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Source: Journal of Raptor Research, 55(1) : 65-78

Published By: Raptor Research Foundation

URL: https://doi.org/10.3356/0892-1016-55.1.65

J. Raptor Res. 55(1):65–78

ASPECTS OF THE ECOLOGY OF URBAN-NESTING BALD EAGLES (*HALIAEETUS LEUCOCEPHALUS*) IN SOUTH-COASTAL BRITISH COLUMBIA

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Abstract.—Bald Eagle (*Haliaeetus leucocephalus*) populations throughout North America have increased considerably since the ban of DDT in 1972 and eagles now inhabit suburban areas in large numbers. To better understand the ecology of urban populations living in south-coastal British Columbia, we compared nest-site characteristics, reproductive rates, and diets of more than 150 breeding pairs of rural-, suburban- and urban-nesting eagles in the Greater Vancouver area. Three-quarters of the nests were located within 230 m of buildings and roads, or within 31 m of a potential source of disturbance. Urban eagles nested in live, taller trees that were close to the edges of patches, whereas rural eagles used shorter trees and occasionally human-made structures such as transmission towers. Eagles at nests located close to patch edges and in areas with greater human land use had higher reproductive rates than those at isolated nests or in remote rural habitat. Waterfowl and gulls (family Laridae) were common in the diet across the study area, but urban eagles also used alternative sources such as C-O sole (*Pleuronichthys coenosus*), Bufflehead (*Bucephala albeola*), and Band-tailed Pigeon (*Patagioenas fasciata*). Eagles in the Vancouver area have adapted to human-altered landscapes; management strategies should focus on maintaining edge habitat, monitoring population expansion in urban areas, and protecting nest sites.

Key Words: *Bald Eagle*; Haliaeetus leucocephalus; *British Columbia*; *diet*; *nest-site characteristics*; *productivity*; *species recovery*; *urban ecology*; *wildlife-human interactions.*

ASPECTOS DE LA ECOLOGÍA DE LOS INDIVIDUOS DE *HALIAEETUS LEUCOCEPHALUS* QUE NIDIFICAN EN LUGARES URBANOS EN LA COSTA SUR DE COLUMBIA BRITÁNICA

Resumen.—Las poblaciones de *Haliaeetus leucocephalus* a lo largo de todo Norteamérica han aumentado considerablemente desde la prohibición del DDT en 1972 y actualmente las águilas habitan las áreas suburbanas en gran número. Para entender mejor la ecología de las poblaciones urbanas que viven en la costa sur de Columbia Británica, comparamos las características del lugar de cría, las tasas reproductivas y la dieta de más de 150 parejas reproductoras que nidifican en ambientes rurales, suburbanos y urbanos en el área del Gran Vancouver. Tres cuartos de los nidos estuvieron localizados dentro de los 230 m de edificios y carreteras, o a menos de los 31 m de una fuente potencial de molestias. Las águilas urbanas anidaron en árboles altos y vivos, cercanos a los bordes de los parches, mientras que las águilas rurales usaron árboles más bajos y ocasionalmente estructuras antrópicas como torres de transmisión. Las águilas con nidos localizados cerca de los bordes de los parches y en áreas con mayor uso antrópico del suelo tuvieron tasas reproductoras más altas que aquellas con nidos aislados o en hábitats remotos. Las aves acuáticas y las gaviotas (Laridae spp.) fueron comunes en la dieta a lo largo de toda el área de estudio, pero las águilas urbanas también usaron fuentes alternativas de alimento, como el pez plano *Pleuronichthys coenosus* y las aves *Bucephala albeola* y *Patagioenas fasciata*. Las águilas en el área de Vancouver se han adaptado a los paisajes antrópicos; las estrategias de gestión deberían enfocarse en mantener el hábitat de borde, seguir la expansión de las poblaciones en las áreas urbanas y proteger los lugares de cría.

[Traducción del equipo editorial]

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INTRODUCTION

Bald Eagle (*Haliaeetus leucocephalus*) populations throughout North America have increased considerably since the ban of DDT in 1972 and formal listing under the Endangered Species Act. They are now reaching or exceeding former population numbers (Hancock 2003, Buehler 2020), although there have been lags in recovery in some areas (Cruz et al. 2018). Despite the fact that raptors in general have had a traditional reputation of being sensitive to human proximity and disturbance (Newton 1979, Bird et al. 1996, Robertson 2002, Gonzalez et al. 2006, Martinez-Abrain et al. 2010), Bald Eagles have invaded suburban areas such as agricultural fields and city parks in large numbers (Berry et al. 1988, Gerrard and Bortolotti 1988, Elliott et al. 2011, Jones et al. 2013). South-coastal British Columbia, from Vancouver Island to the Fraser Valley, is no exception. Several hundred active nests are found in the region, compared to two nesting pairs in the 1960s (Hancock 2003), and between 250 and 1800 Bald Eagles forage daily at the Vancouver landfill site, despite heavy disturbance caused by machinery (Elliott et al. 2006, D. Hancock unpubl. data). Overall, the ecology of Bald Eagles in urban settings is poorly known (Buehler 2020). Generally, Bald Eagles prefer nest trees that are mature and robust, often super-canopy, and with appropriate branching patterns to support the nest and allow easy access for landings (Gerrard et al. 1975, Watts et al. 2007, Buehler 2020). However, Bald Eagle populations breeding in south-coastal British Columbia commonly nest on artificial structures or close to large commercial facilities, with nests sometimes as close as 10 m from residences or roads, or as low as 12 m from the ground (Hancock 2003, R. Goulet unpubl. data). Eagle diet in urban environments has also not yet been fully investigated. Although Bald Eagles' most common prey are salmon (*Oncorhynchus* spp.), carp (*Cyprinus carpio*), yellow perch (*Perca flavescens*), waterfowl and gulls (*Larus* spp.), muskrats (*Ondatra zibethicus*) and hares (*Lepus* spp.; Stalmaster 1987, Gerrard and Bortolotti 1988, Mersmann et al. 1992), web cameras installed at several nests in the region have recorded adult eagles delivering small garbage bags, presumably from nearby landfill sites (D. Hancock unpubl. data).

The overall aim of our study was to investigate the ecology of Bald Eagles living along an urban gradient in south-coastal British Columbia. Specifically, we conducted a comparative study of the (1) nest-site characteristics; (2) productivity; and 3) diet of eagles breeding in three types of habitats: remote rural, suburban, and urban. We hypothesized that there would be differences in some or all of these parameters among these three habitat types. This information will improve our understanding of the ecology of Bald Eagles in human-dominated landscapes, which can inform the management of this species as it continues to expand its range.

METHODS

Study Area. We focused our study from West Vancouver to Central Saanich on Vancouver Island, British Columbia, Canada, an area of 9700 km^2, with the easternmost nests in Chilliwack up the Fraser Valley. A few nests were also sampled around Blaine in northwestern Washington, USA (Fig. 1).

The city of Vancouver is heavily urbanized with important residential agglomerations, commercial facilities, and coastal ports. It also contains fairly expansive forested areas such as Stanley Park and the University of British Columbia (UBC) endowment lands. Most parts of West Vancouver, North Vancouver, and Richmond also are considered urban. South of Richmond is Delta, characterized by numerous agricultural fields, wildlife sanctuaries and protected islands, the Burns bog and its landfill, a golf course, and suburban zones. The part of Surrey included in this study borders Boundary Bay and is mostly agricultural and suburban in nature. The section of the Fraser Valley located between Abbotsford and Chilliwack is mostly agricultural.

Bald Eagles are found throughout the study area, with particular concentrations in Delta. Nonbreeders and juveniles forage in garbage landfills and exploit the low-tide flats for fish (Elliott et al. 2006). Black cottonwood (*Populus balsamifera trichocarpa*) is the most dominant tree species throughout the study area and is particularly common in farmlands, but considerable numbers of Douglas fir (*Pseudotsuga menziesii*) are found along the ocean and inland waters as well as in larger and mature forest stands.

Nest-site Characteristics. We measured nest-site characteristics as in past studies of nesting raptors (Andrew and Mosher 1982, Gerrard and Bortolotti 1988, Anthony and Isaacs 1989, Buehler 2020). Land-use categories (urban, suburban, and remote rural) differed from land-cover types (farmland, forested, residential, developed, and wetland), and due to the fragmented nature of the study area, classifications were not always aligned; for example, a nest on farmland land cover could be in the

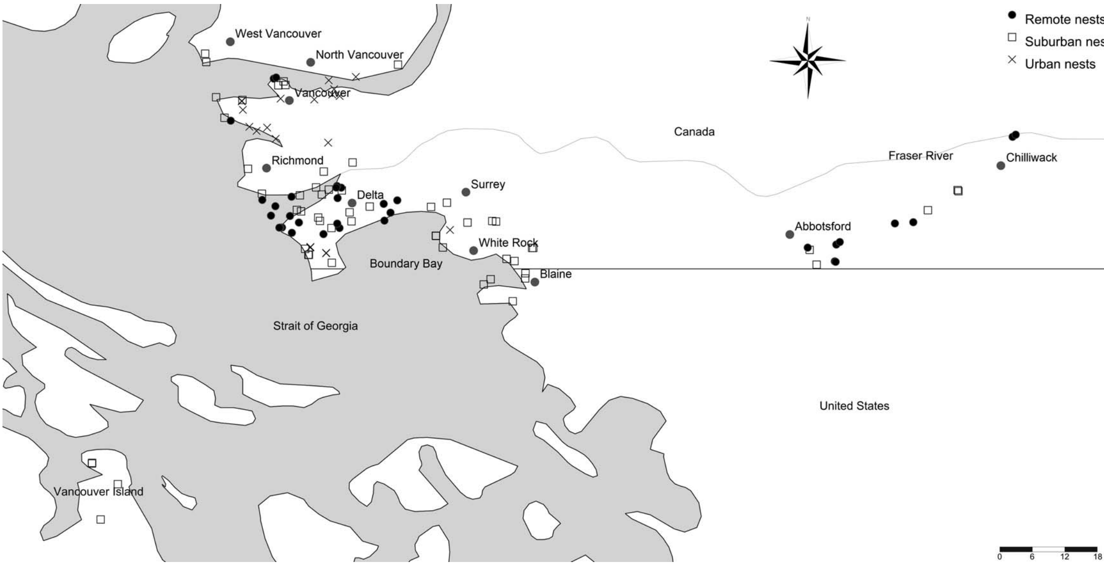

Figure 1. Map of study area, showing the distribution of 112 Bald Eagle (*Haliaeetus leucocephalus*) nests sampled for nest-site characteristics.

remote rural, suburban, or even urban land-use category. Measurement techniques were standard (Table 1); for more details, see Goulet (2010).

Measurements of Reproductive Rates. Previous data on reproductive rates, collected from 2004 to 2007 by researchers, conservation societies, and landowners, comprised incomplete data on egg-laying/incubation, nesting success, and the number of young produced for nests in the study area (D. Hancock unpubl. data). We used these nests as the starting point for our own study, conducted from April to August in 2008 and 2009, with adapted methods chosen to ensure consistency and compatibility between data sets. We included reproductive data from 2004 to 2007 in our analysis as appropriate.

We defined an occupied territory as one with at least one adult on the nesting territory at multiple times during the length of breeding season, i.e., from territory establishment to fledging of young. We considered a nest active after there was evidence of egg-laying (i.e., incubating adult or the presence of young; Grubb et al. 1975, Dykstra et al. 2009). We defined nesting success as the percentage of active nests that resulted in at least one fledged young. Productivity was the number of young successfully fledged per active nest. Fledging referred to the time of the departure of an eaglet from the nest of its own volition for the first time (Steenhof and Newton 2007). We reported productivity according to nesting territories rather than just individual nests (territory defined as in Steenhof and Newton 2007).

We visited each nest to monitor reproductive status at least twice per year. Because our efforts did not cover the first few months of the breeding season when failures are frequent, we did not tally occupancy data, to avoid overestimation of reproductive rate. Therefore, on the first visit (activity survey), we determined whether eggs had been laid; the subsequent visit(s) were conducted around estimated fledging time to determine productivity (McEwan and Hirth 1979, Fraser et al. 1985, Jenkins and Jackman 2006, Watts et al. 2008). We determined nest status by observations made with binoculars from the best viewing angles that minimized disturbance.

Diet. We collected food remains and regurgitated pellets below 68 nests throughout the study area in 2008 (see methods in McEwan and Hirth 1980, Cash et al. 1985). We scanned a zone of about a 10 m-radius on the ground around each nest for feathers, bones, hair, full carcasses, animal parts, and regurgitated pellets. We identified food items by comparison with the reference research and student collection at University of British Columbia's Cowan Vertebrate Museum (Newsome 1977, Marti et al. 2007). Within a given sample, we recorded identification of a species as one occurrence, because it was

Table 1. Characteristics measured at nest sites of Bald Eagles (*Haliaeetus leucocephalus*) in the Pacific south-coastal region in the Vancouver environs, British Columbia, Canada.

NEST-SITE CHARACTERISTIC	ABBREVIATION	DESCRIPTION
Land-use category:		Categories from Millsap et al. (2004)
Remote rural	R	Nests with a percentage of human land use of <5% within 1.5 km of nest
Suburban	S	Nests with a percentage of human land use between 5% and 50% within 1.5 km
Urban	U	Nests with a percentage of human land use >50% within 1.5 km of nest
Latitude	Lat	Obtained in the field with a GPS
Longitude	Long	Obtained in the field with a GPS
Nest substrate/tree species		Identified with field guide (Wenger 1984) or the Wildlife Tree Species Program (WiTS)
Black cottonwood	BC	
Douglas fir	DF	
Artificial structure	A	
Other species	Oth. or Others	
Tree height	THT	Obtained with range finder
Nest height	NHT	Obtained with range finder
Diameter at breast height	DBH	Measured with DBH tape
Tree status:		
Live	L	Assessed visually
Dead	D	Assessed visually
Tree dominance	Dom	Classified compared to other trees in the surroundings using a qualitative scale from 1 to 5 (1 = most dominant)
Tree isolation	Iso	Classified compared to other trees in the surroundings using a qualitative scale from 1 to 5 (1 = most isolated)
Distance of nest tree to closest:		Obtained with ArcGIS 9.3
Water	W	Any accessible and open water body, from permanent stream to wetland to ocean
Shoreline	SL	Any lake or ocean shoreline
Building	Bldg	
Road	Trspt	Any path, track or road potentially used by motor vehicles
Source of potential disturbance	Disturb	Building, road, walking path, public park, agricultural field, boating activity, etc.
Habitat patch edge	Edge	
Percentage of human land use	%LU	Obtained with ArcGIS 9.3 (calculated for a circular plot centered on the nest, with a radius of 1.5 km[a]
Land-cover type:		Type of landscape present at the base of each nest, obtained with ArcGIS 9.3 and validated in the field
Farmland	Farm	
Forested	For	
Residential	Res	
Developed	Dev	
Wetland	Wet	

[a] see Goulet (2010) for details.

difficult to determine whether more than one individual was present (Mersmann et al. 1992).

Statistical Analyses. We used K-means partitioning (Calinski and Harabasz 1974, Legendre and Legendre 1998) to cluster groups of nests with significantly distinctive nest-site characteristics, in the hopes of finding distinctions at the geographic scale (e.g., different land-use categories: urban vs. suburban vs. remote rural areas).

To evaluate the effect of nest-site characteristics on productivity and diet in the different land-use categories (urban, suburban, and remote rural), we used redundancy analysis (RDA; Legendre and Legendre 1998). This allowed us to account for interdependence among nest-site characteristics and their potential combined effect on the response variables. We centered nest-site characteristics, productivity, and diet data on their means, with nest-site characteristics further scaled to standardize their different units. We used Type II scaling for the biplots, to focus on the ordination of the predictor variables (nest data). Both normal and binary productivity (i.e., produced young = 1 and failed = 0) tables were used. We repeated diet analysis at the family and species taxonomic levels to determine most important food items. We used forward selection to select the characteristics with the greatest influence on productivity and diet (Legendre and Legendre 1998).

We performed all statistical analyses using R (R Development Core Team, 2008–2009). Nest-site characteristics are presented as mean ± SD.

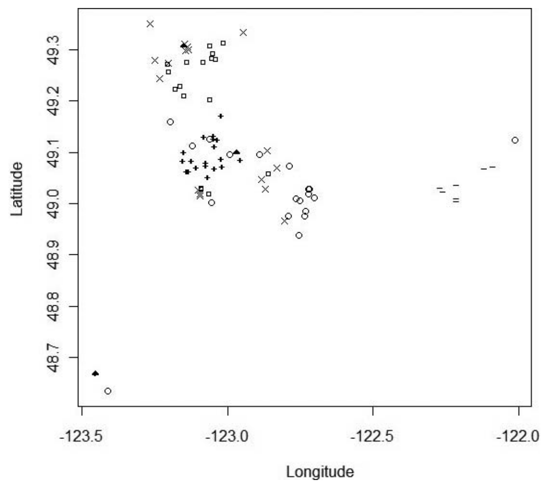

Figure 2. K-means groups for Bald Eagle (*Haliaeetus leucocephalus*) nest-site characteristics ($n = 87$). Nests with similar characteristics have matching symbols and show geographical clumping over urban, suburban, and remote rural areas. Compare to Figure 1 for geographical features.

RESULTS

Nest-site Characteristics. Black cottonwood (62%) and Douglas fir (30.4%) were by far the two most commonly used nest tree species ($n = 158$), followed by artificial structures (4.4%), and other tree species (3.2%). Tree height averaged 35.0 m ± 10.9 m ($n = 101$), nest height 27.7 m ± 10.7 m ($n = 98$), and diameter at breast height (DBH) 115.5 cm ± 41.5 cm ($n = 90$) over the entire study area, with heights ranging from 10 to 67 m and DBHs from 26 to 260 cm. Eagles primarily built their nests in live trees (90% of total) rather than in dead trees or human-made structures. Average tree dominance (2.5 ± 1; $n = 113$) was just above the middle of the scale from 1 to 5, meaning that selected trees were relatively taller than other trees in their surroundings.

By land-use category, most nests were classified suburban (50% of all 112 nests for which land use was determined); 32% of nests were classified remote rural, and the remaining 18% were urban. Nests were located on residential land cover (33.3%), followed by forests (29.9%), farmland (26.5%), and to a smaller extent wetlands (6.9%) and developed areas (3.4%; $n = 117$). Three-quarters of the nests (84 of 112) were located within 1.3 km of water, 230 m of buildings and roads, and 31 m from a potential source of disturbance. Black cottonwood represented two-thirds of all nest tree species in remote rural areas, and Douglas fir accounted for 55% of all urban nests. The great majority (92%) of nests on artificial structures (transmission towers and high-tension poles) were found in remote rural settings, and none of the urban pairs nested on artificial nest substrates.

K-means analysis separated the nests into six groups ($n = 87$), each represented by a different symbol on the nest distribution map (Fig. 2). The nests showed clear geographical clumping, meaning that nests with overall similar characteristics were found among the data and were grouped together over areas with different levels of urbanization.

Reproductive Rate. From the existing 2004–2007 data set, we visited 140 nests again in 2008 and 2009, representing 108 nesting territories with an average of 1.3 nests/territory. Over the 6-yr span, nesting success averaged 68.3% (75% for 2004 [$n = 8$]; 78% for 2005 [$n = 18$]; 65% for 2006 [$n = 23$]; 52% for 2007 [$n = 29$]; 76% for 2008 [$n = 70$]; 66% for 2009 [$n = 70$]) and a total of 248 fledglings were produced in 218 active nests, giving an average productivity of 1.1 young/active nest. When calculated only for successful nests, average reproductive rate was 1.7 young/successful nest. Thirty-nine percent of successful nests produced one young, 55% produced two, and the remaining 6% of nests produced three young.

To test for effects of nest-site characteristics on productivity, we carried out a redundancy analysis for the entire data set, as well as for shorter time spans within the 6 yr to detect more subtle patterns.

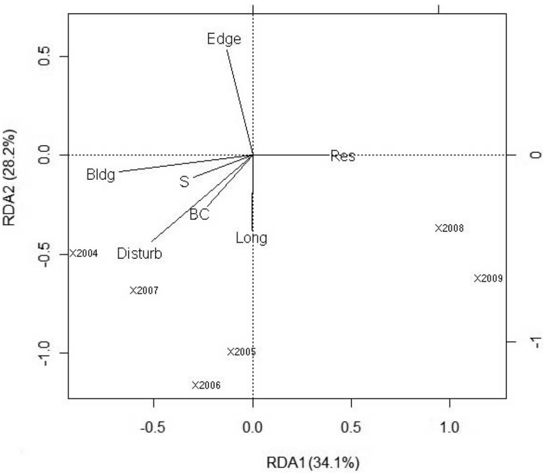

Figure 3. Redundancy analysis after forward selection for binary productivity of Bald Eagles (*Haliaeetus leucocephalus*) in 2004–2009 with respect to nest-site characteristics ($F = 3.77$, df = 7, $P = 0.047$; see Table 1 for a description of abbreviations). Proportion of total variation explained by both predictors is 62.3%. The sequence of years from left to right indicates change in the relationship between nest features and productivity. We represented year symbols by the year number preceded by an X.

Variations in productivity were always significantly explained by nest-site characteristics except for 2008–2009. The most significant effect was for 2007–2009 ($F = 5.705$, df = 15, $P = 0.001$), in which 92.4% of the variation in productivity was explained by the relationship with nest-site characteristics. Farmland land cover and tree height appeared to be the dominant characteristics, along with latitude, distance to road, shoreline, and patch edge. We found similar results for binary productivity. A biplot for 2004–2009 indicated that a nest in 2004 was more productive when built in a black cottonwood, in a suburban landscape but far from buildings and disturbance (Fig. 3). In 2009, after a progressive migration through the bi-plot for each year, productivity had shifted nearly to the opposite pole, suggesting that distance from roads or disturbance, among other factors, was no longer associated with productivity. Proximity to patch edge also seemed to be important for 2009.

Of 26 separate analyses performed with forward selection, distance to patch edge was negatively correlated with productivity 100% of the time, meaning nests on edges were always more productive (Table 2). Percentage of human land use, tree isolation, and farmland land cover pointed in the same direction as productivity 100% of the time, which implies that urban, non-isolated, and farmland nests produce more young. Higher latitudes, remote rural land use, and nests that were far from shorelines were associated with reduced productivity, according to the selection frequencies.

Diet. The samples collected from 68 different nesting sites totaled 622 individual items, of which 542 were identified to family, 474 to genus, and 420 to species. The unknown items for each taxa were not integrated in the analyses. Feathers accounted for 42% of food remains, followed by bones (36%), larger body parts (9%), regurgitated pellets (6%), and hair (2%). Samples represented 35 bird species ($n = 524$), 8 mammals ($n = 44$ items), 6 fish ($n = 46$ items), and 3 invertebrates ($n = 3$ items). Family Anatidae constituted more than half (51.1%) of the identified samples, followed by Laridae (18.1%) and Columbidae (5.7%). Fish were mostly represented by Cyprinids (4.4%) and mammals by Murids (2.4%) and Leporids (1.5%; Table 3). Eight species accounted for 70.9% of identified food remains: Mallard (*Anas platyrhynchos*), Glaucous-winged Gull (*Larus glaucescens*), American Wigeon (*A. americana*), Rock Pigeon (*Columba livia*), Northern Pintail (*A. acuta*), carp, Northwestern Crow (*Corvus caurinus*) and Ring-billed Gull (*L. delawarensis*). Fish and mammals both contributed approximately 7% to the samples, with the most common being carp and eastern cottontail (*Sylvilagus floridanus*).

Of the 622 collected food items, 163 were collected in remote rural land-use areas, 321 in suburban, and 138 in urban settings, which closely resembled the proportion of nests within each land-use category. Birds were the most common food remains in all three landscapes. For the remote rural nests, birds made up 74.8% of items, fish 14.8%, and mammals 6.8%. In suburban settings, birds made up 88.1%, mammals 8.4%, and fish 3.4%. At urban nest sites, birds made up 85.2%, fish 8.1%, mammals 4.4%, and invertebrates 2.2%. Rock Pigeon, Northwestern Crow, C-O sole (*Pleuronichthys coenosus*), Pacific sanddab (*Citharichthys sordidus*), and Ring-billed Gull were more frequent at urban nests than at nests in the other land-use categories. Dungeness crab (*Cancer magister*), blue mussel (*Mytilus edulis*), and softshell clam (*Mya arenaria*) were only found in urban samples (Table 4).

The redundancy analysis conducted at the family level mainly highlighted the importance of Muridae and Paralichthyidae, which could not be assessed

Table 2. Selection frequencies of nest-site characteristics of Bald Eagles (*Haliaeetus leucocephalus*) in the Pacific south-coastal region in the Vancouver environs, British Columbia, Canada, in all performed forward selections.

NEST-SITE CHARACTERISTIC	FREQUENCY OF SELECTION (%)	CORRELATION WITH PRODUCTIVITY (RDAS)[a] +	–	EFFECT ON PRODUCTIVITY
Dist. to edge (Edge)*	92.3	0	20	–
Latitude (Lat)	80.8	2	15	–
Dominance (Dom)	69.2	4	11	+
% Human land use (% LU)*	69.2	14	0	+
Dist. to building (Bldg)	65.4	4	10	–
Remote rural land use (R)*	65.4	0	15	–
Tree isolation (Iso)*	65.4	13	0	–
Dist. to water (W)	65.4	6	7	+/–
Dist. to disturbance (Disturb)	57.7	10	2	+
Farmland land cover (Farm)*	50	9	0	+
Forest land cover (For)	50	3	7	–
Longitude (Long)	46.2	2	8	+
Dist. to road (Trspt)	46.2	2	7	–
Dist. to shoreline (SL)*	42.3	0	9	–
Suburban land use (S)	38.5	5	2	+
Diameter at breast height (DBH)	34.6	2	5	–
Wetland land cover (Wet)	34.6	2	5	–
Nest height (NHT)	34.6	4	4	+/–
Tree height (THT)	30.8	5	1	+
Developed land cover (Dev)*	26.9	3	0	+
Artificial nest structure (A)*	26.9	0	4	–
Dead nest tree (D)	23.1	2	2	+/–
Black cottonwood (BC)*	23.1	3	0	+
Residential land cover (Res)	19.2	4	1	+
Douglas fir (DF)	19.2	2	3	–
Urban land use (U)	19.2	4	1	+
Live nest tree (L)	15.4	1	2	–

[a] We obtained correlations to productivity in resulting RDAs by compiling the number of times an arrow was pointing towards (positive correlation) and away from (negative correlation) year position vectors; asterisks (*) indicate effects with the same correlation with productivity for >95% of tests.

through the species analysis. For species, Snow Goose (*Anser caerulescens*), Mallard, carp, and Northern Pintail were more frequent in remote rural samples; as were Greater Scaup (*Aythya marila*), Canada Goose (*Branta canadensis*), and domestic cattle (*Bos taurus*) in suburban samples; and Rock Pigeon, Northwestern Crow, and C-O sole in urban ones (Fig. 4).

DISCUSSION

Bald Eagles in south-coastal British Columbia appeared to be well-adapted to urban and suburban environments, based on our study of nest-site characteristics, productivity, and diet. Overall, eagles in the study area reproduced well, producing 1.1 young per nest with eggs, indicating a stable population. Most nests were near buildings, roads, and other disturbance, and productivity was positively correlated with urban land use and edge habitats. Food remains indicated that eagles in urban, suburban, and remote rural locations all focused highly on avian prey species (75–81% of the total), though urban eagles also consumed some alternative foods such as marine invertebrates.

Nest-site Characteristics. Although more nests were found in remote rural settings than in urban areas, the fact that a third of the nests were built in residential environments and that 75% of them were within 230 m of buildings and roads or within 31 m of a potential source of disturbance illustrates the adaptability of Bald Eagles to urban landscapes. This contrasts with earlier findings in which eagles avoided human-made structures, and distance of nests from human development averaged >500 m (Andrew and Mosher 1982, Fraser et al. 1985,

Table 3. Percentages of samples in which each family occurred and number of items for each family in food items identified around Bald Eagle (*Haliaeetus leucocephalus*) nests ($n = 68$) in the Pacific south-coastal region in the Vancouver environs, British Columbia, Canada.

FAMILY	COMMON NAMES	%	# FOOD ITEMS
Anatidae	Ducks, geese	80.9	277
Laridae	Gulls	54.4	98
Corvidae	Crows	29.4	21
Columbidae	Doves, pigeons	25.0	31
Pleuronectidae	Dabs, righteye flounders	8.8	6
Paralichthyidae	Lefteye flounders, sand flounders	8.8	7
Muridae	Rats, voles	7.4	13
Leporidae	Hares, rabbits	7.4	8
Cyprinidae	Carps	7.4	24
Bovidae	Cattle	5.9	5
Ardeidae	Bitterns, herons	4.4	3
Gaviidae	Loons	4.4	11
Tytonidae	Barn Owl	4.4	4
Phasianidae	Partridges, pheasants	2.9	7
Phalacrocoracidae	Cormorants	2.9	2
Podicipedidae	Grebes	2.9	3
Didelphidae	American opossum	2.9	4
Alcidae	Guillemots	1.5	1
Emberizidae	American sparrows	1.5	1
Parulidae	New World warblers	1.5	1
Mimidae	Mockingbirds	1.5	1
Rallidae	Coots	1.5	1
Strigidae	Owls	1.5	4
Accipitridae	Eagles	1.5	1
Felidae	Cats	1.5	1
Batrachoididae	Toadfishes	1.5	2
Scorpaenidae	Rockfishes	1.5	1
Salmonidae	Salmon	1.5	1
Cancridae	Rock crabs	1.5	1
Mytilidae	Mussels	1.5	1
Myidae	Softshell clams	1.5	1

Anthony and Isaacs 1989, Livingston et al. 1990, Bowerman et al. 1995, Martinez-Abrain et al. 2010). Because we did not assess availability of habitats in the wider study area, it was unknown whether the use of urban/suburban areas reflected actual selection of these features by some pairs or a forced expansion from ideal to historically suboptimal habitats as the population increased.

Although black cottonwood and Douglas fir were the most predominant species used for nest-building, we could not infer that eagles preferred them over other tree species, because these species were the most available trees over the entire study area. Surprisingly, the eagles in our study did not select the most dominant, i.e., the tallest trees, for nesting, despite previous reports of such a tendency for Bald Eagles (Stalmaster 1987, Anthony and Isaacs 1989, Grier and Guinn 2003, Hancock 2003, Watts and Byrd 2007).

Three-quarters of the nests were built within 1.3 km of a water body. Proximity to water was also important for nest placement in populations in Florida (McEwan and Hirth 1979), Maryland (Andrew and Mosher 1982), Saskatchewan (Gerrard and Bortolotti 1988), Oregon (Anthony and Isaacs 1989) and Minnesota (Grier and Guinn 2003). More specifically, along the coasts of lower Chesapeake Bay, it was the low-salinity waters that best predicted distribution patterns of nesting eagles (Watts et al. 2006). We did not assess whether this was the case in our study.

The nest-site groupings obtained by K-means showed geographical clustering, with distinct groups in Vancouver, Delta, further up the Fraser Valley,

Table 4. Percentages of samples in which each kind of prey occurred (nest locations: R = remote rural nest samples, S = suburban, U = urban) in food items collected from Bald Eagle (*Haliaeetus leucocephalus*) nests in the Pacific south-coastal region in the Vancouver environs, British Columbia, Canada. Items of particular interest are in bold. The last column shows the qualitative tendency of occurrence of some species in food samples as urbanization increases.

Species	Common Name	Total(%)	Nest Location (%)			Tendency
			R	S	U	
Anas platyrhynchos	Mallard	45.6	22.0	15.2	9.4	Decrease
Corvus caurinus	Northwestern Crow	29.4	5.1	8.7	**17.0**	Increase
Larus glaucescens	Glaucous-winged Gull	27.9	**1.7**	**13.0**	11.3	
Columba livia	Rock Pigeon	25.0	**1.7**	6.5	**18.9**	Increase
Anas acuta	Northern Pintail	19.1	**10.2**	5.4	3.8	Decrease
Anas americana	American Wigeon	13.2	6.8	5.4	**0.0**	Decrease
Aythya marila	Greater Scaup	10.3	0.0	**6.5**	1.9	
Chen caerulescens	Snow Goose	8.8	**10.2**	0.0	0.0	
Larus delawarensis	Ring-billed Gull	8.8	1.7	3.3	**3.8**	Increase
Cyprinus carpio	Carp	7.4	**6.8**	**0.0**	1.9	
Branta canadensis	Canada Goose	7.4	1.7	**4.3**	0.0	
Citharichthys sordidus	Pacific sanddab	5.9	0.0	2.2	**3.8**	Increase
Melanitta perspicillata	Surf Scoter	5.9	1.7	2.2	1.9	
Bos taurus	Domestic cow	5.9	0.0	**3.3**	1.9	
Sylvilagus floridanus	Eastern cottontail	5.9	**3.4**	1.1	1.9	
Spatula discors	Blue-winged Teal	4.4	**3.4**	0.0	1.9	
Anas crecca	Green-winged Teal	4.4	**3.4**	1.1	0.0	Decrease
Tyto alba	Barn Owl	4.4	**3.4**	1.1	0.0	Decrease
Pleuronichthys coenosus	C-O sole	2.9	0.0	0.0	**3.8**	
Aythya affinis	Lesser Scaup	2.9	0.0	1.1	1.9	Increase
Phasianus colchicus	Ring-necked Pheasant	2.9	1.7	1.1	0.0	Decrease
Aechmophorus occidentalis	Western Grebe	2.9	0.0	1.1	1.9	Increase
Ardea herodias	Great Blue Heron	2.9	1.7	1.1	0.0	Decrease
Didelphis virginiana	Virginia opossum	2.9	1.7	1.1	0.0	Decrease
Mya arenaria	Softshell clam	1.5	0.0	0.0	**1.9**	
Mytilus edulis	Blue mussel	1.5	0.0	0.0	**1.9**	
Cancer magister	Dungeness crab	1.5	0.0	0.0	**1.9**	
Porichthys notatus	Plainfin midshipman	1.5	0.0	1.1	0.0	
Hippoglossoides elassodon	Flathead sole	1.5	0.0	1.1	0.0	
Pleuronichthys decurrens	Curlfin sole	1.5	1.7	0.0	0.0	
Mareca strepera	Gadwall	1.5	1.7	0.0	0.0	
Bucephala albeola	Bufflehead	1.5	0.0	0.0	1.9	
Melanitta deglandi	White-winged Scoter	1.5	0.0	1.1	0.0	
Bucephala clangula	Common Goldeneye	1.5	0.0	1.1	0.0	
Bucephala islandica	Barrow's Goldeneye	1.5	0.0	1.1	0.0	
Oxyura jamaicensis	Ruddy Duck	1.5	1.7	0.0	0.0	
Patagioenas fasciata	Band-tailed Pigeon	1.5	0.0	0.0	1.9	
Fulica americana	American Coot	1.5	0.0	0.0	1.9	
Cepphus columba	Pigeon Guillemot	1.5	0.0	1.1	0.0	
Larus canus	Mew Gull	1.5	0.0	1.1	0.0	
Gavia stellate	Red-throated Loon	1.5	0.0	1.1	0.0	
Gavia pacifica	Pacific Loon	1.5	0.0	0.0	1.9	
Phalacrocorax pelagicus	Pelagic Cormorant	1.5	0.0	1.1	0.0	
Botaurus lentiginosus	American Bittern	1.5	1.7	0.0	0.0	
Bubo scandiacus	Snowy Owl	1.5	0.0	1.1	0.0	
Mimus polyglottos	Northern Mockingbird	1.5	1.7	0.0	0.0	
Passer domesticus	House Sparrow	1.5	0.0	1.1	0.0	
Felis catus	Domestic cat	1.5	1.7	0.0	0.0	
Phenacomys intermedius	Western heather vole	1.5	0.0	1.1	0.0	
Ondatra zibethicus	Muskrat	1.5	0.0	1.1	0.0	
Microtus townsendii	Townsend's vole	1.5	1.7	0.0	0.0	
Lepus americanus	Snowshoe hare	1.5	0.0	1.1	0.0	

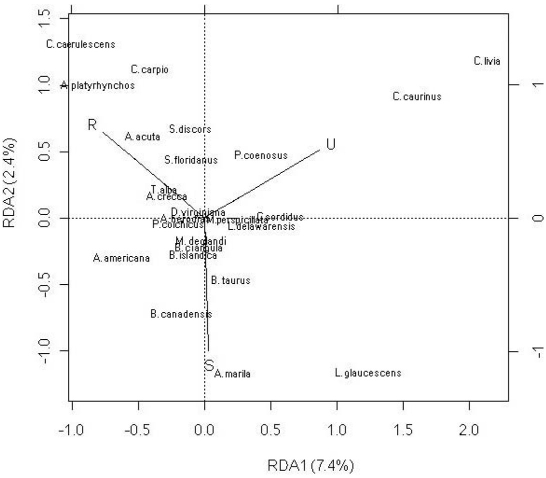

Figure 4. Redundancy analysis (RDA) of land-use category (R = remote rural, S = suburban and U = urban) with respect to presence-absence of prey species (see Table 4 for a description of species names) for Bald Eagles (*Haliaeetus leucocephalus*). Although both RDA predictors explained only 9.8% of the variation in species, the relationship is highly significant ($F = 3.155$, df = 2, $P = 0.001$).

and at the periphery of White Rock and Richmond. These locations have different urbanization patterns. This means that, for example, nests in Vancouver (which is considered urban) were similar to each other but had different characteristics from the other urban, suburban, or remote rural nest clusters.

Reproductive Rate. Nesting success averaged 68% for all 6 yr included in the analysis, which is slightly higher than historical values for eagles in western Washington (Grubb et al. 1975) and northern California (Jenkins and Jackman 2006), although we measured success per active nest rather than per occupied nest, so these values are not completely comparable. Nesting success in the last century varied from 48% to 77% in different populations, with the lowest figures for Alaskan populations that may have been at carrying capacity (Hansen 1987, reviewed in Steidl et al. 1997). Thus, the south-coastal British Columbia population has relatively high nesting success, suggesting that population growth is not currently limited by availability of suitable habitat or prey (Winder and Watkins 2020).

Average productivity in the 6 yr was 1.1 young/active nest and 1.7 young/successful nest. This compares well with values for other populations in Florida (McEwan and Hirth 1979, Millsap et al. 2004), Washington (Grubb et al. 1975), and Chesapeake Bay (Watts et al. 2008), as well as estimates from 17 other study areas in the USA from 1995–2014 (Millsap et al. 2016), though, as a caveat, most of these studies measured productivity in terms of young/occupied nest. Average productivity is lower in protected areas of Alaska (0.8 young/successful nest; Wilson et al. 2018), but this might be a reflection of populations having reached carrying capacity. Based on the minimum estimates of the breeding success and productivity needed to maintain a stable population (i.e., >50% success and >0.7 young/occupied territory, respectively; Sprunt et al. 1973), the Bald Eagle population in the south-coastal British Columbia region is likely stable. The fact that 6% of the successful nests in our study area produced three young suggests a healthy population (Stalmaster 1987, Gerrard and Bortolotti 1988).

Nests close to patch edges, with high percentages of human land use in their surroundings or built on farmlands, had greater productivity than nests in isolated trees or those in remote rural land-use areas. One potential explanation might be that remote rural eagles are currently limited by breeding density on their breeding grounds (Elliott et al. 2011), as those territories have been occupied historically, some since 1960, whereas urban ones have not. Some raptors experience higher productivity in urban settings (Mississippi Kites [*Ictinia mississippiensis*], Parker 1996; Burrowing Owls [*Athene cunicularia*], Millsap and Bear 2000), but others do not (Lesser Kestrels [*Falco naumanni*], Tella et al. 1996). We recommend that management strategies for the eagles in the Greater Vancouver area focus on maintaining edge habitat, monitoring population expansion in urban areas, protecting nest sites on farmland, and investigating any productivity changes in remote zones.

In other studies, Bald Eagle productivity has been variously influenced by habitat characteristics. For example, in Oregon, Bald Eagle productivity was negatively correlated with proximity to roads (Anthony and Isaacs 1989). In contrast to our findings, Hansen's (1987) results for eagles in southeastern Alaska showed that vegetative habitat characteristics at best weakly affected nest success.

Diet. After exploiting the salmon runs on the coast from Alaska to northern Washington, Bald Eagles, as they come back to breeding grounds in the Greater Vancouver region (Elliott et al. 2011), clearly use birds, and especially waterfowl and gulls, as a major source of food, according to food remains we collected. This agrees with the previous literature for coastal eagles (Griffin et al. 1982, Stalmaster 1987, Elliott et al. 2011, Hanson and Baldwin 2017, Buehler 2020). Flounders were the most common fish specimens identified. Some of the more unusual items found in samples, such as crabs, mussels, and steak bones, reflected the variety of feeding opportunities present over the study area. Numerous studies throughout the eagles' range indicate that, when available, fish are the most common taxonomic class in the diet (Gerrard and Bortolotti 1988, Hanson and Baldwin 2017) and birds and mammals make up less of the total diet (28% and 14%, respectively; Stalmaster 1987). As in our study, carp, mallards, doves, Great Blue Heron (*Ardea herodias*), Rock Pigeons, crows, cottontails, and opossums (*Didelphis virginiana*) have been documented elsewhere (Stalmaster 1987, Gerrard and Bortolotti 1988, Mersmann et al. 1992, Buehler 2020).

Some prey species were more abundant in certain land-use categories, such as Snow Geese at remote rural nests, Glaucous-winged Gulls at suburban nests, and Rock Pigeons and Northwestern Crows at urban nests (though these data might have been biased due to larger sample size for suburban nests). Trends favoring some prey species along the urbanization gradient (see Table 4) might describe one of two different scenarios: their actual variation in relative abundance or availability among habitats or a difference in the preferences of remote rural, suburban, and urban eagles. For example, the occurrence of Western Grebe (*Aechmophorus occidentalis*) increased with urbanization, although it has been known for avoiding areas of human activity (Burger 1997), suggesting that urban eagles actually selected for this species.

Redundancy analyses indicated that carp were strongly associated with remote rural nest sites, where they are taken in large numbers from artificial lakes on golf courses (R. Goulet unpubl. data). In urban areas, eagles used some species that were not present in either remote rural or suburban samples, such as C-O sole and Pacific sanddab, which suggests that the birds were using alternative food sources in this environment. Lesser Scaup (*Aythya affinis*) and Western Grebe were also more common in samples from urban nesting sites, which might indicate that these prey were from marine or aquatic origins, as the most-urban sites were coastal. As generalists, Bald Eagles might be better able to find alternative food sources in the suburban and urban environments, where nonnative species and human-made environments offer more options.

As a caveat, we note that collection of food remains alone tends to underestimate prey biomass compared to direct observation (Marti et al. 2007), and creates biases favoring birds and large, bony structures which persist for a longer time on the substrate (Todd et al. 1982, Bielefeldt et al. 1992, Mersmann et al. 1992). However, the collection of regurgitated pellets in addition to food remains in our study helped mitigate this bias somewhat by increasing the representation of small mammals in particular. However, soft-bodied items such as small fish species are definitely underrepresented by both prey remains and pellet analyses (Todd et al. 1982, Mersmann et al. 1992). This bias was evidenced by data from web cameras installed at several nests in the study area showing that the prey consumed at the nest was predominantly small fish and mammals or young Anatids (D. Hancock unpubl. data). Our samples might also misrepresent the eagles' actual diet if prey abundance and availability substantially vary throughout the year and over the study area, or simply because areas under nests in urbanized settings with increased human activity are more likely to be disturbed than those in remote nesting sites.

Conclusions and Recommendations. Our study area demonstrated that Bald Eagles coexist in close proximity to humans, and reproduce well in urban/suburban habitats. We recommend continued monitoring of urban and suburban eagle nests, and also that territories with consistently greater productivity be monitored closely as they are important sources of progeny (Dias 1996, Winder and Watkins 2020).

Future management strategies should incorporate the maintenance and protection of tall mature nesting trees like Douglas fir, especially in and around cities (e.g., segments of forests along developed shoreline such as Stanley Park or UBC's endowment lands). Where feasible and necessary, installation of artificial nest platforms could be considered, especially if landowners cut down nest trees on their property (Bird et al. 2018). Previous buffer limits might have to be reassessed, considering that the birds are now nesting closer to humans. In terms of studying urban eagle habitat, plots with a radius of 1.5 km around the nest seem to be a reasonable target.

Species consumed by eagles varied, likely depending on availability near the nest site. Because small mammals, fish, and invertebrates were most likely underrepresented in this study, we recommend direct or video-recorded observations of foraging birds and food brought into nests to gain a more accurate picture of diet. In the Chesapeake Bay region, Turrin et al. (2015) reported that landfills within 2 km of communal roosts received significantly more eagle activity than others. This pattern may also apply to our study area and may considerably influence eagle diet; the quality of food consumed from landfills should be investigated as the health of populations could be affected in the long term (Gill and Elliott 2003, Elliott et al. 2009).

We further recommend studies of the colonization of new territories, occupancy, post-fledging survival, and movements of breeding pairs in order to have a more complete understanding of the dynamics of this population. Despite some limitations, our study provided clear evidence that Bald Eagles in the Greater Vancouver region of British Columbia have adapted well to urbanization and thrive in this challenging environment.

ACKNOWLEDGMENTS

This study was supported by the Hancock Wildlife Foundation, the Fonds Québécois de Recherche sur la Nature et les Technologies, the Avian Science and Conservation Centre of McGill University and two anonymous donors. We thank John E. Elliot, Robyn Worcester, Rex Kenner, Ildiko Szabo, Ron Ydenberg, Ian Moul, Pierre Legendre, Mary Scott, Karen Bills, Vakil Perhboo, Larissa Lam, and Beverly Day for their technical support and assistance with field work. This study was approved by the McGill University Animal Care Committee and did not require a specific permit under the Wildlife Act of British Columbia.

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Received 1 March 2020; accepted 25 August 2020