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CARRYING CAPACITY FOR BALD EAGLES WINTERING ALONG A NORTHWESTERN RIVER

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ABSTRACT.—Numbers of Bald Eagles (*Haliaeetus leucocephalus*) wintering along the Skagit River, Washington, in a 7-year period were correlated with estimates of numbers of Chum Salmon (*Oncorhynchus keta*) returning to the river to spawn, and inversely associated with daily water flows and average numbers of flood days in January and February. Available salmon biomass, measured every two weeks along 43 km of river, was in surplus of eagle requirements from 24 November 1980 through 4 January 1981, but in deficit thereafter in the same winter of close study. Recruitment of fresh Chum Salmon carcasses continued until mid-January, after which slowly receding river levels exposed additional carcasses. Coho Salmon (*O. kisutch*) spawning in tributaries then became a major food source. We tagged 214 live post-spawn Chum Salmon at spawning sites and we estimate from recoveries that about 13% became available to eagles. Predictions of local carrying capacity for eagles based on salmon escapement figures, the availability index of 13%, and daily food requirements of Bald Eagles showed remarkably close fits with actual numbers of eagles supported by both the entire Skagit River drainage and an intensively studied subunit. A sample of eagles fitted with radio transmitters traveled west from the Skagit and Nooksack rivers to Puget Sound, where visual surveys showed increases in eagle numbers during January and February, corresponding with decreases on the rivers.

Capacidad de mantenimiento de la zona para el Águila Cabeciblanca que inverna a lo largo de un río del noroeste

EXTRACTO.—Las cantidades de Águilas Cabeciblancas (*Haliaeetus leucocephalus*) que invernaban a lo largo del río Skagit, Washington, en un período de 7 años, fueron correlacionadas con números estimados de peces salmón de la especie *Oncorhynchus keta* que retornaban al río para desovar. Estas cantidades de águilas también fueron inversamente correlacionadas con los flujos acuáticos diarios y los números promedio de días de desborde en enero y febrero.

La disponibilidad de salmón para las águilas, medida cada dos semanas a lo largo de 43 km del río, se presentó en exceso desde el 24 de noviembre de 1980 al 4 de enero de 1981, y en déficit el resto del invierno de este estudio. La disponibilidad de salmón a orillas del río continuó hasta mediados de enero; después de este tiempo, cuando el río bajaba su nivel, aparecían provisiones adicionales. Posteriormente el salmón de la especie *Onchorhynchus kisutch,* que desova en los tributarios, constituyó una mayor fuente de alimento.

Hemos marcado, en los sitios de desove, 214 peces vivos de la especie *O. keta,* después de la puesta de los huevos; y se estima, por los peces recobrados, que cerca del 13% estuvo disponible para las águilas. Las predicciones de la capacidad de mantenimiento del área estudiada, se basaron en el número de peces salmón en el río, en el índice de disponibilidad del 13% y en el requerimiento de alimento por día del Águila Cabeciblanca. Estas predicciones mostraron una estrecha correlación con el número de águilas cuyo mantenimiento dependía tanto de toda el área a lo largo del río Skagit como de una porción de ella especialmente estudiada.

Una muestra de águilas equipadas con radiotransmisores viajó al oeste, desde los ríos Skagit y Nooksack, hacia Puget Sound, donde estudios visuales mostraron incrementos en el número de águilas durante enero y febrero. Estos incrementos correspondieron con la bajada del nivel de los ríos.

[Traducción de Eudoxio Paredes-Ruiz]

Populations of birds of prey often appear to be at saturation-level densities in relation to food supplies (Newton 1979). This relationship is most apparent among species with narrow food niches, such as the

Rough-legged Hawk (*Buteo lagopus*) and Gyrfalcon (*Falco rusticolus*), whose nesting populations in some areas reflect changes in food supply (Hagen 1969, Swartz et al. 1975, Platt 1976). Saturation of wintering habitat may be inferred from studies in which the densities of raptors correspond to yearly differences in prey abundance (Craighead and Craighead 1956, Cavé 1968, Smeenk 1974, Thiollay 1978). An actual determination, however, of whether a raptor population exists at carrying capacity requires that numbers of the birds be predicted from a measured amount of available food. Obtaining such data is usually difficult because of problems in 1) determining the available portion of food biomass (i.e., the number of vulnerable calories per unit time), 2) obtaining accurate counts of the raptors, and 3) assessing individual raptor food requirements.

Bald Eagles (*Haliaeetus leucocephalus*) are particularly appropriate subjects for studies of local carrying capacity during winter when they tend toward a diet of carrion (Southern 1963, McClelland 1973, Steenhof 1976, Griffin 1978). In the Pacific Northwest they are attracted to post-spawn salmon carcasses along rivers (Servheen 1975) and to concentrations of ducks and geese crippled or dead from disease and shooting (Keister 1981). Dead salmon lying in shallow water or on river banks are relatively easy to count, thereby allowing researchers to measure a substantial portion of the food actually available to eagles wintering along a river. Additionally, since Bald Eagles themselves are so conspicuous and are likely to be found close to the river, they are easily censused. Lastly, Stalmaster and Gessaman (1984) have developed an energetics model of the caloric requirements of captive Bald Eagles under simulated temperatures, rain, and wind, and have supplemented their estimates of caloric needs with field data on energy costs of wild eagles. They estimated that an average-sized 4.5-kg Bald Eagle wintering on the Nooksack River in western Washington requires about 491 kcal, or 486 g of salmon flesh, per day (Stalmaster 1983).

In this report we 1) estimate the biomass of salmon carrion which occurred during winter 1980–81 along the Skagit River drainage in northwestern Washington, 2) estimate the number of wintering Bald Eagles in attendance, and 3) examine variables which may have affected Bald Eagle carrying capacity during 7 years of censuses. Using tagged fish, we estimate the rate at which post-spawn salmon carrion became available as eagle food. We provide data on the movements of eagles from the Skagit River as food supplies diminished in late winter, and we report changes in eagle numbers in nearby areas that may have absorbed the Skagit River emigrants.

STUDY AREA

Bald Eagles wintering on the Skagit River are distributed along approximately 144 km of the river, from its mouth to Gorge Dam at Newhalem, but they concentrate between the towns of Rockport and Marblemount (Fig. 1). Two major tributaries, the Sauk and Cascade rivers, also attract eagles, as do local creeks and sloughs.

Physical and biotic features related to Bald Eagle occurrence on the Skagit River were described by Servheen (1975) The river runs through a glaciated valley, 1–5 km wide, which is characterized by the Western Hemlock (*Tsuga heterophylla*) life zone (Franklin and Dyrness 1973). In most areas the river banks have an abundance of trees suitable for Bald Eagle perching and the river contains numerous gravel bars where salmon carcasses tend to accumulate. River flows are regulated by three hydroelectric dams upstream of Newhalem.

Five species of salmon spawn in the Skagit drainage, but Chum Salmon (*Oncorhynchus keta*) are most important to Bald Eagles. Chum Salmon spawn from mid-November through December in the Skagit mainstem, side channels, and sloughs; carcasses accumulate along gravel bars during November and December and remain there as eagle food until eaten or removed by floods. Coho Salmon (*O. kisutch*) spawn throughout the winter mainly in tributaries, some of which are quite small. Coho Salmon are distributed more widely than chum, but are less commonly deposited on mainstem gravel bars. Pink salmon (*O. gorbuscha*) spawn abundantly in October in alternate years, but their carcasses are largely gone by the time eagles arrive in numbers.

We conducted telemetric and census work west of the crest of the Cascade Mountains in Washington and British Columbia, and from Seattle to about 80 km north of the city of Vancouver (Fig. 2). The region is a mosaic of agricultural lowlands and mountains covered by coniferous forests. Six major rivers (Squamish, Fraser, Nooksack, Skagit, Stillaguamish, and Snoqualmie) meander westward, often through multiple channels, and all support spawning salmon in winter months. The San Juan and Gulf archipelagos in nearby Puget Sound consist largely of gently rolling conifer-forested hills and cleared pastoral lands.

METHODS

Bald Eagle Censuses. Bald Eagles perched conspicuously in trees along the Skagit River and were readily counted from a slow-moving road vehicle and from a number of fixed vantage points. The census procedure and route were developed by Servheen (1975). Eagles were counted two or three times per week from late November through mid-March. The route followed the river from Newhalem downstream to the Sauk River confluence, a distance of 43 river km (Fig 2). We also surveyed several off-river locations, including Illabot Slough, Harrison Slough and County Line Ponds, and a short section of the Cascade River near its mouth. For analysis, eagle census results were averaged for each of eight 2-wk periods.

To project the total number of eagles present in the study

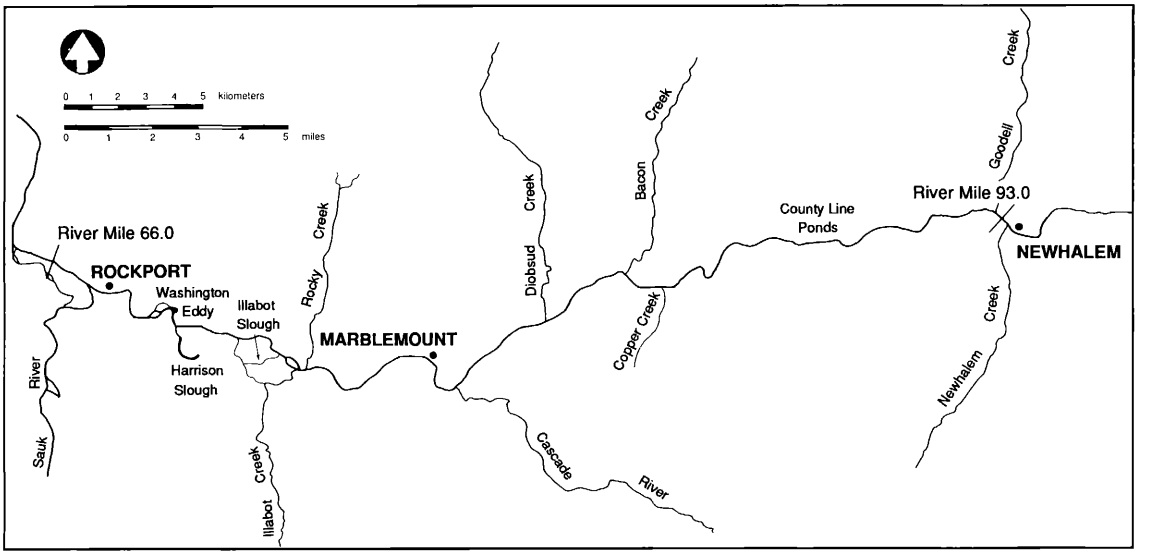

Figure 1. Upper Skagit River study area where Bald Eagles were counted and salmon carrion estimated.

area, we estimated the proportion of each standard half-mile (0 8 km) river segment (Williams et al. 1975) that was visible to the census-taker ($N = 54$ segments). We then divided the mean numbers of eagles seen in the segments by the resulting visibility coefficients to calculate the actual number of eagles present in each standard half-mile.

Because of more cryptic coloration, subadults perched in trees were more difficult to detect than adults. Following Hancock (1964), we examined adult to subadult ratios in samples of perched eagles, those flying, and those standing or feeding. During winter 1979–80 we recorded 244 subadults and 243 adults in our sample of flying eagles. We observed 138 subadults and 125 adults standing or feeding. However, the perched sample showed a ratio of 995 subadults to 1321 adults. We concluded that if perched subadults had been as readily seen as adults our overall sample of eagle observations would have been larger by about 10%, so we adjusted our estimates accordingly.

To evaluate differences in yearly numbers of wintering eagles we tabulated eagle census data from previous studies between Marblemount and the mouth of the Sauk River. These surveys were made in winters 1973–74 and 1974–75 by Servheen (1975), in 1976–77 and 1977–78 by Wiley (1977, 1978), and in 1978–79 by Skagen (1979). Additionally, we conducted censuses by boat every 2 wk during winter 1980–81 on the Skagit River from the Sauk River mouth to Sedro Woolley (67.2 km) and on the Sauk River from its mouth to Darrington (33.6 km).

Salmon Carcass Surveys. Throughout winter 1979–80 we conducted weekly counts at night of salmon carcasses at Washington Eddy, a gravel bar about 600 m long, between Rockport and Marblemount. The technique, first used by Servheen (1975), involved walking the length of a gravel bar along the edge of the water, and returning along the high water mark. All fish found were measured and classified according to location, species, sex, proportion of flesh remaining, and whether accessible to eagles. We left all fish intact where found.

The following winter, using a shallow-draft jet-boat, we surveyed for salmon carcasses every 2 wk along the 43 km stretch of the Skagit River from Goodell Creek at Newhalem to the mouth of the Sauk River near Rockport (Fig. 1). We walked all exposed gravel bars and examined all backwaters, sloughs, eddies, high water marks, and river edges on foot or by boat and completed the counts in 2 d. We recorded data similar to those collected during the night counts (see above) and continued the surveys into late February when no edible fish parts were observed.

From a sample of 55 whole, post-spawn chum carcasses we determined average weights and measurements of both sexes of fish. Then, by subtracting the mean weight of salmon skeletons from which all edible portions had been consumed by eagles, we obtained average weights of edible flesh. We similarly estimated the weight of edible flesh on Coho Salmon using a sample of 10 post-spawn fish. For salmon carcasses of unknown sex, the average of male and female weights was used. From numbers of carcasses, and from the varying portions of flesh remaining, we calculated amounts of available fish biomass (in kcal) for each half-mile segment of river.

Salmon Disk-tagging. From 24 November to 19 December 1980, we captured 214 live, post-spawn Chum Salmon with drift nets in the upstream portion of the study area between Copper Creek and Goodell Creek. The distribution of capture sites fairly represented the location of major Chum Salmon spawning activity in this section. In all, we tagged 173 fish in the mainstem and 41 in a side-channel. After capture we immediately placed each fish in a water-filled tank to await processing. All were tagged, while in a water trough, with numbered blue plastic disks (Peterson style, with single green flags) attached by nickel pins just below the

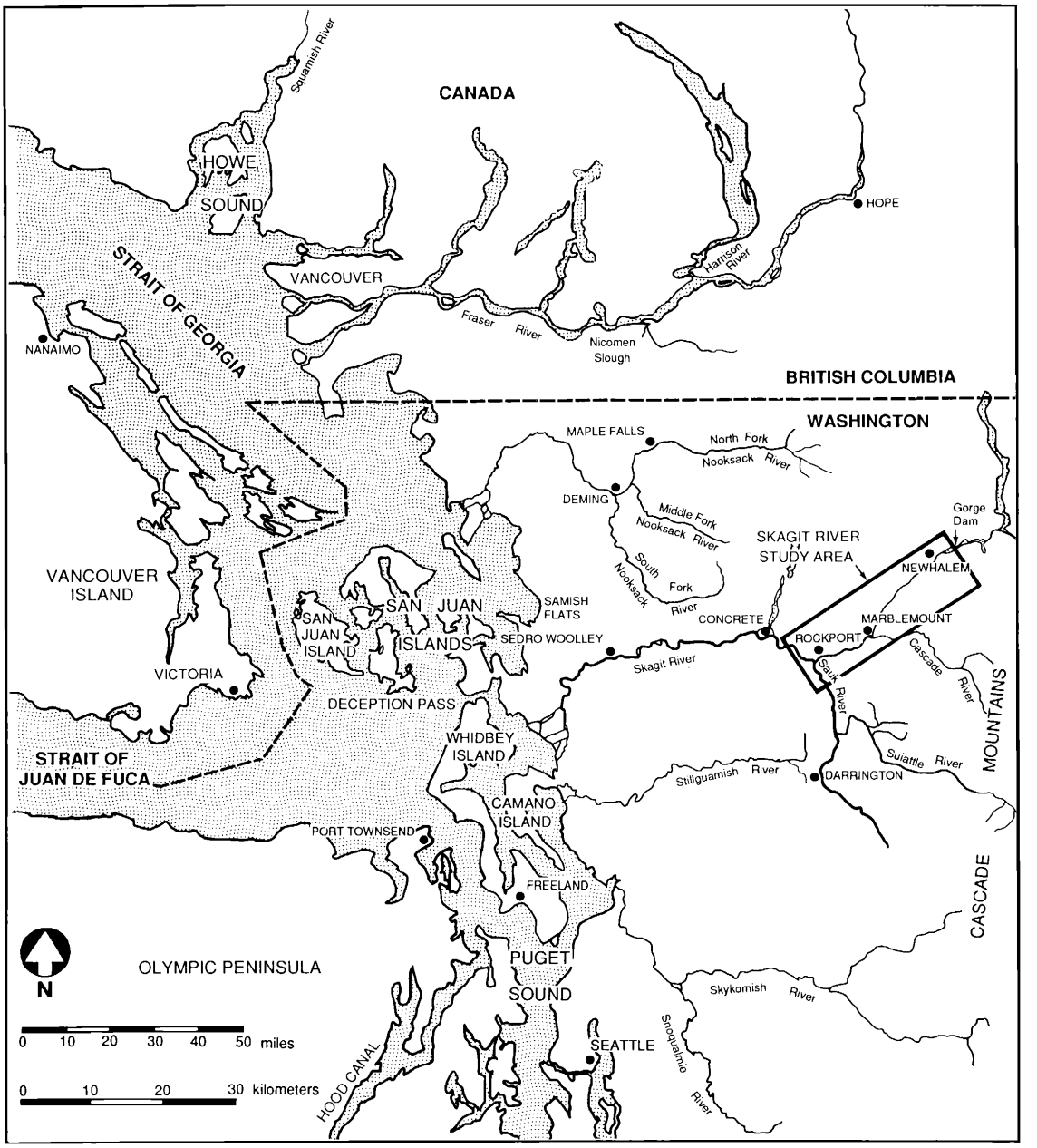

Figure 2. Study region to which radio-tagged Bald Eagles traveled from the Skagit and Nooksack rivers.

dorsal fin (Nielsen and Johnson 1985). Each fish was scored as to sex, length and state of vigor, and was released at the capture site within a few minutes of netting. We judged 188 fish to be in good or excellent condition, 24 to have little vigor and 2 to be very weak. We searched for tagged fish during our routine carcass surveys and conducted two extra searches solely for tagged fish during December. All fish counted in the surveys were examined for tags or evidence of tag placement.

Radio Telemetry. During January and February of 1980

Table 1. Factors that may influence the numbers of Bald Eagles wintering on the Skagit River from Marblemount to the mouth of the Sauk River. Census data were obtained from the following sources: 1973–75 from Servheen (1975), 1976–78 from Wiley (1977, 1978), 1978–79 from Skagen (1979), and 1979–81 (this study).

Winter	Skagit River Eagle Abundance Index Value[a]	Chum Salmon[b]				Mean Daily Flow[c] Dec.–Jan.	Number of Flood Days[c,d]	Highest Daily Flow[c] Dec.–Jan.	Precipitation (inches)[d] Dec. + Jan.	Mean Air Temperature[d] (°C) Dec + Jan.
		Skagit	Nooksack	Fraser	Squamish					
1973–74	4.0	31	20	453	235	19–24	7	31–73	31	2.9
1974–75	6.5	57	15	565	142	16–17	2	43–32	27	3.3
1975–76	No data	20	10	235	55	35–20	12	108–32	30	3.3
1976–77	6.2	85	7	589	114	12–15	2	23–46	11	3.4
1977–78	6.0	32	16	539	120	26–15	9	58–20	19	3.1
1978–79	13.9	115	9	487	114	11–10	0	14–15	12	0.2
1979–80	5.0	16	23	328	26	28–16	8	114–22	23	2.2
1980–81	4.6	21	25	375	222	30–15	10	120–38	15	4.7
Mean values	6.6	59	16	476	139	20–16	5.4	58–35	19.7	2.8

[a] Eagle abundance index values were computed by summing mean numbers of eagles observed per day per 2-wk periods 2–7 (see Table 2) The results were divided by 1000.

[b] Salmon escapement values (divided by 1000) obtained from the Departments of Fisheries, Washington and British Columbia.

[c] Flow (cubic feet per second divided by 1000) records from U.S. Geological Survey (measured at Concrete, Washington).

[d] Flood days were arbitrarily identified as those when average flows exceeded 30 000 cubic feet per second; precipitation and temperature figures were obtained from U.S. Office of Climatology (measured at Concrete, Washington).

and 1981, we captured 25 Bald Eagles with padded and weakened leg-hold traps and fit each eagle with a radio transmitter. We caught 10 eagles on the Skagit River and 7 on the Nooksack River in 1980, and 6 on the Skagit River and 2 on the Nooksack River in 1981. Radio transmitters (Telonics, Inc., Mesa, AZ; 2-stage), weighing 27–41 grams and containing batteries with a 5-month life, were tied and glued to the dorsal bases of the central 2 rectrices (Young 1983). Each eagle was released at the place of capture.

We tracked eagles with road vehicles and fixed-wing airplanes using a Telonics TR-2 receiver coupled with a TS-1 programmable scanner. Airplane telemetry surveys included the part of western Washington and British Columbia lying west of the Cascade crest and the town of Hope, British Columbia, north of Olympia and Gray's Harbor in southwestern Washington, and south of Nanaimo on Vancouver Island. Our radio-tracking flights occasionally covered the entire area but concentrated on Puget Sound, Hood Canal, the western Cascade slope north of Seattle, the Skagit, Nooksack, and Fraser river valleys, the San Juan Islands, Howe Sound and the lower Squamish River, and the eastern side of Vancouver Island.

Regional Censuses. We censused Bald Eagles at least once every 2 wk from 24 November 1980 through 14 March 1981 in the following six areas believed to be potential destinations of eagles emigrating from the Skagit River: 1) Samish Flats. From near Blanchard on Samish Bay to the southern end of Padilla Bay, including Hat Island and March Point Peninsula; censused by road vehicle. 2) Deception Pass. Deception Island and mainland shores as viewed from Pass Island and Deception Pass State Park Beach; primarily a foot census. 3) San Juan Island. From Friday Harbor Airport southeast to Cattle Point and back on American Camp Road, by road vehicle. 4) Nooksack River. Between Maple Falls and Deming including about 8 km of the Middle Fork and 21 km of the North Fork; by road vehicle. 5) Fraser River (British Columbia). Three separate locations: the mouth of the Harrison River, Nicomen Slough, and the Fraser River near Hope; by road vehicle and on foot. 6) Squamish River (British Columbia). From Westwold Gate downstream 30 km to the estuary and including a 5 km segment of the Cheakamus River, 2 km of the Mamquam River, and Judd Slough; by road vehicle and on foot. Each census team consisted of a vehicle operator (where appropriate) and an observer who searched, with binoculars and a 20-power spotting scope, for eagles in trees, on gravel bars, driftwood, riverbanks, and in the air. Two-week periods were standardized for comparison between units, and if more than one census was performed in a 2-wk period a mean number of eagles was calculated.

Results and Discussion

Differences in Yearly Eagle Abundance. Bald Eagles appear in numbers on the Skagit River in November, peak in January in most years, and leave by mid-March. Table 1 shows gross differences in numbers of Bald Eagles counted along the Skagit River between Marblemount and the Sauk River during

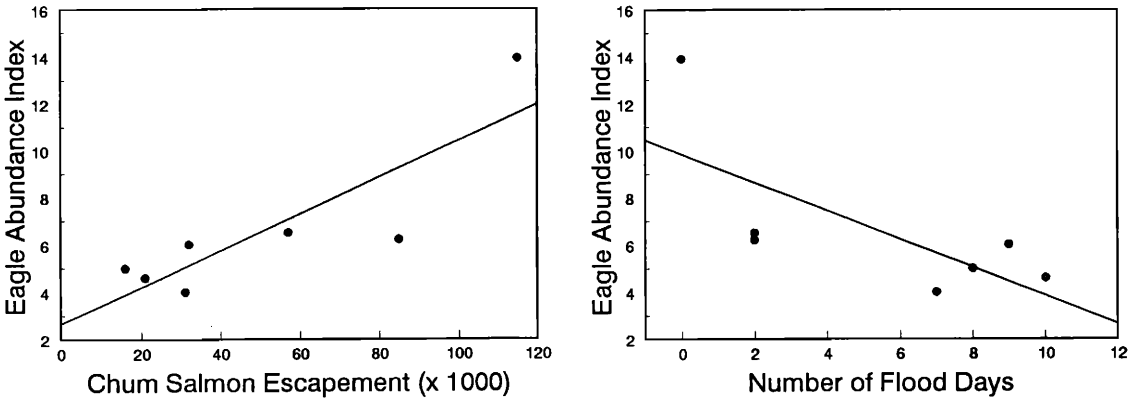

Figure 3. Relationship of Bald Eagle numbers on the Skagit River to 1) the estimated number (escapement) of Chum Salmon ascending the river to spawn, and 2) the number of flood days recorded.

seven winters of censusing. Eagle numbers were significantly correlated with Chum Salmon escapement (the number returning to spawn) to the Skagit River (Spearman rank correlation rho = 0.821, $P < 0.05$; Wilkinson 1985), and negatively correlated with daily flow rates and numbers of flood days averaged for January and February (Spearman rho = 0.857, $P < 0.05$, in both cases; Fig. 3).

During winter 1978–79, characterized by low temperatures and low rainfall, Skagen (1979) observed more than twice the number of eagles on the Skagit River than in other years. Numbers of spawning Chum Salmon that year were estimated by the Washington Department of Fisheries to be the highest on record. River flows were low, and no daily average discharge of over 30 000 cubic feet per second (flooding) was recorded at the gauging station at Concrete, Washington, during December and January. In contrast, flooding occurred on the Skagit River on an average of 6.3 d in this same two-month period during each of the other six years. The low flows recorded during 1978–79 probably caused a higher than normal rate of salmon carcass deposition on gravel bars (M. Aguero pers. comm.) and no floods occurred to wash the carrion away.

Servheen (1975) counted very large numbers of Chum Salmon carcasses on Washington Eddy gravel bar in winter 1974–75, when the number of high-water days and the mean December flow were both below average. During the last week in December he found 700 whole or partially consumed fish. By comparison, in the corresponding week during winters 1979–80 and 1980–81 we found only one and three fish, respectively, on the Washington Eddy bar.

Numbers of eagles on the Skagit River also may be influenced by availability of salmon carcasses on other rivers in the region. During winter 1978–79, when Skagen (1979) witnessed uncommonly high eagle numbers on the Skagit River, the escapement of Chum Salmon to the Nooksack River (Fig. 1) was 9000, or 56% of the mean (Table 1). This was a significant reduction from the previous high of 20 000 spawners in 1973–74. In the Fraser River in nearby British Columbia an average number of chum spawned in 1978–79, but the Squamish River (Howe Sound, BC), which is known to attract large numbers of eagles, had a slightly below average chum escapement. Attraction of eagles to other rivers also may explain why the large numbers of salmon carcasses recorded by Servheen (1975) on the Skagit River in 1974–75 did not generate an attendance of eagles comparable to that in 1978–79 (Table 1).

Relatively low numbers of eagles visited the Skagit River during winters 1979–80 and 1980–81. In both years Chum Salmon escapements there were far below average, while river flows were higher than in other years, both in mean daily flows and in highest water levels (Table 1). Chum Salmon escapements to the nearby Nooksack River in both years were the highest recorded for that river. Note that there were more eagles and fewer fish on the Skagit River in 1979–80 than in 1980–81. Chum Salmon escapement to the Squamish River (180 km to the north, which normally supports more eagles than the Skagit River) was ex-

Table 2. Eagles and salmon carcasses in the Skagit River study area during winter 1980–81. Eagle numbers were projected on the basis of visibility of each one-half-mile segment surveyed plus a weighting factor for perched subadults (see Methods). Eagle requirements of 486 g per day are from Stalmaster (1983).

Two-week Period	Mean No. Eagles per Day	Edible Chum (kg)	Eagle Requirement (kg)	Days Eagles Supported by Food Surveyed	Expected 2-week Consumption (kg)	Food Surplus (kg)	No. Chum (or Coho) Needed
1 24 November–7 December	40.9	1217.0	19.9	61.2	278.3	+939	0
2 8 December–21 December	109.6	1264.2	53.3	23.7	745.7	+518	0
3 22 December–4 January	94.7	733.1	46.0	15.9	644.3	+89	0
4 5 January–18 January	121.5	452.0	59.0	7.6	826.7	−375	102 (217)
5 19 January–1 February	110.6	227.0	53.7	4.2	752.5	−525	142 (303)
6 2 February–15 February	95.0	89.7	46.2	1.9	646.4	−557	151 (322)
7 16 February–28 February	57.8	0	28.1	0	393.3	−393	0 (227)
8 1 March–14 March	16.0	0	7.8	0	108.9	−109	0 (63)

tremely low in 1979–80 (19% of the mean), and it is quite possible that some of the eagles displaced there by such a food shortage might have gone to the Skagit and Nooksack rivers.

The lowest numbers of eagles on the Skagit River during the 7-year period was in winter 1973–74, when the chum escapement was estimated to be about one-half the average. Other conditions probably also contributed to the relative sparsity of eagles there: a flood occurred on the Skagit River in January, and the Nooksack and Squamish rivers showed above average Chum Salmon escapement.

Available Salmon Biomass. Based on weights of post-spawn salmon carcasses, we estimated that the average Chum Salmon carcass from the Skagit River weighed 4.78 kg, of which 3.69 kg might have been used by eagles. Each Coho Salmon produced, on average, about 1.73 kg of edible flesh.

Table 2 shows the relationship of projected Bald Eagle numbers along the 43 km long study area to the measured amount of salmon flesh available during winter 1980–81. From 24 November to 4 January the amount of food we found along the river was in surplus of that required by the eagles present. However, a deficit of available salmon compared to eagle requirements occurred after mid-January. The deficit continued to mount through 15 February and then declined as eagle numbers steadily diminished.

Persistence of Bald Eagles during the period in which we observed the biomass deficit implied either that recruitment of carcasses continued or that eagles were obtaining food from other sources. For example, during the fifth 2-wk period, when the estimated amount of available food should have sustained the eagles present in the study area for only 4 d, there was still enough fish flesh available 2 wk later to feed the eagles present for 2 d.

During our twice-monthly carcass counts we found "new" fish on the gravel bars as older ones were eaten or had otherwise disappeared. Until about 9 January 1981 these were primarily recently spawned Chum Salmon, but after 21 January there was no evidence of such recruitment. However, there was a gradual reduction in river flow from early January until mid-February. As the water receded, carcasses caught in low vegetation and in backwater pools were exposed or became available to eagles in shallow water.

To test attrition of the food value of carcasses, we collected 17 muscle tissue samples from dead Chum Salmon for caloric measurement. Laucks Testing Laboratories, Inc. (Seattle, WA) detected no variation in protein, fat, and caloric contents between tissue samples collected on 22 December 1980, on 21 January 1981 and on 3 February 1981 (ranges = 13.8–15.2% protein, 0.1–0.3% fat and 0.60–0.67 kcal/g).

Coho Salmon spawning in tributaries served as a principal food for eagles after mid-January. Table 2 shows the numbers of Coho Salmon carcasses (in parentheses) required to make up the food deficit computed for each 2-wk period. Eagles that could not find food on the main gravel bars in the study area could have been supported by 1132 Coho Salmon carcasses.

This represents about 13% of the estimated natural (non-hatchery) Coho Salmon escapement to the study area (Washington Department of Fisheries, 1977 Coho Salmon distribution estimate).

Many of the Coho Salmon carcasses accessible along tributaries were probably swept into deeper water during flooding. However, a series of ponds ("County Line Ponds," Fig. 1) provided Coho Salmon carrion for Bald Eagles through February and early March 1980, despite high water in the nearby Skagit River. These ponds, created as gravel pits during a dam construction project, were inundated by ground water percolation and were connected with the Skagit River mainstem via two small outflows. Were such habitat more abundant along the river, larger numbers of eagles could have been sustained.

Other potential food sources in the study area included mammal and bird carrion, live rabbits and live waterfowl. During our field work in both years we found carcasses or remains of several ducks, four deer, a rabbit, a gull, a raccoon and a beaver. Some of these had been eaten by eagles, however, it was our impression that densities of these potential foods in the study area were quite low, hence they were probably not very important to eagles.

Territoriality by some adult eagles along the river may have accounted for short-term preservation of chum carcasses. Certain individuals guarded carcasses against other eagles and we speculate that this extended the utilization of a carcass by an individual eagle over several days. The consequence of such behavior, if it occurred widely in the wintering population, might partially account for the apparent availability of carcasses through February.

Local Carrying Capacity for Bald Eagles. Of the 214 live post-spawn Chum Salmon we tagged with numbered plastic disks in the upstream portion of the study area, we found 29 as carcasses during gravel bar surveys. An additional tagged fish was taken alive in a net by fishermen 131 km downstream of the release site. The 29 carcasses represent 13.5% of the total number tagged. They drifted a mean distance of 7.7 km (range 0–37.8 km) from points of tagging or last recapture, and had an average recovery interval of 13.6 d (range 1–37 d). We detected no significant difference between recovery rates of salmon tagged in the mainstem and in the side-channel. Of 173 Chum Salmon tagged on the mainstem, 18 (10.4%) were found on the mainstem when dead and available to eagles.

Of the 29 tagged salmon recovered, 10 had been fed on by bears near the area of tagging. All remaining 19 recoveries were either on shore or exposed in shallow water and all were available to eagles. Of these, 2 had been completely devoured by eagles (except for head and bones), 7 were partially eaten by eagles and 10 were intact. Each tagged carcass was apparently available only for a short time since we never located a tagged carcass on a subsequent survey.

We initially assumed that salmon were deposited on gravel bars by simply drifting there after death. However, during our gravel bar counts, particularly those at night, we observed live salmon actively beaching themselves by "nosing" into shallow water, and they did so even after we repositioned them in deeper water. This beaching may be an important mechanism by which salmon become available to eagles.

The data from the Chum Salmon disktagging allowed us to estimate the carrying capacity of the Skagit River for Bald Eagles. Based on our regular eagle censuses in the Skagit River study area, the Sauk River, and the lower Skagit River from the Sauk River confluence to Sedro Woolley, we estimate that 22 743 eagle-days occurred in the entire Skagit drainage during winter 1980–81 (see Methods section). Our component estimates are as follows: Skagit River (Sauk River mouth to Gorge Dam) 9288, Lower Skagit River 6744, Sauk River (mouth to Darrington) 3705, Sauk River (upstream of Darrington) 926, Suiattle River 1080 and all other tributaries = 1000 eagle days.

The predicted Chum Salmon escapement (Washington Department of Fisheries estimate) to the Skagit drainage for winter 1980–81 was 21 350 fish. If 13% became available to eagles, as suggested by our salmon tag recoveries, and if Stalmaster's estimate of 486 g required by each eagle per day is correct (Stalmaster 1983), Chum Salmon provided potential food for 21 073 eagle-days. This figure falls close to the 22 743 eagle-days we calculate having actually occurred in the Skagit system.

In an intensively studied area, there was also agreement between the numbers of eagles and the numbers of spawners. Based on a Peterson index, we estimated that 3400 Chum Salmon spawned in the 14 km of the Skagit River between Copper Creek and Goodell Creek, where we captured salmon for disk tagging. If about 4% became available to eagles within this area, as tag recoveries suggest (side-channel carcasses eaten by bears excluded), then about 136 chum carcasses occurred as potential eagle food. These contained about 502 kg of edible flesh, which could support, if eagles were the only beneficiaries, a total of 1033 eagles for 1 d. From our eagle censuses we projected that 1096 eagle-days

actually occurred in this stretch of river during the winter.

The relationship between food availability and eagle occurrence is more complex than suggested by these close fits. Our carcass surveys demonstrated early surpluses and late-winter deficits of Chum Salmon. While it is conceivable that, during the early period, most or all of the excess Chum Salmon carrion (as noted in the surveys) persisted on the gravel bars until eaten by eagles, the deficits apparent by mid-January implied the existence of additional food, namely Coho Salmon off the mainstem.

Bald Eagle Movements. Our findings indicate that, at least in years of moderate to low salmon carcass availability, Bald Eagle numbers on the Skagit River after mid-January are rather closely defined by food availability. In flood years or those of low salmon escapement, eagles are forced, sometimes suddenly, to abandon salmon carrion for other types of food. For yearling eagles, the loss of salmon as a food option may require the hasty development of new foraging skills. To explore these considerations, we tried to determine destinations of eagles departing the Skagit and Nooksack rivers and how they might obtain food.

Five of the 25 telemetered eagles remained for at least one month along the river where they were captured. Those in the Skagit drainage ($N = 3$) responded to local depletions of Chum Salmon carrion by relocating to stretches of river where carcasses were more abundant or to tributaries or ponds where spawned-out Coho Salmon were accessible. In 1979–80, when Coho Salmon evidently were important to eagles, four of the five radio-tagged birds remaining along the upper Skagit River held tenaciously to Coho Salmon concentrations.

As food diminished, telemetered eagles left the upper Skagit and Nooksack rivers (Table 3). Seven radio-tagged birds flew to river areas other than where they were captured. Presumably attracted to salmon carcasses, they went to the lower Skagit, the Sauk, the Snoqualmie, and the Fraser rivers (Table 3). Two eagles tagged on the Skagit River (No. 7 and 9) moved upstream toward Newhalem, and then presumably departed eastward. Several other telemetered birds may also have gone eastward since we failed to detect them to the west, northwest or southwest. At least seven radio-tagged eagles eventually flew westward to Puget Sound or the Strait of Georgia. We detected them in the San Juan Islands, Deception Pass, on coastal flats and at estuaries. At least two of these eagles may have summered at Puget Sound: one adult was still in the Puget Sound area on 13 April 1980, after which it lost its transmitter. Another adult (No. 22) remained in Puget Sound environs through at least 7 June 1981, when radio-tracking flights were terminated. R. Knight (pers. comm.) believed the bird to be associated with a nest on Protection Island near Port Townsend on 9 April 1981, but by 17 April it frequented the vicinity of Freeland on Whidbey Island, on 12 May Lofall on Hood Canal, and by early June Freeland again.

Several records of long-range movement were obtained during this study. Two subadults, tagged in early February, were detected at Knight Inlet, British Columbia, on 19 April 1981. One eagle was in southeast Alaska on 26 February 1981 (J. Hodges pers. comm.). Movements to the south included an adult south of Olympia, Washington, on 6 March 1981, and another adult on 13 February 1981 at Lower Klamath Lake in northern California (Keister 1981). This bird returned to the Skagit River by 26 February but was not detected thereafter. Servheen and English (1979) present a discussion of migration routes to and from the Skagit drainage.

Regional Eagle Censuses. As Bald Eagle numbers decreased along six rivers from January to February, wintering populations generally increased during the same period at three census locations near Puget Sound (Table 4). Both census data and the telemetry data are in agreement that some of the eagles displaced from rivers by declining salmon carrion were attracted to Puget Sound.

Foraging opportunities were diverse in the bays, estuaries, beaches, and coastal flats of Puget Sound and the Strait of Georgia. At Samish Flats, eagles fed mainly on waterfowl. C.M. Anderson (in lit.) recorded 53 birds (including 47 waterfowl) in a sample of 62 eagle prey. C.M. Anderson also observed eight attempts by Bald Eagles to capture live ducks; two of these were successful. L. Brewer (pers. comm.) saw eagles take flying gulls and wounded geese in shallow water. Eagles have also been observed foraging in the littoral zone of Puget Sound (C. LaRiviere in lit., see also Vermeer and Morgan 1989); we saw a radio-tagged subadult take fish stranded in a tidal pool. Prey records from San Juan Island include fishes, Old World rabbits (*Oryctolagus cuniculus*), and seabirds (Retfalvi 1965, 1970, Knight et al. 1990).

Some of the straits and channels in Puget Sound attracted Bald Eagles. At Deception Pass on 3 March 1981 we watched a number of eagles perched in conifers overlooking the channel. We observed no apparent foraging behavior for 6 hr, but at the tidal

Table 3. Movements of radio-tagged eagles by 2-week period. Birds 1–10 were tagged on the Skagit River (Census Unit 1) in January and February 1980; birds 11–17 on the Nooksack River (Unit 7) in February 1980; birds 18–22 and 25 on the Skagit River in January and February 1981; and birds 23–24 on the Nooksack River in February 1981. Locations outside of the study region (see Figure 1) are marked with an asterisk.

Eagle No.	Estimated Age (years)	Two-Week Period						Last Location	Date
		22 Dec.–4 Jan.	5 Jan.–18 Jan.	19 Jan.–1 Feb.	2 Feb.–15 Feb.	16 Feb.–28 Feb.	1 Mar.–14 Mar.		
1	2	Skagit R.	—	Puget Sound	Puget Sound	Puget Sound	Fraser R.	Nooksack Estuary	Mar. 28
2	2	Skagit R.	—	—	Snoqualmie R.*	Puget Sound	Puget Sound	Camano Island	Apr. 2
3	1	—	Skagit R.	Skagit R.	Skagit R.	Skagit R.	Nooksack R.	Nooksack R.	Mar. 20
4	1	—	Skagit R.	Puget Sound	Puget Sound	Puget Sound	Puget Sound	Strait of Georgia*	Apr. 2
5	5+	—	—	Skagit R.	Skagit R.	Skagit R.	—	Fraser R.	Feb. 25
6	5	—	—	Skagit R.	Sauk R.	Sauk R.	—	Sauk River	Mar. 1
7	3	—	—	Skagit R.	Skagit R.	Skagit R.	Skagit R.	Skagit R.	Mar. 14
8	5	—	—	—	Skagit R.	—	—	Skagit R.	Feb. 13
9	3	—	—	—	Skagit R.	—	—	Skagit R.	Feb. 10
10	2	—	—	—	Skagit R.	Skagit R.	—	Skagit R.	Feb. 22
11	5+	—	—	—	Nooksack R.	Nooksack R.	Puget Sound	Puget Sound	Apr. 13
12	1–2	—	—	—	Nooksack R.	Nooksack R.	Fraser R.	Knight Inlet, B.C.*	Apr. 25
13	3	—	—	—	Nooksack R.	Nooksack R.	Fraser R.	Fraser R.	Feb. 29
14	3	—	—	—	Nooksack R.	Nooksack R.	Nooksack R.	Nooksack R.	Mar. 5
15	3	—	—	—	Nooksack R.	Nooksack R.	Fraser R.	Fraser R.	Mar. 8
16	2	—	—	—	Nooksack R.	Nooksack R.	—	Nooksack R.	Feb. 19
17	3	—	—	—	Nooksack R.	Nooksack R.	Nooksack R.	Knight Inlet, B.C.*	Apr. 25
18	5+	—	Skagit R.	—	N. California*	Skagit R.	—	Skagit R.	Feb. 26
19	5+	—	Skagit R.	—	—	—	SW Wash.*	SW Wash.*	Mar. 6
20	5+	—	Skagit R.	Skagit R.	Skagit R.	Skagit R.	Skagit R.	Skagit R.	Mar. 13
21	1–2	—	Skagit R.	—	—	—	—	Skagit R.	Jan. 18
22	5+	—	—	Skagit R.	Puget Sound	Puget Sound	Puget Sound	Puget Sound	Jun. 7
23	1–2	—	—	—	Nooksack R.	Fraser R.	—	SE Alaska*	Feb. 26
24	3	—	—	—	—	Nooksack R.	—	Nooksack R.	Feb. 22
25	3	—	—	—	—	Skagit R.	—	Skagit R.	Feb. 28

change we recorded at least 9 successful foraging attempts in 1 hr and saw up to 16 eagles soaring in a group over the channel. In one instance eight eagles vied for possession of one fish. Typically, eagles took 15–25 cm long fishes from the surface of the water. The prey were most likely Pacific Sandlance (*Ammodytes hexapterus*), which are known to stem the tidal currents of channels in large schools. In addition, spawning runs of Pacific Herring (*Clupea harengus*) occur in February and March in the Deception Pass area (Simenstad et al. 1979). During the tidal ebb, when we observed the foraging eagles, the waters of Deception Pass move with great force and velocity. Resultant upwelling currents may make certain fish vulnerable or perhaps underwater predators such as salmon or harbor seals become sufficiently active at these times to force small fish to the surface. Eagles also frequent Active Pass in the Gulf Islands (R.W. Campbell pers. comm.), and Retfalvi (1965) observed that nesting eagles at San Juan Island prefer to forage in narrow channels rather than open water.

Summary and Management Implications. Data from the Skagit River support the hypothesis that the overall number of eagles present during the winter is a function of the availability of salmon carcasses. While the latter depends mainly on the number of salmon ascending the river to spawn, several additional factors influence carcass availability to eagles. Low river flows are most conducive to carcass deposition on gravel bars, while high water tends to remove carcasses or place them out of sight in vegetation. Low flows are encouraged by low precipitation, restrictive dam regulation and low air temperatures. The latter produces and retains snow at higher elevations, while higher temperatures, especially with heavy rains, cause snowmelt and flooding.

During our study, Bald Eagles were below carrying capacity during November and December. A reason for this is that Chum Salmon spawn earlier in southeastern Alaska and northern British Columbia than in the Puget Sound region, and these areas may retain eagles in the early part of the winter (Waste 1982). In general, when salmon carcasses are available in abundance on other rivers in the Northwest, lower numbers of eagles might be expected to concentrate on the Skagit River.

Spawning areas such as shallow sloughs, because of their physiography, are more likely than other habitats to accumulate accessible fish carcasses. Sloughs, gravel bars, backwaters and other shallow habitats favoring carcass deposition are widely distributed, and may be differentially affected under varying hydrologic conditions. A wide distribution of spawners may therefore favor high overall eagle numbers, and is dependent on spawning habitat management, sympathetic programs of dam operation and possibly high genetic variability of salmon.

Table 4. Results of Bald Eagle censuses in the Pacific Northwest during winter 1980–81. Asterisks indicate only one survey was performed within the month, all other figures are averages of two or more surveys.

	Mean No. of Eagles per Survey			% Change
	December	January	February	January to February
Rivers				
Upper Skagit	61	81	49	−39
Lower Skagit	41	80	31	−61
Sauk	32	*44	19	−57
Nooksack	84	178	67	−62
Fraser	230	373	117	−69
Squamish	310	955	220	−79
Puget Sound				
Deception Pass	2	7	25	+257
Samish Flats	15	25	27	+8
San Juan Island:				
Ground survey	25	26	41	+64
Air survey	—	*110	*138	+25

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