Black-tailed deer habitat-use in relation to natural and urban landscape features across Oak Bay, B.C.

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Executive Summary

We researched black-tailed deer habitat-use in relation to natural and urban landscape features across the municipal district of Oak Bay, BC. We collected location data from 20 satellite telemetry collars deployed on female deer over a period of two years to determine what natural and urban landscape features deer select or avoid in this region. This information provides guidance on what aspects of the Oak Bay landscape are allowing black-tailed deer to use this urban area. We applied resource-selection function analysis which compares observed deer locations to randomly selected available locations across the study area. Deer strongly select areas with high vegetation greenness and large residential lots. Natural landscape features (specifically, vegetation greenness and tree cover)—rather than urban features—best predict deer habitat-use. However, the inclusion of large residential lots in our natural model is an even stronger predictor of deer habitat-use. In addition to this strong selection for vegetation greenness and large residential lots, deer also show strong positive selection for areas near golf courses and parks. Deer show a weaker selection for small and medium-sized residential lots and avoid areas with high road densities. Deer association with tree cover was ambiguous. We conclude that within the District, neighbourhoods in the north and south of Oak Bay are being extensively used by deer due to the prevalence of large residential lots with heavily landscaped gardens, as well as large grassy and watered green spaces (e.g. parks and golf courses). These features provide resource subsidies for urban black-tailed deer that otherwise do not exist in the naturally dry historic Garry Oak savannahs, and are less prevalent in higher-density neighbourhoods with small yards.

Background Information

Urban Deer:

Columbia black-tailed deer (BTD), *Odocoileus hemionus columbianus,* are native to British Columbia (BC), including Vancouver Island. They are one of the three closely related subspecies of mule deer (*Odocoileus hemionus*) indigenous to western North America. BTD are a key herbivore maintaining ecosystem function, an important prey species[1] as well as a game species for many British Columbians. However, the changing landscape of BC's urban and suburban areas has been generally favourable to deer. Their natural predators – bear, wolves, and cougars – are largely excluded from most urban and suburban areas. In addition to the effective exclusion of predators from their ecological roles in deer-population control, suburban landscapes also provide extensive forage to deer. Both of these ecological changes – predator exclusion and deer forage subsidies - are observed in the Victoria Capital Regional District (CRD), which spans 13 municipalities on the Saanich Peninsula of southern Vancouver Island, including the District of Oak Bay. The CRD covers a range of landscapes from urban through suburban, rural residential, agricultural, and protected areas. Elements from these landscapes provide both opportunities and challenges to urban deer.

BTD populations are very sensitive to factors affecting recruitment [2,3]. Deer select high-energy and high-nutrient plants to eat[4]; the abundant backyard gardens and agricultural crops in BC suburban areas provide ample deer food, potentially allowing BTD to breed more often and more successfully than in natural landscapes. Urban environments have been shown to impact wildlife behaviour resulting in unique adaptations that differ from their non-urban counterparts [5,6]. Having detailed information on localized BTD forage and site preferences, aversions, and

associated movement patterns is an important tool for suburban deer management by informing how people's actions and changes to the landscape are contributing to urban deer distribution.

Habitat Selection:

Managing BTD populations around suburban centers to achieve long-term stability requires information on basic population parameters (density, distribution, demographics) as well as habitat selection and movement patterns. However, limited data exist on black-tailed deer in suburban centers. One knowledge gap is the lack of information on how BTD select or avoid different habitats such as parks and green spaces, and how these features may contribute to deer abundance. Traditional surveys are based on herd counts—which are known to be inaccurate[7]—or aerial surveys which are nearly impossible in suburban areas. As an alternative, citizen-based surveys engage the public and provide baseline information. However, data derived from citizen-led surveys often suffer from spatial biases[8] likely arising from preferential sampling (e.g. sampling close to home, roadside observations); they lack the rigour to scientifically or politically warrant or defend management actions. Deer locations gathered from global positioning system (GPS) telemetry collars offer a statistically robust alternative to herd counts and citizen-led surveys in urban areas, and can be used in resource selection function (RSF) analyses to make inferences on how animals use different habitat types[9]. RSFs are an analysis that compare observed (or "used") animal locations to "available" locations across the study area. Habitat data (e.g. forest cover, proximity to roads) at used and available locations are compared to make inferences on the relative selection of different habitats by individuals[10]. Measured across multiple individuals, these data can be used to form conclusions about the population. RSFs have been used to assess animal movement patterns and travel-corridor use[11,12], understand animals' spatial awareness and habitat selection at different scales [13,14], and assess

preference for habitat features designed for species conservation[15]. In this report, we constructed RSFs from location fixes collected by 20 GPS-collars deployed on female BTD in Oak Bay over 2 years (February 2018 to March 2020). We combined GPS location data with Oak Bay natural and urban landcover data to investigate the question: how are BTD distributed over the suburban landscape of Oak Bay, and what landscape features do they select or avoid?

Methods

Study Area:

The District of Oak Bay is a suburban community located on the southern tip of Vancouver Island, British Columbia. The district is characterized by small- and large-lot residential areas, light urban development, golf courses, as well as a number of managed and

natural parks dispersed throughout the municipality. The district is bordered by the Salish Sea to the east and south, and shares municipal borders with the city of Victoria and the district of Saanich. Along with 12 other municipal governments, it forms part of the CRD, operating under the provisions of the Province of British Columbia Local Government Act (District of Oak Bay, 2018).

Urban Deer Capture and Collaring:

In February and March 2018, we deployed 20 GPS collars on female black-tailed deer in the district of Oak Bay. We located deer for capture by conducting road surveys throughout the entirety of our study area to attempt as even coverage of collars across Oak Bay as possible. However, captures are necessarily constrained to where deer occur, so some areas were not sampled (no suitable deer were found) and captures are somewhat clustered in space (Supplementary Information, Figure A1). Capture was conducted *via* dart-delivered chemical immobilization by an experienced wildlife veterinarian using current regulatory approvals and field protocols. Upon capture, we fitted each deer with a LOTEK Lifecycle GPS collar programmed to automatically obtain a precise GPS location every 13 hours, providing 1-2 location fixes on a daily basis. Each collar was fit with a mechanism programmed to release the collar from the animal 2 years after initial deployment. Retrieved collars from study deer mortalities throughout 2018-2019 were re-deployed on new individuals.

Landscape Habitat Features:

We obtained Oak Bay natural and urban landscape features from publicly available datasets from BC provincial and municipal governments, Habitat Acquisition Trust, and the US Geological Survey (USGS). All habitat analyses were conducted in ArcGIS 10.6 (ESRI, Redlands, CA, USA).

Natural landcover features included vegetation greenness and tree cover. We derived indices of vegetation greenness (Normalized Difference Vegetation Index; NDVI) from cloud-free USGS 2018 Landsat-8 imagery for the growing season (April to September). NDVI is a commonly used spatial metric in ecology to measure plant coverage and plant growth: it is thus tied to where vegetation is growing and also how well it is growing (indicative of water and nutrient levels). Image pixel values were averaged across the season to derive a vegetation

greenness value at a 30-m spatial resolution. We used the percent-area of tree canopy cover calculated from high-resolution 2011 CRD aerial imagery datasets by Habitat Acquisition Trust[16].

For urban landscape features, we reclassified zoning maps for Oak Bay and surrounding districts into residential, urban, and green-space classes, and verified using satellite imagery. Residential areas were further classified into small, medium, and large lots. Urban features included road and impervious surfaces (e.g. parking lots, industrial areas). Green space was further classified into public green spaces and golf courses. We investigated all landscape feature variables for collinearity and variance inflation, which undermine the statistical significance of independent variables, and ensured these were not present in our models. Due to high correlation between impervious surfaces and other variables (e.g. small residential lots and roads), we excluded impervious surfaces from our analysis.

Deer Habitat-Use on an Urban Landscape:

We evaluated the relationship between deer and features of the urban landscape using RSFs with a used-available design. Deer selection or avoidance of various natural and urban features is indicated by the probability of use by each landscape variable. RSF models determine the most likely relationship between the number of times a deer is observed in a habitat and the availability of that habitat in the landscape. As an analogy, if deer are observed 5 times on a golf course and golf courses are available to be used 10 times, there is a 50% probability of deer using golf courses. If deer are observed 5 times in small lots but those are available for use 100 times, there is a 5% probability of deer using small lots.

Technically speaking, we used a logistic regression in a generalized linear model (GLM; binomial errors, logit link) with used locations (1) and randomly selected available locations (0) regressed against natural and urban landscape covariates. We evaluated deer habitat-use at the population level, which compares deer habitat-use in the entire range of the population, in this case, the entirety of the Oak Bay.

We defined "used" locations as those where we received a successful location fix from any of our collared deer across the study period, for a total of 3924 used locations. "Available" locations were randomly generated across the entirety of Oak Bay, with three available points generated for each used point. This larger ratio of available locations allows us to more accurately measure what is available to deer in Oak Bay. For each used and available location, we calculated the average vegetation greenness and the percent area of tree cover across a 50-m radius buffer. Within this buffer, we also calculated the percent area of three categories of residential lots (small, medium, and large lots). We measured roads as road density (km/km^2) within the buffer. As parks and golf courses in our study area covered large areas with a patchy distribution, we evaluated deer association to these features using the distance to these features instead of the percent area of features within the 50-m radius of points. For each used and available location, we measured the distance to the nearest park/green space as well as distance to the nearest golf course.

We tested four hypotheses about how we expected deer to respond to urban landscape features. In the model selection approach[17] we use, each hypothesis is represented by a different statistical model, each containing different landscape features. We weigh the amount of support for each model by determining how much of the variability in deer selection is explained by that model. For example, if deer are 10% more likely to be observed with each 10% increase in green

spaces, this is a 1:1 relationship that explains all the variability in deer occurrence. Of course, this never happens. But each model produces an Akaike Information Criterion (AIC) score that in essence measures *how much the model deviates from a perfect 1:1 fit*, relative to other models in the candidate set and penalized by the number of landscape features in the model – because simple is always better. The lower the AIC score, the tighter the relationship between deer and the landscape feature.

We first tested four hypotheses and their corresponding candidate RSF models predicting deer habitat-use in relation to: 1) natural land cover features (vegetation greenness and tree cover), 2) residential features (small, medium, and large residential lots) 3) road density, and 4) urban green space (golf courses, parks, green space; Table 1). We ranked candidate models using AIC scores and normalized AIC weights, which are analogous to the probability that a model is the best-fit model out of the set of candidates[18].

To further explore which individual urban features best predicted deer habitat-use, we ranked 7 models containing a single urban landscape variable alongside natural features (i.e. vegetation greenness and tree cover; Table 2).

Lastly, to compare deer selection or avoidance across the various natural and urban landscape features, we evaluated variable coefficients in a single "global" model containing all selected landscape features. We predicted deer to show a positive association with areas of high vegetation greenness and tree cover. We predicted deer to avoid areas with high road density and a high proportion of small-sized residential lots due to both increased human activity associated with these areas, and less available shelter. In contrast, we expected deer to select for medium and large-sized residential lots, as these would be more likely to provide natural forage and shelter as well as a lower density of humans and traffic. We predicted deer to select for areas

near golf courses due to shelter and forage associated with the perimeter of the golf course, but predicted an avoidance of parks due to increased presence of humans and dogs.

Table 1. Four candidate model sets describing general categories of natural and urban landcover features predicted to influence deer habitat-use.

Model Set	Variable	Description
1. Natural	NDVI	Average vegetation greenness (index value 0 – 1)
	Tree_Cover	Percent area with tree cover
2. Residential	Large_Lots	Percent area with residential lots >1051m^2 in land size
	Medium_Lots	Percent area with residential lots >1051^2 and <2527m^2 in land size
	Small_Lots	Percent area with residential lots <2527m^2 in land size
3. Roads	Road Density	Density of roads (km/km2)
4. Green Space	Parks	Distance to nearest park or public green area
	Golf_Courses	Distance to nearest golf course

Table 2. Candidate models testing individual urban landscape features in combination with natural landscape covariates in predicting deer habitat use beyond the effect of natural features.

Model Set	Model Number	Included Variables
Natural Only	1	NDVI + Tree_Cover
Natural + Small Lots	2	NDVI + Tree_Cover + Small_Lots
Natural + Medium Lots	3	NDVI + Tree_Cover + Med_Lots
Natural + Large Lots	4	NDVI + Tree_Cover + Large_Lots
Natural + Road Density	5	NDVI + Tree_Cover + Roads
Natural + Parks	6	NDVI + Tree_Cover + Parks Distance
Natural + Golf	7	NDVI + Tree_Cover + Golf Course Distance

Results

Natural landcover features best predict deer habitat-use across Oak Bay compared to models containing only urban landscape features (Table 3). However, inclusion of large residential lots in the natural model vastly improves our ability to predict deer habitat-use (Table 4), with an AIC weight of 1 conclusively identifying large residential lots as an important predictor.

Deer select most strongly for areas with high vegetation greenness and a large proportion of large residential lots (Figure 1). The strong and positive selection for large residential lots had a similar effect size on predicting deer habitat-use as did vegetation greenness, the most important natural predictor of deer distribution in Oak Bay. Deer also show strong positive associations with areas near golf courses and parks (Figure 1). Deer show a weaker selection for small and medium-sized residential lots and avoid areas with high road densities. Deer association with tree cover was ambiguous, without clear selection or avoidance of areas with high tree cover. Extrapolation of observed deer responses (i.e. beta coefficients) to natural and urban landcover covariates across our study area highlights neighbourhoods in north Oak Bay and the southern portion of the District as providing highly suitable habitat for urban black-tailed deer (Figure 2).

Table 3. Selection of generalized linear models (binomial errors, logit-link) of black-tailed deer habitat-use across Oak Bay, BC. We competed four general model sets predicting deer habitat-use, with each model containing a combination of natural landscape features ("Natural") or urban landscape features ("Residential", "Roads", "Green Space").

Model Name (Model #)	**K**	**AIC**	**Delta AIC**	**ModelLik**	**AICWt**	**LL**	**Cum. Weight**
Natural (1)	3	16,774.1	0	1	1	-8,384.0	1
Residential (2)	4	16,813.9	39.8	0	0	-8,402.9	1
Green Space (4)	3	16,953.6	179.6	0	0	-8,473.8	1
Roads (3)	2	17,255.2	481.1	0	0	-8,625.6	1

Table 4. Selection of generalized linear models (binomial errors, logit-link) of black-tailed deer habitat-use across Oak Bay, BC. We competed 7 model sets predicting deer habitat-use, with each model containing a combination of natural landscape features (NDVI and Tree Cover) as well as a single urban landscape feature.

Model Name (Model #)	**K**	**AIC**	**Delta AIC**	**ModelLik**	**AICWt**	**LL**	**Cum. Weight**
Natural + Large Lots	4	16,295.6	0	1	1	-8,143.8	1
Natural + Parks Distance	4	16,632.0	336.4	0	0	-8,312.0	1
Natural + Roads	4	16,644.7	349.0	0	0	-8,318.3	1
Natural + Golf Distance	4	16,655.5	359.8	0	0	-8,323.7	1
Natural + Small Lots	4	16,715.6	419.9	0	0	-8,353.8	1
Natural	4	16,774.1	478.4	0	0	-8,384.0	1
Natural + Medium Lots	4	16,774.5	478.9	0	0	-8,383.3	1

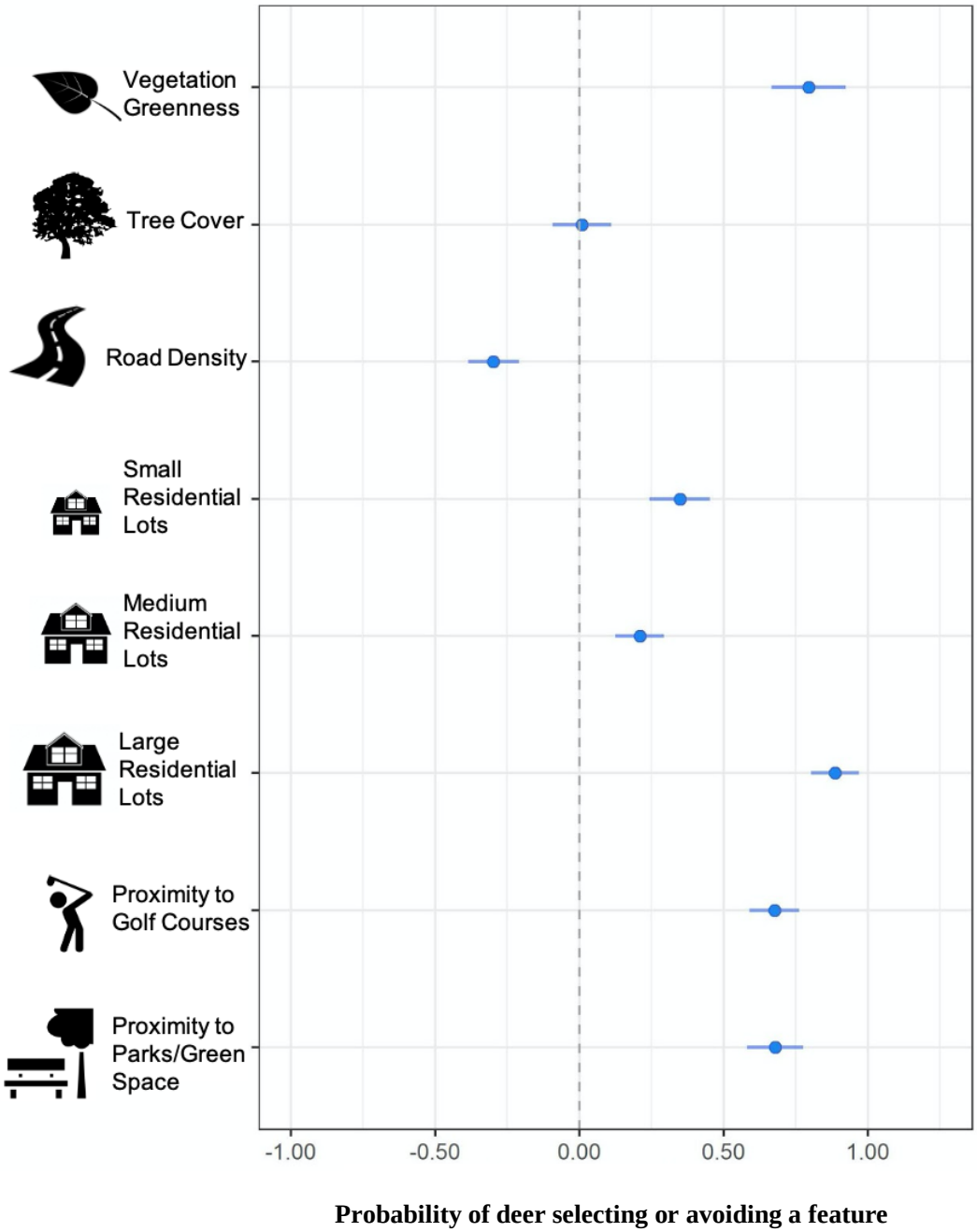

Figure 1. The probability of black-tailed deer selecting (or avoiding) natural and urban landscape features across Oak Bay, BC. Values greater than 0 represent selection for these features by deer (e.g. vegetation greenness, large residential lots) while values less than 0 indicate avoidance (e.g. roads). Values overlapping zero indicate neither avoidance nor selection (e.g. tree cover). Vegetation greenness and large-sized residential lots were the most important predictors of deer habitat-use.

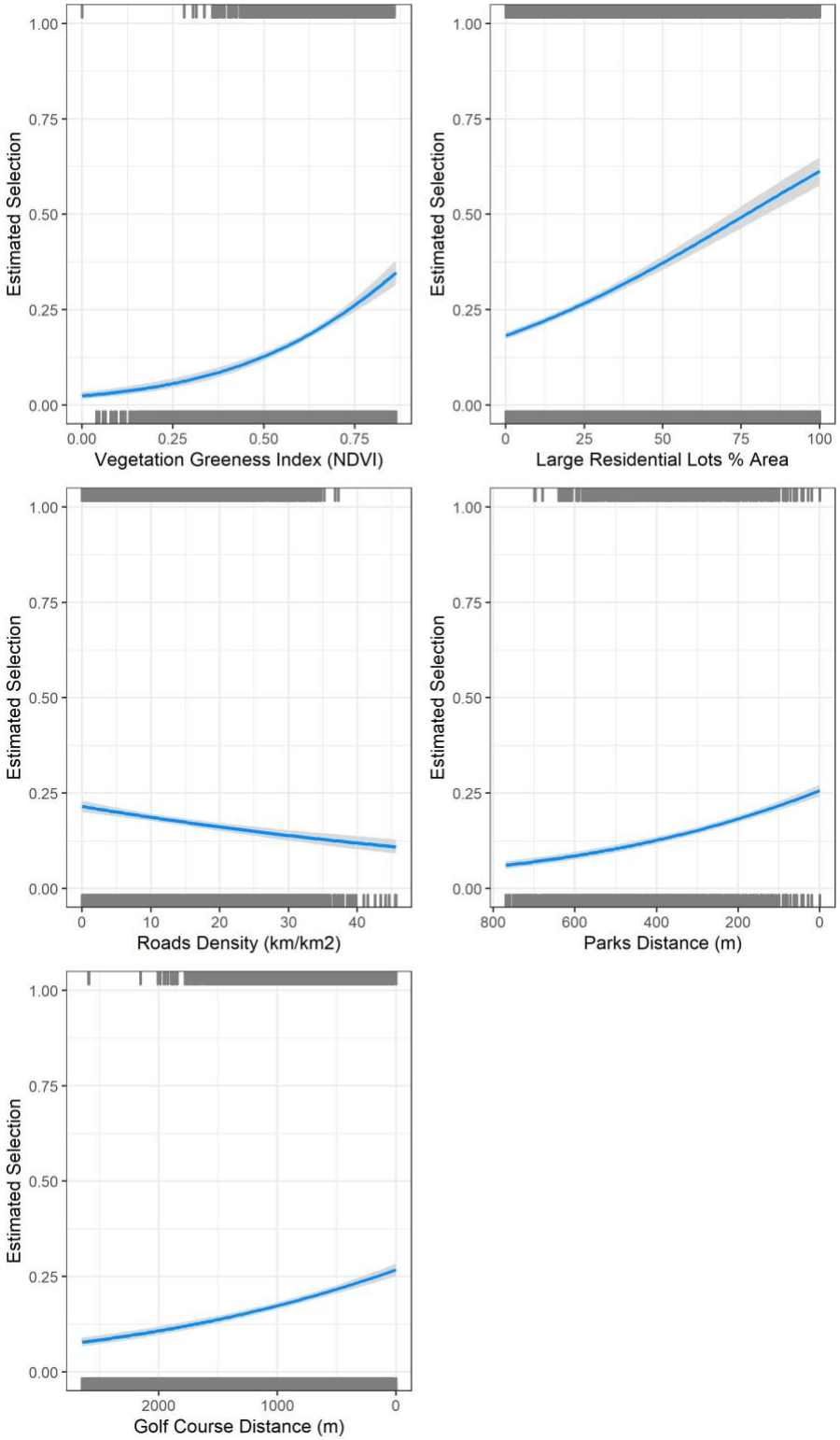

Figure 2. Effect size of the estimated habitat selection relationships of black-tailed deer in Oak Bay, BC. A steep slope indicates a strong relationship.

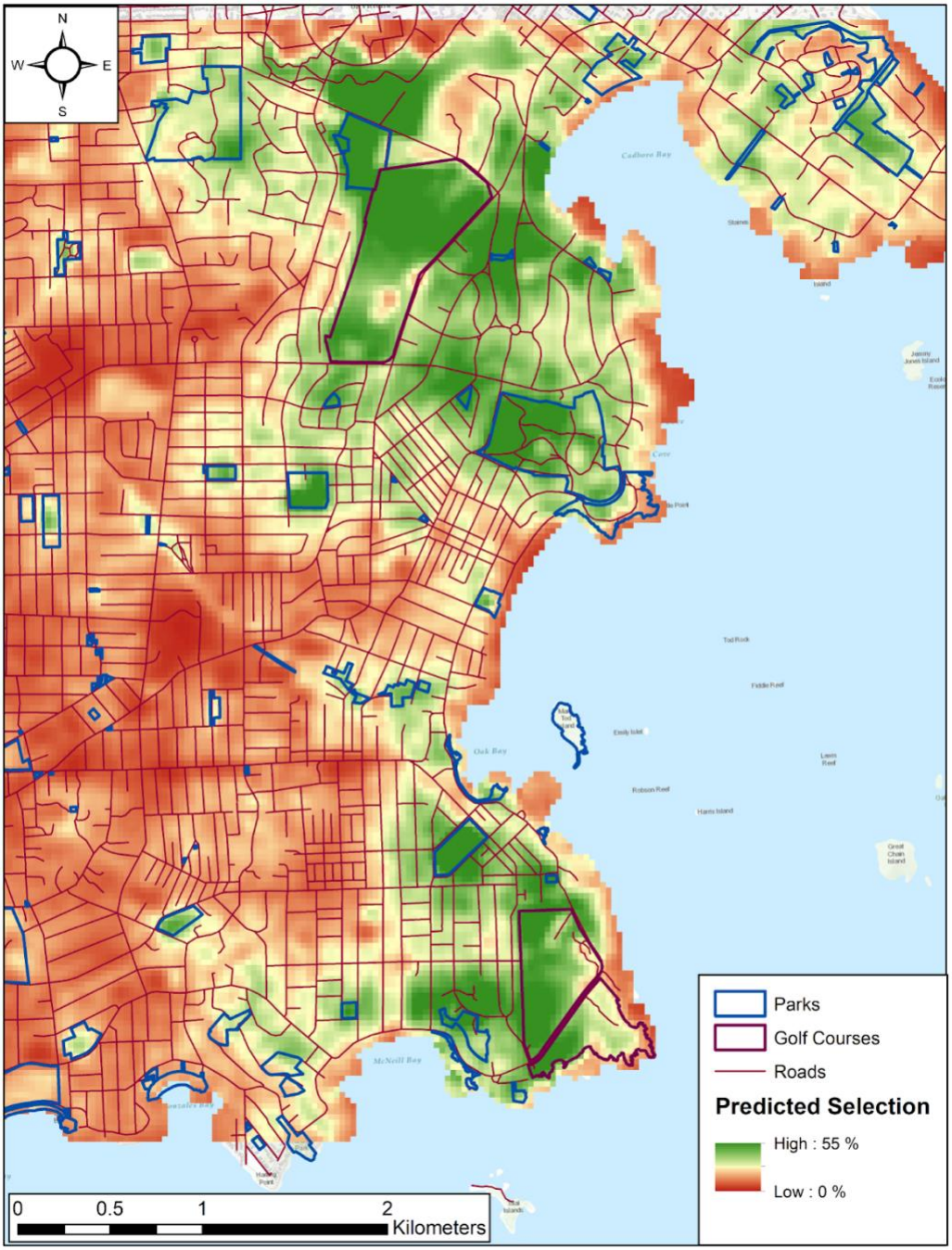

Figure 3. Black-tailed deer habitat-use across the District of Oak Bay, BC based on extrapolated predicted deer response (beta coefficients) to natural and urban landscape features. Green areas represent areas with high predicted deer habitat-use, while areas with low predicted habitat-use are shown in red. Golf courses and parks are outlined in purple and blue, respectively. Roads are shown as red lines.

Discussion

Deer habitat-use across Oak Bay, BC is best predicted by a combination of natural features as well as large residential lots. Proximity to golf courses and parks were also selected for by deer, while areas with a high road density were avoided. Deer showed a weaker selection for small and medium-sized residential lots, and no response to tree cover. Our results provide insights into deer responses to both natural and urban features of the landscape, with important implications for landscape management across Oak Bay.

Landscaping practices across Oak Bay are likely playing a significant role in shaping deer habitat-use and distribution across the District. Deer selection for areas with high-productivity vegetation highlights the importance of forage availability in predicting deer habitat-use. Higher vegetation greenness is represented in areas with healthy and dense vegetation, and is inversely linked to dry or drought conditions[19]. We observed a tight correlation with vegetation greenness (measured as NDVI) and the normalized difference moisture index (Supplementary Information, Figure A2), with higher soil moisture associated with higher vegetation greenness. Our reference to the observed values of vegetation greenness and tree cover across Oak Bay as "natural" may therefore not be representative of true historic values prior to colonial landscaping practices. The district of Oak Bay was historically a large expanse of the now endangered Garry oak ecosystem[20], a habitat associated with extended summer drought, Garry Oak trees, camas and other dry, nutrient-poor vegetation. Landscaping practices including lawn watering and irrigation on golf courses has likely changed conditions across Oak Bay to support high-productivity plants of greater palatability to deer. This conversion of historically well-drained, drought-resistant Garry oak ecosystems to modern watered lawns and

high-productivity vegetation is an important contributor to the observed increase in native black-tailed deer in Oak Bay, and likely to municipalities across the Capital Regional District.

Beyond the effects of natural vegetation, large residential lots are also a highly significant predictor of urban deer habitat-use in our study area. Large-sized residential lots are generally represented in neighbourhoods of low human density. Deer are therefore likely responding to the decreased human disturbance associated with these neighbourhoods, as well as the likely higher density of high-productivity vegetation associated with larger residential lots. Deer naturally select meadow environments, and these large lots may approximate those natural features within the urban landscape. Thus neighbourhoods with larger lot sizes and high investment into landscaping – features often associated with affluence – are therefore more likely to experience higher deer use.

Anecdotal evidence suggests that deer in our study area show a strong affiliation to golf courses. However, as golf courses provide open sightlines, probability of deer observation by the public is therefore much higher and likely to bias observational conclusions around deer distribution across Oak Bay. Our analysis confirms that proximity to golf courses is a positive, though comparatively weak, predictor of deer habitat-use. As deer capture for GPS collaring was not permitted directly on the golf courses, it is possible that deer association with this habitat type may be underrepresented in our study. However, we compensated for this potential underrepresentation by collaring deer at the edges of golf course habitat, where deer would be expected to use both the golf course and neighbouring properties throughout their home range. Deer association with areas of a high proportion of golf course habitat may be further evaluated through the concomitant camera trapping study evaluating deer distribution and density across Oak Bay.

Conclusions

Deer habitat-use across Oak Bay is best predicted by a combination of vegetation and large-sized residential lots. Extrapolated deer responses to vegetation and urban features highlight areas in both the north and south end of the district as providing high-quality deer habitat. Urban practices of lawn watering and irrigation likely contribute to a greater abundance of high-productivity plants sought out by deer. Large residential lot sizes likely provide both high-quality forage to deer via urban landscaping practices, as well as reduced human density and disturbance. Conversion of historical drought-resistant Garry oak ecosystems into lush and landscaped urban environments may explain the observed increase in black-tailed deer across the Oak Bay and surrounding municipalities of the CRD.

Acknowledgements

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Literature Cited

1 Ballard, W. B., Carbyn, L. N. & Smith, D. W. Wolf interactions with non-prey. (2003).

2 Gilbert, B. A. & Raedeke, K. J. Recruitment dynamics of black-tailed deer in the western Cascades. *The Journal of wildlife management* **68**, 120-128 (2004).

3 Forrester, T. D. & Wittmer, H. U. A review of the population dynamics of mule deer and black-tailed deer O docoileus hemionus in N orth A merica. *Mammal Review* **43**, 292-308 (2013).

4 Weckerly, F. W. Selective feeding by black-tailed deer: forage quality or abundance? *Journal of Mammalogy* **75**, 905-913 (1994).

5 Wright, C. A., Adams, I. T., Stent, P. & Ford, A. T. Comparing Survival and Movements of Non-Urban and Urban Translocated Mule Deer. *The Journal of Wildlife Management* **84**, 1457-1472 (2020).

6 Schell, C. J. *et al.* The evolutionary consequences of human–wildlife conflict in cities. *Evolutionary Applications* **14**, 178-197 (2021).

7 McCullough, D. R. In my experience: what do herd composition counts tell us? *Wildlife Society Bulletin*, 295-300 (1994).

8 Geldmann, J. *et al.* What determines spatial bias in citizen science? Exploring four recording schemes with different proficiency requirements. *Diversity and Distributions* **22**, 1139-1149 (2016).

9 Boyce, M. S. & McDonald, L. L. Relating populations to habitats using resource selection functions. *Trends in ecology & evolution* **14**, 268-272 (1999).

10 Seidel, D. P., Dougherty, E., Carlson, C. & Getz, W. M. Ecological metrics and methods for GPS movement data. *International Journal of Geographical Information Science* **32**, 2272-2293 (2018).

11 Chetkiewicz, C. L. B. & Boyce, M. S. Use of resource selection functions to identify conservation corridors. *Journal of Applied Ecology* **46**, 1036-1047 (2009).

12 Abrahms, B. *et al.* Does wildlife resource selection accurately inform corridor conservation? *Journal of Applied Ecology* **54**, 412-422 (2017).

13 Laforge, M. P., Brook, R. K., van Beest, F. M., Bayne, E. M. & McLoughlin, P. D. Grain-dependent functional responses in habitat selection. *Landscape Ecology* **31**, 855-863 (2016).

14 Anderson, D. P. *et al.* Scale-dependent summer resource selection by reintroduced elk in Wisconsin, USA. *The Journal of Wildlife Management* **69**, 298-310 (2005).

15 Stewart, F. E. C. *Understanding and sampling spatial ecological process for biodiversity conservation in heterogeneous landscapes*, (2018).

16 Taylor, A. Capital Regional District land cover mapping 1986, 2005, and 2011, Summary Report. (Habitat Acquisition Trust, 2013).

17 Burnham, K. P., Anderson, D. R. & Huyvaert, K. P. AIC model selection and multimodel inference in behavioral ecology: some background, observations, and comparisons. *Behavioral ecology and sociobiology* **65**, 23-35 (2011).

18 Burnham, K. P. & Anderson, D. R. A practical information-theoretic approach. *Model selection and multimodel inference* **2** (2002).

19 Drisya, J. & Roshni, T. in *Integrating disaster science and management* 451-460 (Elsevier, 2018).

20 GOERT. *What Remains of Garry Oak Ecosystems?*, <https://goert.ca/about/what-remains/> (2021).

Supplementary Information

Figure A1. Home ranges of female BTD representing areas where 97.5% of each individual's space use is expected to occur. 16 out of 20 GPS collars collected sufficient location fixes to plot the individual's home range. Each individual deer is represented by a unique colour. Home range zones are based on GPS telemetry-location fixes collected from February 2018 to March 2020.

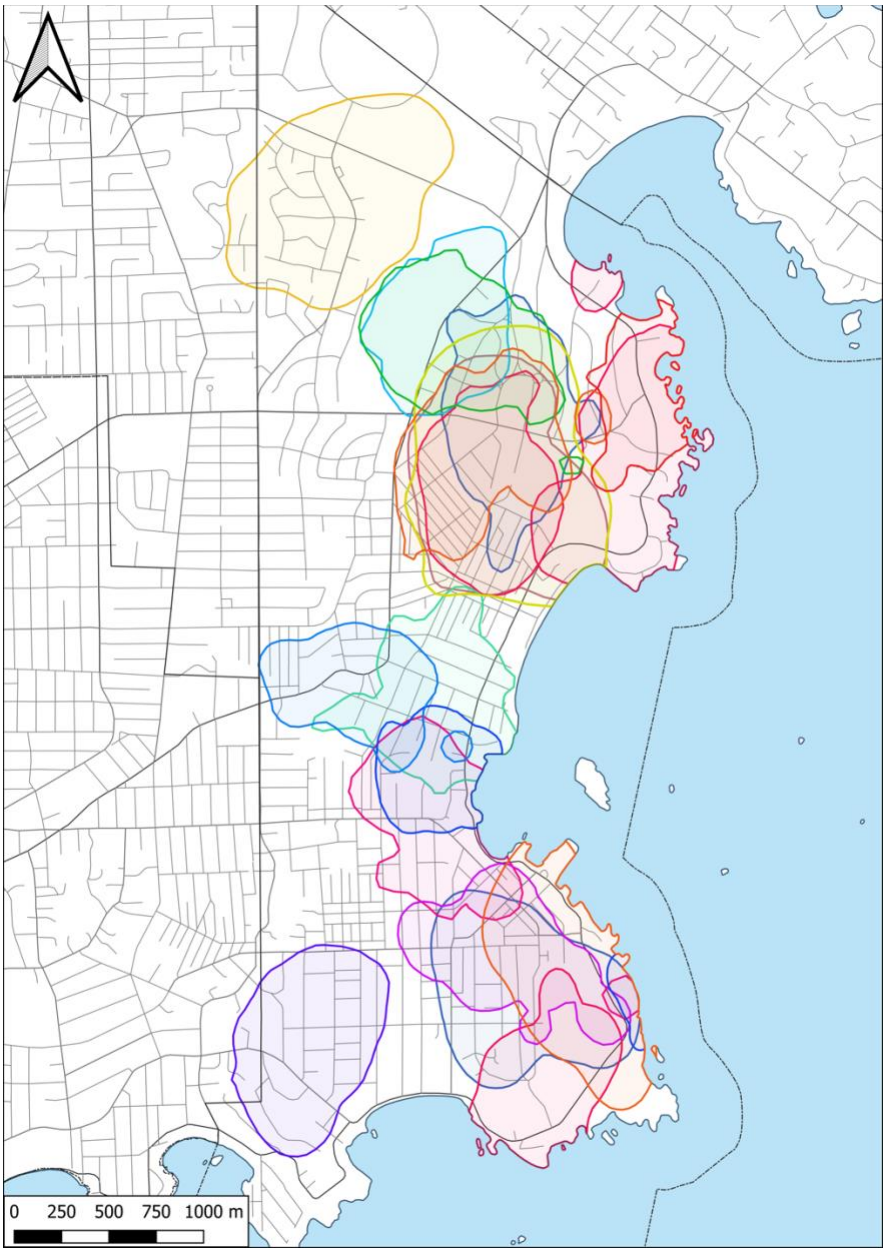

Figure A2: Correlation between Normalized Difference Vegetation Index (NDVI) and Normalized Difference Moisture Index (NDMI) across Oak Bay, BC. NDMI and NDVI show a strong positive relationship of 0.92.