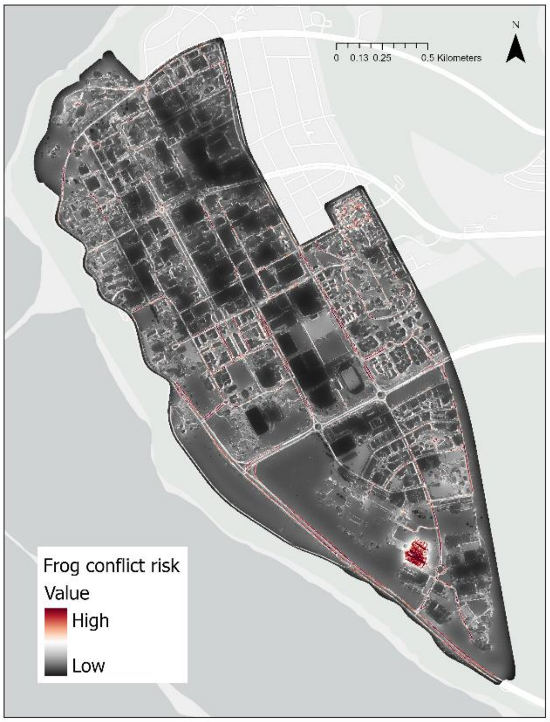
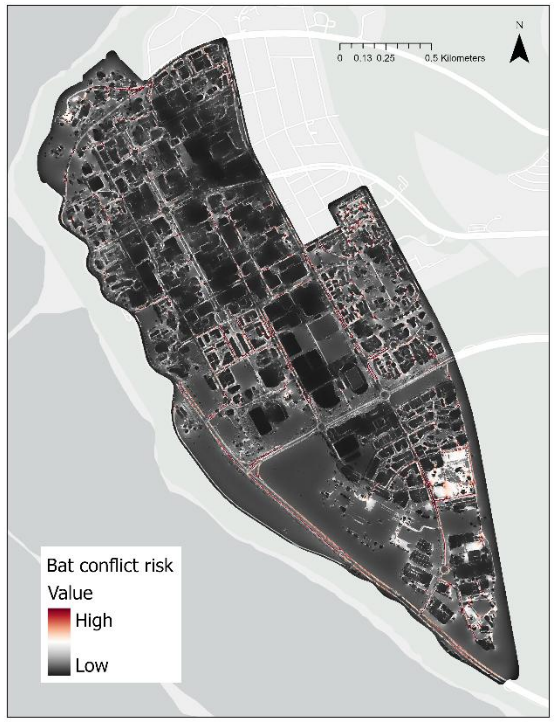
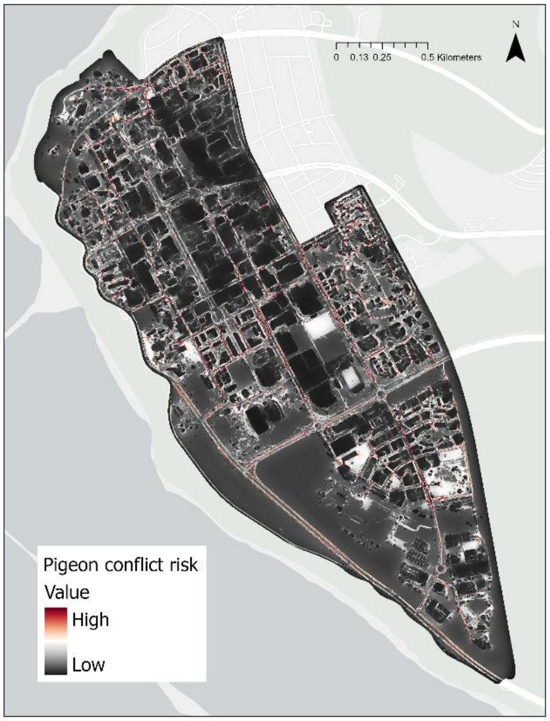
Appendix A.

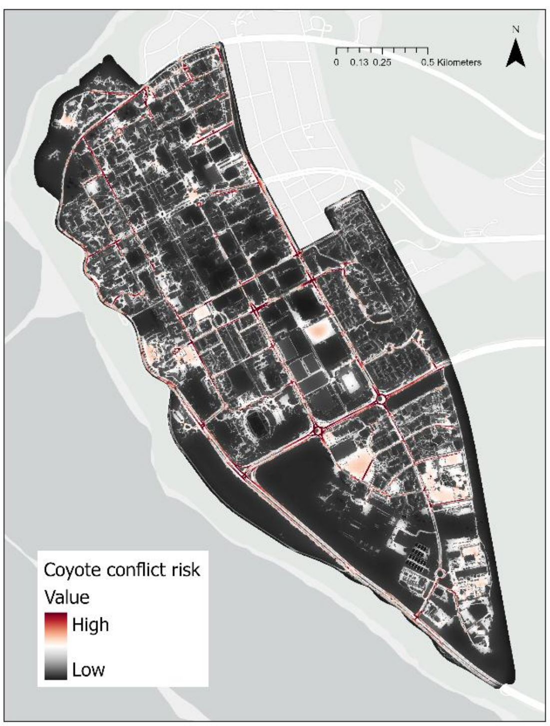
Species-specific conflict maps representing the overlap between human traffic and each of *Hyla regilla* (Pacific treefrogs), *Myotis lucifugus* (little brown bats), *Patagioenas fasciata* (band-tailed pigeons), *Sciurus carolinensis* (grey squirrels), and *Canis latrans* (coyotes).






N
0 0.13 0.25 0.5 Kilometers
Pigeon conflict risk
Value
High
Low


N
0 0.13 0.25 0.5 Kilometers
Squirrel conflict risk
Value
High
Low


N
0 0.13 0.25 0.5 Kilometers
Coyote conflict risk
Value
High
Low