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FORAGING ECOLOGY OF BALD EAGLES AT AN URBAN LANDFILL

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ABSTRACT.—We observed Bald Eagles (*Haliaeetus leucocephalus*) foraging at the landfill in Vancouver, British Columbia, Canada, 1994–1996 and 2001–2002, to determine (1) diet and time budgets of eagles visiting the landfill; (2) whether food taken from the landfill provided a significant energy source for local eagle populations; and (3) the effects of eagle density and weather on eagle behavior. Eagles fed primarily on human refuse (95%, $n = 628$), but food items taken from the landfill accounted for only $10 \pm 3\%$ of their daily energy needs. Subadults foraged at the landfill more often than adults, and most "refuse specialists" appeared to be subadults. Eagle time budgets consisted of mostly resting (91%), the remainder largely spent drinking (2.6%), scavenging (2.3%), and pirating (1.8%). Resting increased with wind speed, and foraging efficiency declined with precipitation, consistent with the hypothesis that the landfill is primarily a location for resting during inclement weather. Foraging efficiency decreased when number of eagles and piracies increased, and percent of eagles foraging decreased with increased numbers of eagles. The home ranges of only 2 of 11 radio-tagged eagles, both subadults, consisted largely (>20%) of the landfill; home-range size and percent of the home range that included the landfill were negatively correlated, suggesting that most eagles visited the landfill occasionally while a few spent most of their time there. We concluded that (1) the Vancouver landfill was not a major energy source for eagles, in part because their foraging is inefficient due to the large number of potential pirates; (2) most eagles apparently used the landfill primarily as a site for resting during inclement weather (the landfill is protected from the wind, is slightly warmer than surrounding areas due to decomposing refuse and the surrounding conifer trees, and is relatively free of human activity); and (3) a small population of largely subadult refuse specialists appeared to gain much or all of their energy from the landfill. *Received 14 December 2004, accepted 2 March 2006.*

Landfills can provide a constant and abundant food source for birds, potentially increasing reproductive success at nearby nesting colonies (Pons and Migot 1995, Tortosa et al. 2003) and allowing some regions to support otherwise unsustainable populations (Sibly and McCleery 1983). During the breeding season, landfills are particularly important for several species, including American Crow (*Corvus brachyrhynchos*, Stouffer and Caccamise 1991), Alpine [currently Yellow-billed] Chough (*Pyrrhocorax graculus*, Delestrade 1994), White Stork (*Ciconia ciconia*, Tortosa et al. 2003), Black Kite (*Milvus migrans*, Blanco 1997) and Common Raven (*Corvus corax*, Restani et al. 2001). Foraging at landfills, however, can lower avian survivorship and reproduction (Pierotti and Annett 1991, Smith and Carlile 1993, Annett and Pierotti 1999) due to poor food quality (Smith and Carlile 1993, Annett and Pierotti 1999), increased transmission of disease (Durrant and Beatson 1981, Monaghan et al. 1985, Ortiz and Smith 1994), ingestion of synthetics (Inigo Elias 1987), and contamination by toxins (Millsap et al. 2005). During the nonbreeding season, some populations of Bald Eagles (*Haliaeetus leucocephalus*) are highly mobile foragers, traveling thousands of km to congregate where food is abundant (Knight and Knight 1983, Knight and Skagen 1988, Restani et al. 2000). Because food availability during late winter is critical to eagle survivorship (Sherrod et al. 1976, Stalmaster and Gessaman 1984), the additional food available at landfills might contribute to increases in local eagle populations (Hancock 2003). Sherrod et al. (1976) and Jackson (1981) attributed a population increase of eagles to increased food supply at a landfill.

Understanding the population effects of landfills in British Columbia is important for several reasons. Moul and Gebauer (2002), Sullivan et al. (2002), and Vennesland (2004) suggested that landfills increased eagle carrying capacities, which, in turn, impacted waterbird populations. Increased eagle numbers

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in the Pacific Northwest (Dunwiddie and Kuntz 2001, Watson et al. 2002), purportedly due to anthropogenic food sources, has led some First Nation groups of British Columbia to request permission to harvest eagles. The Vancouver landfill manager is considering a number of bird-harassment techniques, including covering the active area with netting, to reduce bird numbers and the potential for aircraft-bird collisions at a nearby airport (P. Henderson pers. comm.). The potential consequence of such practices on eagle populations is unknown.

On the other hand, eagles have died from pentobarbital poisoning after eating euthanized animals that were improperly wrapped at landfills on Vancouver Island, Canada (three poisoned; Wilson et al. 1997), and at numerous locations in the United States (50 cases nationwide; Millsap et al. 2005). Millsap et al. (2005) reported reduced survival of "suburban" eagles compared with "rural" eagles, with 11% (n = 18) of mortality occurring at landfills. While no eagle mortality has been reported at the Vancouver landfill (Elliott et al. 1996, 1997), dozens of Glaucous-winged Gulls (*Larus glaucescens*) died in 1999 following ingestion of chocolate at this landfill.

Despite the abundance of literature concerning eagle foraging ecology and the large number of eagles that frequent landfills throughout North America (Stalmaster 1987, Gerrard and Bortolotti 1988, Buehler 2000), there are few published reports on the relevance of landfills to eagle foraging and population ecology. We initiated a study to determine (1) diet and time budgets of eagles visiting the Vancouver landfill; (2) whether food from the landfill provided a large energy source for local eagle populations; and (3) effects of eagle density, age, and weather on eagle behavior. Because eagles in the Pacific Northwest are primarily avivores in late winter (Watson et al. 1991, Hunt et al. 1992, Peterson et al. 2001), we suspected that eagles at the Vancouver landfill fed primarily on the gulls (>30,000) that regularly visit the site in mid-winter (Ward 1973). We expected that intraspecific pirating also would play an important role at the landfill, as it does along salmon streams (Stalmaster and Gessaman 1984, Hansen 1986, Knight and Skagen 1988).

METHODS

Study area.—The Vancouver landfill (49° 15′ N, 123° 10′ W), located near Vancouver, British Columbia, Canada, is a 10-ha disposal site for urban and commercial waste. Surrounding the landfill are agricultural lands where eagles often hunt or scavenge ducks foraging on winter cover crops. Boundary Bay—where eagles often hunt and scavenge wintering waterfowl numbering in the hundreds of thousands—is 5 km south of the landfill. During 1994–1998, there were five major eagle roosts within a 5-km radius of the landfill (Peterson et al. 2001), including one at Deas Island (49° 18′ N, 123° 10′ W) and South Arm (49° 18′ N, 123° 108′ W).

The landfill included an active refuse-deposition area (~1 ha), where most eagle foraging occurred. Many additional eagles perched in the trees and on fence posts surrounding the landfill. The location of the active area changed yearly. Although eagles at the landfill were continually surrounded by loud machines, the machines did not deter the birds, as they regularly perched on active machinery or grabbed food as it was being dumped, compacted, or moved. By contrast, eagles in surrounding areas were often harassed by dogs, photographers, eagle-watchers, and automobiles, and there have been a number of recent instances where eagles have been shot in Greater Vancouver. For example, during 1998–2001, three large roost sites—including Deas Island and South Arm—are believed to have been abandoned (the birds moving elsewhere) due to nearby housing developments.

Observations.—To determine diets, time budgets, and foraging behaviors, we visited the Vancouver landfill at least once per week from 11 January to 18 April 1994 (total observation = 132 hr), 25 January to 1 March 1995 (48 hr), 13 February to 28 March 1996 (68 hr), and 10 November 2001 to 28 April 2002 (224 hr). Observations took place between 06:00 and 20:00 PST in 4-hr, randomly chosen blocks. All observations were made by at least two observers inside a vehicle approximately 50 m from the active area. Due to topography of the active area, we were unable to make observations from elsewhere. Eagles were habituated to vehicles and heavy machinery, which were always present and often <50 m from eagles, so it seemed unlikely that we influenced eagle behavior. Because virtually all foraging occurred within the active area (>99%), and because we could monitor most of the entire landfill from our vantage point atop the landfill, we concluded that our observations included all foraging events.

Once each hour, we drove around the rim of the landfill, counted adult and subadult eagles, and classified eagle behaviors as resting, bathing, preening, pirating, eating, scavenging, drinking, or hunting. We classified all eagles <5 years old as subadults according to the methods outlined in McCollough (1989). We classified eagle behavior as follows: pirating (chasing or harassing another bird carrying or eating food), scavenging (picking through the garbage in the landfill active area), and foraging (carrying food, pirating, scavenging, or hunting). We classified the number of food items obtained per eagle foraging attempt as ''foraging efficiency.'' During 1994–1998, we also visited two roost sites (Deas Island and South Arm) beginning an hour prior to sunset twice a week and recorded direction of arrival to determine whether the eagles at the landfill were using these roost sites.

We recorded wind speed, precipitation, temperature, and percent cloud cover at the active site at the beginning and end of each observation period. For analysis, beginning and ending values were averaged. Detection probabilities for adult versus subadult eagles can vary, especially when the birds are perched (Anthony et al. 1999). However, the proportion of subadults seen flying and foraging at the landfill was similar to the proportion seen roosting in the surrounding trees (KHE unpubl. data); thus, we concluded that we counted all eagles present (Hancock 1964, Anthony et al. 1999). We recorded the direction of arrival or departure of all incoming or outgoing eagles.

Energy consumption.—Following the protocol set out by Dykstra et al. (1998), Warnke et al. (2002), and Gill and Elliott (2003), we identified any item an eagle attempted to eat during the observation period and estimated its size relative to the eagle's talons or mandibles. At the beginning of each field season, we spent 10 hr practicing food-item identification. Based on 104 items retrieved later, we obtained accuracies of >95% for classifying type and size and 80% for estimating food mass based on size estimates. We assumed, therefore, that our mass estimates were accurate to within 20%. We estimated the mass and caloric value of each food item based on its size by using a sample of food items collected at the landfill or from a local grocery store. We classified each food item as red meat waste (mammalian origin, including bones and suet), chicken, gull, rat, garbage, or fish. To estimate post-assimilation energetic efficiencies, we used the mass-specific energetic and percent edible values provided in Stalmaster and Gessaman (1982) for captive eagles feeding on mammalian meat (black-tailed jackrabbit, *Lepus californicus*), birds (Mallard, *Anas platyrhynchos*), and fish (chum salmon, *Oncorhynchus keta*). We necessarily assumed that bone and suet had mass-specific post-assimilation energetic values identical to jackrabbit. Thus, we (1) estimated size and categorized food items; (2) used regressions on a sample of items we collected and weighed to develop an item-specific relationship between size and mass; (3) used the regression between size and mass on a subsample of measured items to estimate the mass of each food item observed; (4) used mass-specific caloric values from the literature to estimate actual caloric values of each food item observed; and (5) estimated digestive efficiency from Stalmaster and Gessaman's (1982) post-assimilation energetic efficiencies to determine actual energy absorbed.

Since the main factors influencing energy intake and number of eagles present were time of day and date, respectively (see Results), and because both of these relationships were clearly nonlinear, we used Akaike's Information Criterion (AIC_c) to determine what higher-order polynomial best described the relationships between energy intake versus time of day, and number of eagles present versus date (Burnham and Anderson 1998:66–67). In both cases, quadratic polynomials provided the best fit (energy intake: $\Delta AIC_c = 8.5$; number of birds: $\Delta AIC_c = 26.1$, compared to the null model). Thus, we used the relationship between energy intake and time of day observed during our random observation periods to estimate the total number of food items taken for each day:

$$\sum_i \alpha + \beta T_i + \gamma T^2{}_i,$$

where α, β and γ are the coefficients for the quadratic regression of number of prey items eaten per hour against number of hours after sunrise (T_i). The summation was taken over all hours between 0.5 hr before sunrise and 0.5 hr after sunset. Energy intake per day is the product of average energetic value of food items, *n*, and the number of food items per day, assuming energy content of food items does not change with time of day or date:

$$\sum_i n(\alpha + \beta T_i + \gamma T^2{}_i).$$

Finally, energy intake per day is divided by the predicted number of eagles to determine the energy intake per eagle per day:

$$\sum_{i,j} \frac{n(\alpha + \beta T_i + \gamma T^2{}_i)}{a + bD_j + cD^2{}_j},$$

where *a*, *b* and *c* are the coefficients for the quadratic regression of the number of eagles present against date (D_j). The summation was taken over all dates between 1 February and 31 March. An alternative formula, which averaged energy intake for each observation period over the entire season, provided almost identical results (KHE unpubl. data).

To estimate the population increase resulting from energy obtained at the landfill, we used Stalmaster's (1983) model, which converts salmon carcass availability into "Eagle Use Days." We modified the "consumable salmon biomass" section of the model to represent the average energy intake of eagles at the landfill (207 ± 62 kJ/day; see Results). We set the flight time to 0.084 hr/day (0.7% of a 12-hr day; see Results) and human disturbance to 0 hr (human disturbance at the landfill was minimal); otherwise, we used default values reported in Stalmaster (1983). The 20% error estimate associated with food energy estimates and the error estimate (SD) associated with the quadratic regression coefficients were propagated through the formula following Stalmaster (1983). This uncertainty was then increased by 19% to account for error within the model itself (Stalmaster 1983).

Radio telemetry.—In the agricultural fields surrounding the landfill, we radio-tagged nine eagles (four adults, five subadults) during 22–31 January 1997 and three subadult eagles on 18 January 1998. We used 172 mHz backpack transmitters weighing 90 g (Advanced Telemetry Systems, Isanti, Minnesota). Half-inch Teflon Ribbon (Bally Ribbon Mills, Bally, Pennsylvania) was used to attach transmitters in the backpack "X" configuration, as described by Buehler et al. (1995). Birds were caught using floating fish snares or padded leg-hold traps. Birds were tracked for 0–17 days over the next 3 months. Only verified (triangulated) locations were included in the analysis. To reduce bias, we only included the 11 individuals for which we had >15 samples. The fixed kernel density estimator (set at 95%), using least-squares cross validation, was calculated using the ArcView 3.2 Animal Movement Analysis extension (Hooge 2005) for individual birds. Fixed kernel calculates utilization distributions using a probabilistic model and infers the relative amount of time the animal spends in any one place. We calculated home-range size and the percent of the home range consisting of the landfill.

Statistical analysis.—For each behavior (resting, bathing, preening, pirating, eating, scavenging, drinking, and hunting), we constructed a linear model in which hours after sunrise, date, weather (cloud cover, precipitation, wind, and temperature), and number of eagles present were the independent variables. We also constructed linear models—with number of eagles, percent of eagles foraging or pirating, and foraging efficiency as dependent variables—and weather (cloud cover, precipitation, wind, and temperature), date, hours after sunrise, number of eagles, number of pirating events, and percent of eagles foraging as independent variables. We inserted quadratic terms into the models to account for the dependence of eagle numbers on date and foraging on time of day, as described above. For each model we used a positive stepwise method to remove all nonsignificant factors (at $P < 0.05$). We report the R^2 values for the model that included only significant factors. We used contingency tables with Yates' correction for continuity to compare behaviors of subadults and adults (Zar 1999). We used Rayleigh's Test to determine whether the directions of birds coming in to roosts coincided

TABLE 1. Foods consumed by Bald Eagles at the Vancouver landfill, British Columbia, Canada, during 1993–1996 and 2001–2002. Eagles consumed primarily red meat waste (mammalian origin) and bones.

Food item	No. consumed	Percent of total diet	Wet mass (g)[a]	Energetic value (kJ)[a,b]
Red meat waste	194	30.7	320 (35)	1,160 (130)
Bones	142	22.4	450 (35)	1,625 (125)
Garbage[c]	42	6.6	210 (50)	0
Fat/suet	26	4.1	340 (70)	1,230 (250)
Glaucous-winged Gull[d]	14	2.2	980 (90)	5,505 (500)
Fish	3	0.4	310 (80)	920 (240)
Rat	2	0.3	245 (80)	890 (290)
Chicken	1	0.2	480	2,700
Unknown	204	32.3		

[a] Mean value (SE).
[b] Based on the mean estimated mass, using the percent edibility from Stalmaster and Gessaman (1982) and mass-specific caloric information provided by the appropriate food labels from nearby grocery stores or the literature.
[c] Includes inedible items, largely paper.
[d] Includes 10 scavenged and 4 killed gulls.

with directions from the landfill (Batschelet 1981). We performed all tests in STATISTICA (StatSoft, Inc. 2004). We tested for normality (Kolmogrov-Smirnov) and homogeneity of variance (Levine's test) before using parametric statistics, and we used arcsine transformations prior to doing statistical tests on percentages. Our *P*-values include Bonferroni adjustments for multiple comparisons, as calculated by STATISTICA. If analysis of covariance provided no significant variation between years, data from separate years were pooled. Results were considered significant if $P < 0.05$. Results are presented as means ± SE.

RESULTS

Diet and energy intake.—Household food refuse, particularly red meat waste and bones, made up 95% of known food items of Bald Eagles foraging at the landfill (Table 1). Although some meat was identifiable (e.g., sausage or hamburger), most was unidentifiable and clearly putrid or decomposing. Eagles also consumed garbage, including paper towels and plastic bags. Glaucous-winged Gulls (10 scavenged, 4 captured live) composed only 2.2% of the diet. Average energy intake per eagle was 207 ± 62 kJ/day, which was 10 ± 3% of the required daily energy intake. The number of "Eagle Use Days" (1,300 ± 400) at the landfill during the winter was equivalent to 17 ± 5 eagles over the peak period of use from February–March.

Time budgets and behavior.—Eagles at the landfill spent most (91.0%) of their time resting. Resting occurred primarily later in the day and when more eagles were present. Resting was linearly related ($R^2 = 0.21$) to number of hours after sunrise ($t_{185} = -4.4$, $P < 0.001$) and wind ($t_{186} = 4.0$, $P = 0.004$). Percent time bathing (0.06%), drinking (2.6%), eating (1.2%), flying (0.7%), hunting (0.3%), pirating (1.8%), preening (0.6%) and scavenging (2.3%) were not explained by environmental variables.

Peak numbers at both the landfill and nearby roosts occurred in late winter (Fig. 1), after eagle numbers had peaked at local salmon spawning streams (Dunwiddie and Kuntz 2001). The highest count was 453 on 26 February 2001 (Fig. 1). The percentage of adults present at both the landfill and nearby roosts declined with date at similar rates (Fig. 1). The percentage of eagles foraging declined as the number of eagles present increased and when precipitation fell (Table 2), and was greatest during the first 3 hr after sunrise (Fig. 2). Foraging efficiency increased as wind speed increased, and it declined with date, number of eagles pirating, number of eagles present, and when precipitation fell (Table 2). Overall, 60% of food items obtained were later pirated; 84% of theft attempts were directed against other eagles; and 16% were directed against gulls. The percentage of eagles pirating increased as the percentage of eagles foraging increased, and decreased with the number of eagles present (Table 2). The likelihood of a food item being pirated increased with size of the food item ($R^2 = 0.45$, $P < 0.001$).

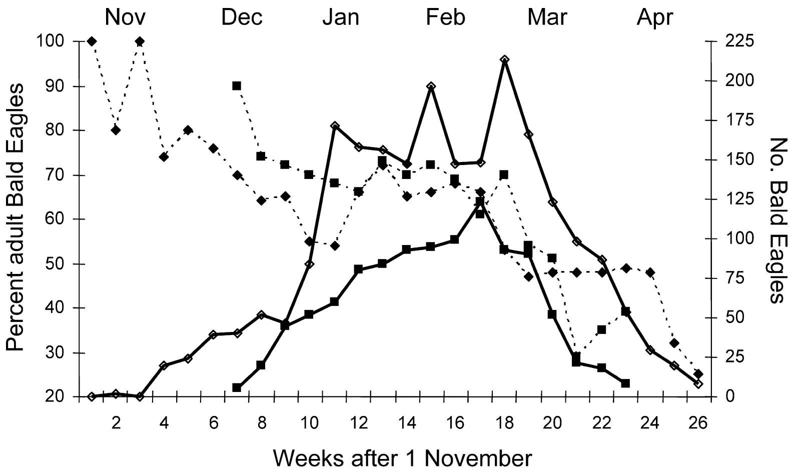

FIG. 1. Bald Eagle numbers (solid lines) and the percentage of adult (as opposed to subadult) eagles (hatched lines) present at the Vancouver, British Columbia, Canada, landfill (diamonds) and at two nearby roost sites (squares) during the weeks after 1 November. Eagle numbers are weekly averages of daily peak numbers, and percentages of adult eagles are weekly averages. Values were averaged over 1993–1996 and 2001–2002 (landfill) and 1993–1996 (roosts) winters. Roosts were inactive in 2001–2002.

Subadults spent more time pirating, scavenging, flying, and bathing, whereas adults spent more time hunting and resting (Table 3); however, foraging efficiency and pirating success were similar between adults and subadults (Table 3).

Eagles arriving to roost at the South Arm and Deas Island sites came from significantly different directions than that of the landfill ($Z = 14.5$, $P < 0.001$). Eagles arrived at the landfill primarily from adjacent agricultural fields and not from the South Arm and Deas Island roosts ($Z = 18.6$, $P < 0.001$).

Radio telemetry.—Six of the 11 radio-tagged eagles had home ranges that included the landfill (Table 4, Fig. 3). There was no relationship between number of points used for analysis and home-range size. The two in-

TABLE 2. Number of eagles present at the Vancouver landfill, British Columbia, Canada, 1993–2002. Eagle numbers increased with increasing wind, precipitation, and cloud cover. The percentage of eagles foraging decreased with precipitation and number of eagles present. The percentage of eagles pirating decreased with number of eagles but increased with number of eagles foraging. Foraging efficiency increased with wind and decreased with precipitation, date, number of eagles present, and number of eagles pirating.

	No. eagles		Eagles foraging (%)		Eagles pirating (%)		Foraging efficiency[a]	
Effect	t_{187}	P	T_{186}	P	t_{187}	P	t_{186}	P
Wind	4.2	<0.001		NS[b]		NS	2.6	0.012
Precipitation	4.1	<0.001	−2.1	0.010		NS	−2.4	0.019
Cloud cover	7.5	<0.001		NS		NS		NS
Date		—[c]		NS		NS	−3.1	0.002
Temperature		NS		NS		NS		NS
Hour after sunrise		NS		—[d]		NS		NS
No. eagles present		—	−2.7	0.007	−2.7	0.008	−2.4	0.02
Eagles foraging (%)		NS		—	3.0	<0.001		NS
No. eagles pirating		NS		NS	—		−9.9	<0.001
R[e]		0.46		0.48		0.08		0.53

[a] Number of food items taken per foraging attempt.
[b] Not significant ($P > 0.05$).
[c] The linear model for number of eagles fitted to a quadratic term to account for the effect of date.
[d] The linear model for percentage of eagles foraging fitted to a quadratic term to account for the effect of hours after sunrise.
[e] Refers to the total linear model once nonsignificant factors have been removed (positive stepwise).

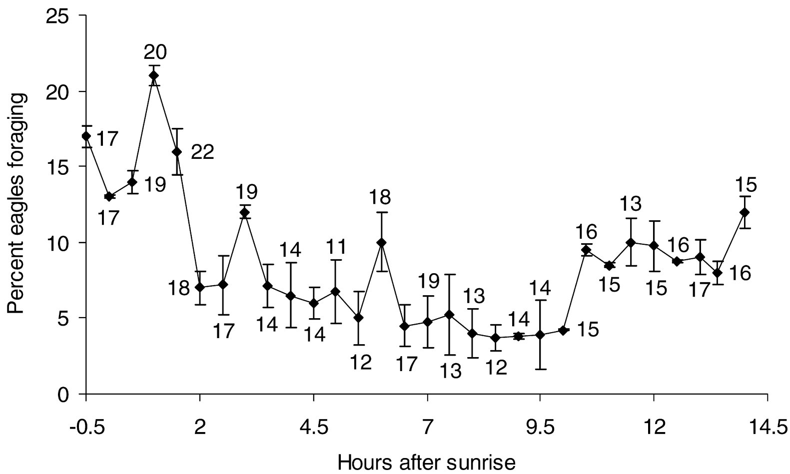

FIG. 2. Percent of eagles foraging in relation to hours after sunrise at the Vancouver, British Columbia, Canada, landfill during the winters of 1993–1996 and 2001–2002. Peak foraging occurred in early and late hours of the day. Based on these data, the quadratic regression for percent of eagles foraging = 0.18(time of day)^2 −2.8(time of day) ± 16; R^2 = 0.67. Error bars represent SE; sample sizes appear above, below, or to the right of data points.

dividuals whose home ranges largely consisted of the Vancouver landfill (e.g., >10% of their home range was the Vancouver landfill) had the smallest home ranges, and home-range size was negatively correlated with the percentage of the home range that encompassed the landfill ($t_5 = -3.05$, $P = 0.04$, $r^2 = 0.70$).

TABLE 3. Percent time adult and subadult Bald Eagles spent engaged in various behaviors at the Vancouver landfill, British Columbia, Canada, 1993–2002. Adults spent more time resting and hunting than subadults, whereas subadults spent more time scavenging, pirating, flying, and bathing. Foraging efficiency, pirating success, and percent time spent drinking and preening were equivalent between the two groups.

Behavior	Adult	Subadult	χ^2_1	P
Resting	93.1	88.2	3.7	0.048
Drinking	2.4	2.7		NS[a]
Scavenging	1.0	5.4	22.4	0.001
Pirating	0.5	4.9	33.7	0.001
Preening	0.6	0.6		NS
Flying	0.2	1.5	9.2	0.001
Hunting	0.8	0.1	5.5	0.016
Bathing	0.02	0.1	6.2	0.014
Foraging efficiency[b]	0.31	0.33		NS
Pirating success[c]	0.48	0.49		NS

[a] Not significant ($P > 0.05$).
[b] Number of food items taken per foraging attempt.
[c] Percentage of pirating attempts that were successful.

DISCUSSION

Contrary to initial expectations, the Vancouver landfill accounted for only 10 ± 3% of the energy intake of the eagles that frequent the landfill. Furthermore, the actual intake was likely <10% because we assumed liberal values for major food items, such as bone and rancid foods, and the eagles wasted considerable amounts of food that we could not quantify. Eagle behavior was similar to that of Herring Gulls (*Larus argentatus*), which use landfills primarily for social interaction and loafing, especially when higher-quality food is available elsewhere (Belant et al. 1993). Nearby waterfowl concentrations probably represented a higher-quality food base (Peterson et

TABLE 4. Home-range sizes of eagles radio-tagged near the Vancouver landfill, British Columbia, Canada, decreased during winter 1997 and 1998 as the landfill portion of their home range increased.

Bird	Year	Age	Area in landfill (%)	Home range (km^2)
373	1997	Subadult	1.7	20.4
241	1997	Subadult	1.5	27.8
190	1997	Adult	0.9	37.3
210	1998	Subadult	3.4	14.2
072	1998	Subadult	20.4	2.5
062	1998	Subadult	50.6	1.5

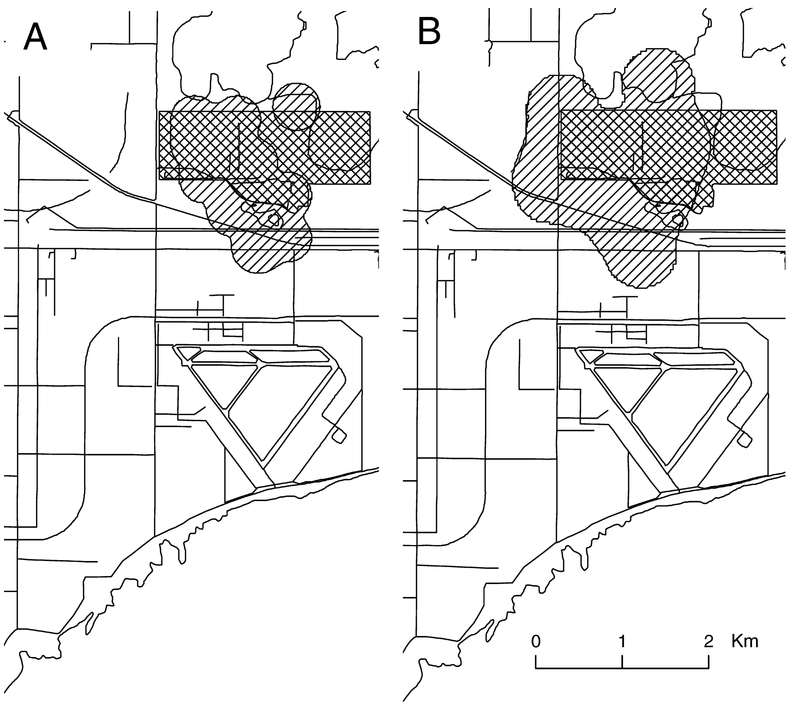

FIG. 3. Home ranges of two (A, B) "refuse specialist" Bald Eagles (>20% of their home ranges comprised the Vancouver landfill) radiotagged near the landfill in Vancouver, British Columbia, Canada, during the winters of 1997 and 1998. Forward slashes (///) represent eagle home ranges; crosshatching represents the Vancouver landfill.

al. 2001), and most eagles may have foraged on waterfowl. Consistent with this hypothesis, resting and overall numbers of eagles peaked during periods of inclement weather because the landfill is protected from the wind, is slightly warmer due to decomposing refuse and surrounding conifer trees, and is relatively free of human disturbance—all of which are known to reduce the energetic costs associated with resting (Stalmaster and Newman 1979, Keister et al. 1985). The possibility of feeding at the landfill was likely an added bonus.

It is improbable that the landfill contributed significantly to an increased eagle carrying capacity in the region, as the observed energy intake only accounted for an additional 17 ± 5 eagles during peak eagle use. This is a very small number compared to the 500–1,000 eagles that use the surrounding area in late winter, and it does not account for the 30-fold population increase that has occurred over the last 30 years. Percent of eagles foraging declined with a decrease in the number of eagles present, suggesting that the number of foragers stayed relatively constant and the remainder only visited to rest. Thus, some eagles (the refuse specialists) may have foraged primarily at the landfill and obtained much of their energy needs there. Furthermore, the standard deviation for average energy intake (264 kJ/day) was greater than the average intake rate (207 kJ/day) itself, indicating wide variation among individuals.

Consistent with the existence of refuse specialists, 2 of 11 (18%) radio-tagged eagles had a fixed kernel home range that mostly (>20%) included the landfill, whereas another 4 visited the landfill only occasionally (Table 4). Visual inspection of the home ranges of the two refuse specialists suggests that they rarely left the landfill; most of the points outside the landfill appeared to be in adjacent conifer trees, which are used for resting (Fig. 3). The refuse specialist estimate (18%) is quite close to our estimate for the proportion of the local population that was supported by energy intake from the landfill (10 ± 2%). It appears that younger eagles were the refuse specialists, because they spent more of their time foraging and older eagles spent more time resting at the landfill—possibly because younger eagles are less efficient hunters than the adults (Stalmaster and Gessaman 1984, Brown 1993, Bennetts and McClelland 1997). A similar study at a nearby salmon stream in late winter showed a strong relationship between pirating success and age (Stalmaster and Gessaman 1984), and, at the Vancouver landfill, subadults pirated more than adults; this may reflect a change in dominance structure associated with the predictability of anthropogenic food sources (e.g., Restani et al. 2001). Moreover, home ranges of refuse specialists in a wide variety of taxa are much smaller than the average home range size, and reduced home range size is often associated with a change in social structure due to increased density at landfills (e.g., Blanchard and Knight 1991, Delestrade 1994, Gilchrist and Otali 2002).

Pirating was common at the Vancouver landfill, which may partially explain why few eagles forage there. Foraging efficiency and the percent of birds foraging declined as the number of birds present and pirating increased. Although piracy is also common at waterfowl carcasses (Peterson et al. 2001) and salmon streams (Stalmaster and Gessman 1984), it may be that the higher quality of those food types makes pirating them more worthwhile energetically. Eagles at the landfill pirated primarily conspecifics; thus, although both gulls and eagles competed for the same resource (human refuse), there appeared to be few interactions between them.

At both the landfill and nearby roosts, the timing of peak eagle numbers and the percentage of adults present were similar, supporting our assumption (based on radiotelemetry) that individuals regularly moved between these sites (this study, Servheen and English 1979, Hunt et al. 1992). The percentage of subadults increased over the winter at both locations, not only because subadults learned about food concentrations from adults (Knight and Knight 1983, Bennetts and McClelland 1997, Restani et al. 2000), but also because many breeders returned to their territories in late fall (Stalmaster and Kaiser 1997).

Eagles spent most of their time resting (91%). At the landfill, they rested more than they did at the Columbia River estuary (54%; Watson et al. 1991), and they spent less time flying (0.7% versus 6%). Overall, time spent flying was similar to that reported on the Nooksack River (1.0%; Stalmaster and Gessaman 1984). In previous studies, eagles (Sherrod et al. 1976) and gulls (Sibly and McCleery 1983, Coulson et al. 1987) at several landfills foraged whenever the landfills were active, with peak foraging occurring when the landfill machinery activities stopped. In contrast, eagles at the Vancouver landfill—where food was available almost continuously because refuse dumping started every day before sunrise (06:30) and did not end until after sunset (18:30)—foraged primarily during early morning and late afternoon (Fig. 2). This reflects the typical diurnal feeding patterns of eagles (Watson et al. 1991; Elliott et al. 2003, 2005), as well as the short day length during Vancouver winters.

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