BALD EAGLE POPULATION SURVEYS OF THE NORTH PACIFIC OCEAN, 1967–2010

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ABSTRACT—Bald Eagle (*Haliaeetus leucocephalus*) populations along the north Pacific coast from southern British Columbia to the Alaska Peninsula have been monitored since 1967 with aerial surveys using a universal random plot design. This survey consisted of 233 plots, each 168.3 km^2. The expanded population estimate for adults totaled 58,000 after applying a visibility correction factor of 2.0. This accounted for roughly half of the world's population. With multiple surveys, I determined that populations in southeast Alaska, Prince William Sound, and the Alaska Peninsula increased until the late 1980s and remained stable thereafter. All possible plots, under this survey design, can be delineated for future replication or modification using 2 simple equations.

Key words: aerial survey, Alaska, Bald Eagle, British Columbia, *Haliaeetus leucocephalus*, north Pacific coast, population status, shoreline

Bald Eagles (*Haliaeetus leucocephalus*) are ubiquitous along the northwest coast of the Pacific Ocean from British Columbia to the Alaska Peninsula, accounting for roughly half of the North American breeding population (Buehler 2000). Bald Eagles in Alaska and British Columbia were once targeted for persecution through official bounty programs. In Alaska, records show 128,273 bounty payments were distributed to hunters between 1917 and 1953 (Robards and King 2004); certainly many additional eagles were lost and not collected. Concern for Bald Eagles within the contiguous United States culminated in the passage of the Bald Eagle Protection Act in 1940. Bald Eagles in Alaska gained their protection at statehood in 1959. The need to monitor their abundance in Alaska was recognized, and the 1st regional survey was conducted in southeast Alaska in 1967 (King and others 1967). Aerial population surveys have proven the best method of assessing abundance during the breeding season (Hodges 2004). One sampling design spanned this region and the 44-y period from 1967 through 2010. The complete survey design can be described with 2 mathematical equations. This paper summarizes the aerial population counts in their simplest form.

METHODS

The study area included the saltwater shorelines of the Gulf of Alaska and British Columbia (Fig. 1). The coastline is composed of intricate combinations of fiords, straits, bays and islands. Heavy coniferous forests cloak the shorelines, except in the far western areas of the Alaska Peninsula and Kodiak Island which are predominantly treeless. The complex shoreline totals 63,400 lineal km, roughly 7% of the shoreline of the world (Bird 2008). Southern British Columbia has been influenced by substantial human development and logging of the shoreline forest (Hodges and others 1984). Northern British Columbia, southeast Alaska, Prince William Sound, and the south Alaska coast have localized sections of shoreline that have been extensively logged. The remaining regions exhibit relatively little disturbance of the coastal habitat.

To effectively survey a large study area which spans 12 degrees of latitude and 42 degrees of longitude, we developed a special survey design (Hodges 2004). This design was characterized by randomly selected plots of the same size whose boundaries aligned with cardinal compass points (hereafter referred to as universal plots). A design center point was chosen at 57.325°N latitude and 134.000°W longitude. The rows of plots on the Y axis were 7 minutes of latitude (7 nautical miles; 13 km) in height. All plots within a row were 7 nautical miles wide along the X axis. The north or south boundaries of each plot were parallel to the lines of latitude,

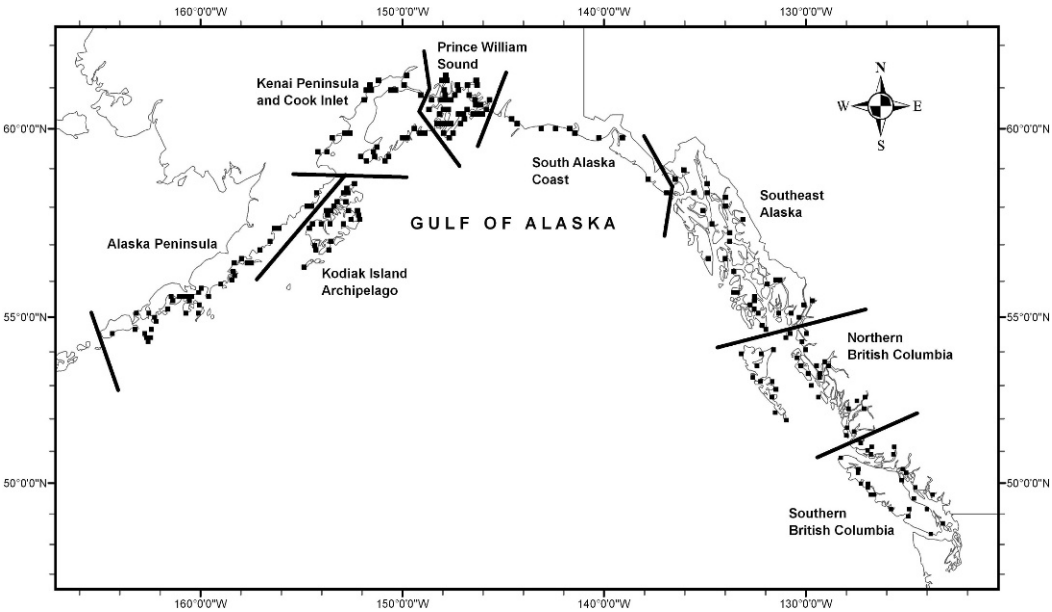

FIGURE 1. Bald Eagle aerial survey plot locations and region designations.

and the east or west boundaries of each plot were parallel to the lines of longitude. Each plot had an X and a Y integer coordinate corresponding to its position east and west (X), and north and south (Y) of the design center point. The center point of any plot (X, Y) was obtained from the equations:

$$\text{Center Latitude} = 57.325 + 0.1167 * Y$$

$$\text{Center Longitude} = 134 - X * (0.1167/\cos(\text{Center Latitude})).$$

All possible plots containing shoreline were mapped. The area was divided into 8 geographic regions. Simple random samples of these plots were selected within each region (Fig. 1). The exception was British Columbia where a stratified sample with optimum allocation of effort was used (Hodges and others 1984). Of the 1848 possible plots, 233 (13%) were selected. With very few exceptions, surveys were conducted between the calendar dates of 20 April and 10 May. This was a period when adult eagles were attending their nest sites and usually incubating eggs in all surveyed areas. Population estimates were expanded from samples by region.

The shoreline was flown with a single pass at an elevation which provided the best view of the near shore perching habitat. In most cases the altitude was 70 m above sea level. Steep terrain and tall cliffs usually required higher altitudes to afford the best view of the likeliest perching habitats. Survey speed was 160 km/h. The observer sat in the right front seat. The pilot served as a 2nd observer. Only the saltwater shoreline interface was surveyed. Eagles with predominately white heads were classified as adults. A specially modified turbine-powered de Haviland Beaver aircraft was used for all surveys except those flown in southeast Alaska in 1967 and Prince William Sound in 1973 and 2005. The aircraft had exceptionally good visibility for both pilot and observer.

Survey data were analyzed by region as simple random samples, except British Columbia, where the sample design was stratified with optimum allocation of effort and could not be treated as a simple random sample.

The original survey was flown in southeast Alaska in 1967 and again in 1977 and 2007 and used a different plot system. The plots (30) were 8 statute miles/side (165.8 km^2) rather than the 7 nautical miles/side (168.3 km^2) for the universal plots. In 1982, an effort was

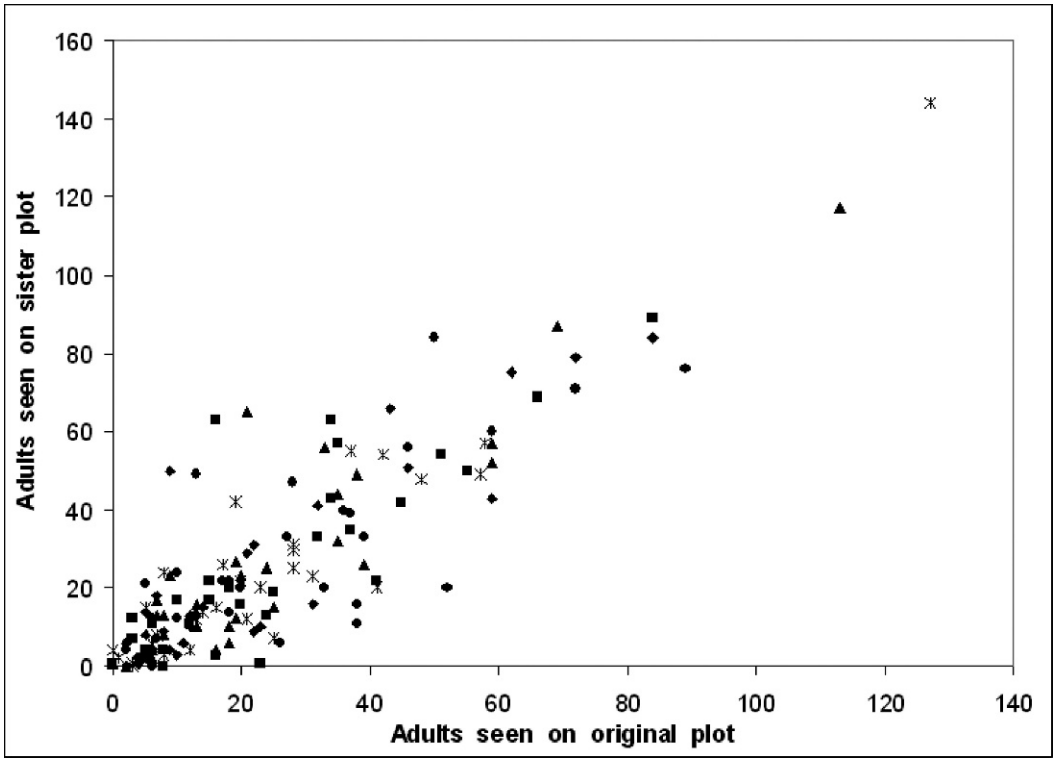

FIGURE 2. Correlation between original plots and their sister plots in southeast Alaska. Graphed points are from 30 plots and 5 surveys (1982-diamond, 1987-square, 1992-circle, 1997-triangle, and 2002-asterisk).

initiated to incorporate the original plots into the universal plot design. A sister plot from the universal plot design was determined for each of the original plots. An original plot's sister plot was the new universal plot that overlapped the original plot by at least 50%. Both original plots and universal sister plots were surveyed in 1982, 1987, 1992, 1997, and 2002. Because of the overlap between sister plots and original plots, there was high correlation between the two (Fig. 2). The 5 y of combined surveys provided a weighted average ratio, by plot, of universal sister plot to original plot. The original plot count was multiplied by this ratio to estimate the presumed number of eagles that would have been counted on each of the universal sister plots for the years 1967, 1977, and 2007.

In Prince William Sound, Bowman and Schempf (1999) estimated perception bias (observed proportion of the eagles within view of the observer) at 0.79 using the double observer method with 4 classes of detection probabilities: perched easy, perched difficult, flying, and incubating. They used radio-tagged eagles to estimate that 21% of the eagles were unavailable to be seen. Their cumulative proportion seen was estimated at 0.62 and the visibility correction factor was 1.6. Their correction factor was biased low because of the heterogeneity in detection probabilities within their 4 detection classes (Savage and Hodges 2006). In Chesapeake Bay, Buehler and others (1991) estimated their visibility correction factor at 2.38. In this analysis, I arbitrarily chose an intermediate visibility correction factor of 2.0.

RESULTS

Numbers of adult Bald Eagles varied by region and year (Table 1). Eagle numbers were lower in the early part of the study period before stabilizing in all areas with multiple surveys (Table 1). Southeast Alaska stabilized by 1982, Prince William Sound by 1989, and the Alaska Peninsula by 2000. Stabilized mean values for each plot are presented in Table 2.

TABLE 1. Adult Bald Eagle population estimates from plot samples across the north Pacific coast, 1967–2010. Simple random sampling was used by region, except as noted. Coefficients of variation are in parentheses.

	Southern British Columbia	Northern British Columbia	Southeast Alaska	South Alaska Coast	Prince William Sound	Kenai Pen. and Cook Inlet	Alaska Peninsula	Kodiak Archipelago
1967			8473 (0.15) [1]					
1973					1728 (0.12) [2]			
1977			8425 (0.14) [1]					
1980	4073 [3] (0.16)	5006 [3] (0.16)						
1982			12,444 (0.18) [4]	720 (0.36)	1736 (0.18)	456 (0.20)		
1983							1442 (0.10)	1082 (0.11)
1987			13,617 (0.16) [4]					
1989				342 (0.29)	2288 (0.17) [5]			
1990					2082 (0.15) [5]			
1991					2354 (0.16) [5]			
1992			14,212 (0.15) [4]					
1995					2659 (0.18) [5]			
1997			13,923 (0.18) [4]					
2000							2647 (0.10) [6]	
2002			11,152 (0.15)					
2005					1876 (0.12)		2333 (0.10) [6]	
2007			12,934 (0.15) [1]					
2009					2434 (0.15)			
2010							2789 (0.10)	

[1] Original 1967 plots were surveyed but then adjusted to presumed sister plot values based on the 5 y (1982–2002) ratios when both original plots and sister plots were surveyed.
[2] Estimate used plots of similar size, but is the only estimate in this table not based on the universal plot design.
[3] Estimates are from Hodges and others (1984) because the original plot selection was based on a stratified sample with optimum allocation of effort which would cause a simple random sample analysis to be biased.
[4] These estimates differ from Jacobson and Hodges (1999) who used the original 1967 plots. This paper uses their sister plots.
[5] These estimates differ from Bowman and others (1997) who augmented with complete counts of the islands in Prince William Sound.
[6] These estimates differ from Savage and Hodges (2006) because their analysis was based on a stratified random sample.

Adult population levels along the saltwater coastlines can be described in round numbers as follows: 4000 in southern British Columbia (1980); 5000 in northern British Columbia (1980); 13,000 in southeast Alaska (mean, 1982–2007); 500 on the south Alaska coast (mean, 1982 and 1989); 2300 in Prince William Sound (mean, 1989–2009); 500 in Kenai and Cook Inlet (1982); 2600 in the Alaska Peninsula (mean, 2000–2010); and 1100 in the Kodiak Archipelago (1983). Total combined population was estimated at 29,000; the population of adult eagles in the study area numbers about 58,000 assuming a visibility correction factor of 2.0.

Discussion

This paper brings together all of the Bald Eagle survey data that has been collected under one umbrella survey design for half of the world population. Active persecution of eagles during the first half of the twentieth century likely suppressed population levels dramatically. We may have witnessed the final stages of recovery in southeast Alaska by 1982, in Prince William Sound by 1989, and on the Alaska Peninsula sometime between 1983 and 2000. A low estimate in Prince William Sound in 2005 was probably due to use of a different aircraft, pilot, and observer.

The stabilized population levels indicate populations at equilibrium with their environment. In all areas except southern British Columbia the populations are probably at or near the historic carrying capacity. In spite of past logging in southeast Alaska and Prince William Sound, availability of nesting habitat is not seen as a significant limiting factor. The US Fish and Wildlife Service and the US Forest Service cooperatively began protecting breeding territories in 1968. Full protection of the shoreline timbered fringe on the Tongass National Forest (80% of the land base in southeast Alaska) began in 1997 with the establishment of a 1000-ft (304.8-m) buffer strip of no cutting.

The Exxon Valdez oil spill in Prince William Sound on 24 March 1989 did not have a lasting effect on the Bald Eagle population (Bowman and others 1997). A slightly reduced population in 1990 was followed by higher numbers in 1991 and 1995. Prince William Sound estimates in

TABLE 2. Adult eagles observed by plot. Mean values are for those years after the population stabilized in regions with multiple surveys. Sample size (n) and the universe of plots (N) are specified by region. British Columbia plot data may be found at Hodges and others (1984).

Southeast Alaska		
n = 30, N = 510		
1982–2007 Averaged		
X	Y	Mean
−9	14	4.4
−11	12	18.3
−4	11	56.0
−7	9	62.2
−4	9	85.9
0	8	14.3
0	6	32.3
−5	5	48.7
4	3	1.4
−3	2	46.3
1	0	53.0
1	−2	29.0
−4	−6	6.9
0	−6	38.5
2	−9	20.8
12	−11	4.0
13	−11	9.9
10	−12	11.8
2	−14	49.1
3	−14	50.9
7	−15	22.9
7	−16	17.9
6	−17	0.9
7	−18	12.1
8	−19	2.9
13	−19	20.3
16	−19	14.6
18	−20	11.3
9	−22	16.8
10	−23	4.1

S. Alaska Coast		
n = 10, N = 90		
1982 and 1989 Averaged		
X	Y	Mean
−13	9	27.5
−17	12	5.0
−22	21	0.0
−27	21	3.0
−32	22	2.5
−33	23	1.5
−36	23	2.5
−39	23	0.0
−44	24	4.5
−45	25	22.5

Prince William Sound		
n = 40, N = 110		
1989–2009 Averaged		
X	Y	Mean
−50	27	18.5
−51	28	34.7
−52	28	8.7
−49	29	5.5
−52	29	62.7
−53	30	80.5
−55	31	40.7
−58	31	10.3
−51	32	4.2
−53	32	24.2
−55	32	0.3
−51	33	4.0
−57	33	8.2
−58	33	1.2
−57	34	1.3
−56	30	22.7
−58	30	36.5
−61	29	6.5
−59	27	27.0
−62	27	7.7
−60	26	27.7
−60	24	51.5
−61	24	24.2
−57	29	5.2
−54	27	3.0
−58	24	2.0
−60	22	7.2
−58	29	32.3
−52	26	15.0
−53	26	19.3
−51	26	7.5
−55	26	41.8
−56	26	58.3
−55	25	26.3
−56	24	7.2
−59	24	17.8
−58	22	21.2
−59	21	3.5
−59	29	19.7
−58	27	34.0

Kodiak and Afognak		
n = 25, N = 127		
X	Y	1983
−85	9	15
−84	9	12
−84	10	18
−82	11	15
−87	7	20
−88	6	9
−89	5	13
−90	5	6
−85	5	14
−83	5	1
−83	4	6
−85	3	7
−83	3	7
−87	2	5
−92	2	5
−94	2	2
−95	1	3
−91	−2	9
−95	−3	5
−92	−4	14
−95	−4	10
−99	−8	3
−90	2	9
−90	4	2
−85	7	3

Alaska Peninsula		
n = 40, N = 206		
2000–2010 Averaged		
X	Y	Mean
−91	9	7.3
−93	6	19.7
−94	6	4.3
−102	1	17.7
−103	1	6.0
−105	−2	7.7
−108	−4	10.7
−111	−7	1.7
−112	−7	6.3
−113	−6	14.0
−115	−7	8.7
−116	−9	11.5
−116	−10	11.7
−117	−11	6.0
−120	−12	11.0
−124	−15	14.7
−125	−13	19.7
−126	−14	16.3
−127	−17	6.3
−128	−19	27.3

Alaska Pen. cont'd.		
−128	−15	14.7
−129	−15	11.7
−129	−16	6.0
−130	−15	3.7
−131	−15	0.0
−131	−19	10.3
−133	−15	14.3
−133	−16	2.7
−135	−18	16.7
−139	−20	27.7
−139	−21	16.0
−140	−19	12.7
−141	−23	9.0
−142	−25	33.3
−143	−19	9.0
−143	−24	12.0
−143	−25	38.0
−143	−26	12.7
−145	−23	15.3
−151	−24	8.7

Kenai Pen. and Cook Inlet		
n = 27, N = 145		
X	Y	1982
−64	22	2
−65	22	1
−66	23	14
−68	21	11
−69	21	3
−73	17	7
−74	16	1
−76	17	4
−78	16	10
−79	17	4
−76	18	6
−75	19	3
−63	30	4
−66	32	0
−68	31	1
−69	31	2
−65	34	1
−71	33	0
−73	32	0
−74	31	3
−73	31	0
−75	29	1
−80	22	1
−81	22	4
−84	21	2
−86	18	0
−88	18	0

this paper differ slightly from Bowman and others (1997) because those authors used a stratified analysis in 1982 and they used the complete coverage of all island shorelines in 1989–1991 and 1995, whereas I used only the simple random sample of plots for all years.

The coefficients of variation (CV) in Table 1 are quite acceptable considering the simple random plot design and highly variable amounts of shoreline habitat within the plots. The CVs were <0.20 for all surveys except the South Coast which had a sample size of only 10 plots. Sample sizes for other regions were adequate, from 25 to 40 plots.

The value of the best estimates by plot in Table 2 will manifest itself in the future. Each plot has an estimated number of adult eagles that is representative of the natural or stabilized abundance. All 1848 plots can be defined from the equations in this paper. All surveyed plots or a subset of plots may be replicated. For the 6 regions with simple random samples, new plots may be appended to the sample if desired. British Columbia plots were selected with optimum allocation of effort which precludes the ability to append to the survey without knowing the strata classification for every plot in the region.

For compatibility of data, future surveys should be accomplished in aircraft with excellent visibility. If the pilot is unable to meaningfully assist with locating eagles, a back seat observer should be used instead. A Cessna 206 aircraft was used in Prince William Sound in 2005 instead of the turbine-powered de Haviland Beaver, which in part accounted for the abnormally low count that year. Improved counts for wildlife surveys with the turbine-powered Beaver have been documented by Hodges and others (1996).

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