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Modelling of a Resident Bald Eagle *Haliaeetus leucocephalus* Population using Empirical Life Table Parameters

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ABSTRACT

Over the course of a 10-year study of a resident breeding population of 10 nesting pairs of Bald Eagles, population parameters were empirically derived and used to predict population changes. I estimated annual adult survivorship at 94.6% with data from banding and colour-banding 17 resident adults. Survivorship of first-year birds was estimated at 76.9%, based on radiotelemetry data from 13 nestlings fledged from two cohorts in the study area in 1989 and 1990. Reproduction, as measured by the monitoring of nest sites, was determined to be 0.81 young fledged per occupied nest. These parameters and a few conservative assumptions were used to run Time-Zero© (Fort Collins, Colorado), a packaged population model. With this model I estimated that the population would increase, and that the number of nesting pairs would double in 20 years. The model was very sensitive to estimates of survivorship; for instance, if the estimate of adult survivorship was reduced to 80% (as opposed to 94.6%), the programme forecast only 3 nesting pairs remaining after 16 years. These results indicate the importance of conserving habitat to increase survivorship for wintering and nonbreeding birds, in addition to protecting traditional nest territories.

INTRODUCTION

Bald Eagles *(Haliaeetus leucocephalus)* once bred over most of California, including the Sacramento and San Joaquin valleys, the Sierra-Nevada and coast ranges, and the entire length of the California Pacific coast (Detrich 1985). Through various anthropogenic factors, by 1970 this once-expansive breeding population was reduced to fewer than 30 nests, concentrated in north-central California (Thelander 1973). The federal government banned dichlorodiphenyltrichloroethane (DDT) in 1972, and efforts increased to research and manage the species. By 1988, the number of eagles nesting in California grew to about 75 pairs (Jurek 1988, 1990). In 1992 the breeding population of Bald Eagles in California was estimated to be more than 90 pairs; despite the population growth, Bald Eagles continue to be recognized as an endangered species by both the state and federal governments (USFWS 1986).

Over the course of a 10-year study of resident Bald Eagles in the Pit River drainage in Northern California, a number of common life table parameters were empirically estimated (Jenkins 1992). Although estimates of reproductive success are often obtained on Bald Eagles (Swenson *et al.* 1986) and other raptors, estimates of adult and juvenile survivorship are rarely obtained. Moreover, it is unusual to obtain these estimates from a single subpopulation within one particular drainage.

In this study I used estimates of empirically derived population parameters from Bald Eagles in the Pit River drainage to run a packaged population model called Time-Zero©. The objective of the model is to provide predictive insight into what might be expected to occur in a Bald Eagle population exhibiting these life-table parameters. Using this method provides insight into the relative importance of the parameters, and provides an opportunity to adjust population parameters and determine how such adjustments might affect population predictions (Grier 1980). This method also allows for an evaluation of life-table parameters necessary for an endangered population to grow. Knowledge of the importance of specific population parameters may lead to an emphasis on certain conservation strategies.

STUDY AREA

The Pit River originates in Modoc County, drains much of north-eastern California, and is a major tributary of the Sacramento River system. The Pit River Study Area (PRSA) includes 78 km of reservoir and riverine habitat on the Pit River in Shasta County.

My study area includes an intergradation of habitat types characteristic of Cascade and Sierra Nevada mountain regions. Seven habitat types occur in the study area (Holland 1986). The area around Lake Britton is dominated by Ponderosa pine (*Pinus ponderosa*) forest in open stands as tall as 70 m. Oregon oak woodland is found primarily at the easternmost portions of the Lake Britton area, and is interspersed with Ponderosa pine and valley- and foothill-introduced grasslands. Small areas of Sierra mixed-coniferous forest, north coast riparian woodland, montane chaparral, and meadow and seep habitat also occur at Lake Britton (Holland 1986).

Downstream from Lake Britton, the Pit River canyon is dominated by Sierra mixed-coniferous forest, which is also the dominant habitat at the three downstream reservoirs. This habitat is similar to Ponderosa pine forest, but is denser, often slightly taller (75 m), and composed of several dominant species. These species include Ponderosa pine, Douglas fir (*Pseudotsuga menziesii*), incense cedar (*Libocedrus decurrens*), and sugar pine (*Pinus lambertiana*).

METHODS

REPRODUCTIVE SURVEYS

The 10 PRSA Bald Eagle nests were each surveyed several times every breeding season to determine their status and the eventual outcome of each nesting event. Nests were surveyed from the ground and from a helicopter, which was flown high (500 m) above the nest to avoid disturbing nesting adults. Nests were surveyed at least three times each season (Jurek 1990): early (March) to determine occupancy; in mid-nesting season (April-May) to determine presence of eggs or young; and late (mid June) to determine the number of young fledged. Data collection followed standard methods as described by Postupalsky (1974). Other data were obtained by trapping, banding and radiotelemetry.

POPULATION MODELLING

I modelled the PRSA Bald Eagle population using a packaged software modelling programme called Time-Zero distributed by Quaternary Software, Inc., Fort Collins, CO. An age-specific population model was employed, using empirically derived productivity and survivorship data from the PRSA Bald Eagle population for the required life table values.

I used the age-specific model to divide the population into age classes, each with specific natality and survivorship rates. Births were computed in yearly time steps as a product of population size and natality rates. Each age class was updated by multiplying its size by its survivorship and adding the product to the next age class. I made the following assumptions in the model: 1) eagles first breed after reaching five years of age, 2) 50% of offspring are female, 3) all females reaching adulthood produce young, 4) no emigration or immigration is occurring among the population, and 5) no age classes except adults (10 pairs) exist at the beginning of the model.

RESULTS

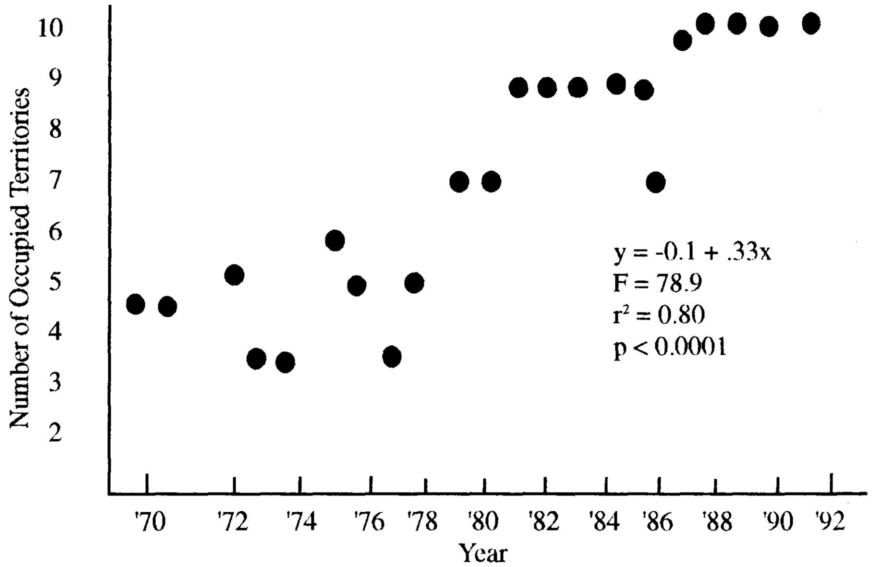
Breeding Adults

At present, 10 Bald Eagle nesting territories occur in the PRSA, six of which are at Lake Britton. Four other nesting territories are distributed among small dowstream reservoirs: two at the Pit 4 Reservoir, one at the Pit 5 Reservoir, and one at the Pit 6 Reservoir. Several territories at Lake Britton and the Pit 4 Reservoir are separated by 1 km or less, a density that rivals those of nesting Bald Eagles in presumably saturated habitat in south-east Alaska (Hodges 1982). A statistically significant ($F = 78.9$, $p < 0.001$, $R^2 = 0.80$) increase in the number of occupied nesting territories has occurred over the past 20 years in the PRSA (Figure 1). This is the densest nesting aggregation of Bald Eagles in California.

Productivity

Production of young between 1970 and 1991 in the 10 PRSA nest sites has averaged 0.81 young per occupied site, with 55.7% of the occupied nests successfully producing

Figure 1. Number of reported occupied Bald Eagle nesting territories in the PRSA between 1970 and 1991 (Jenkins 1992).



young (Table 1). This figure includes data from the South Shore nesting territory of Lake Britton which, despite 17 years of occupancy, has failed to produce young, a result possibly related to pesticide contamination (Jenkins 1992). Removing this territory from the production calculations produces a figure of 0.93 young per occupied site and a success rate of 63.4%. This figure is within the productivity range reported for Bald Eagles across North America, including California.

Adult Survivorship

Seventeen resident breeding adults have been banded and/or colour-banded in the PRSA since 1983 (Jenkins 1992). Excluding one that was shot, there are 16 adults that have collectively bred in the PRSA for 74 years, or an average of 4.63 years each. This calculation includes two eagles banded in 1983 with USFWS bands, one of which is believed to have continued breeding on her same territory, and one that is believed to have been replaced on her territory in 1991. Tarnished USFWS bands appeared on these birds, although efforts to recapture them for colour-banding proved unsuccessful. The calculation also uses a mean of two years residency for each of two birds that were replaced on their breeding territories at some unknown time between 1983 and 1988.

Twelve of the original 16 eagles continued to breed in the PRSA in 1991; that is,

Table 1. Reproduction in 10 Bald Eagle nesting territories in the PRSA from 1970 to 1991 (Jenkins 1992).

Nest Territory	*Year First Reported*	*Number of Years Observed*	*Times Known Occupied*	*No. of Times ONS[a]*	*Total Young Produced*	*No. of Young per Year Occupied*
Dry Lakes	1975	17	17	3	23	1.35
Two Knobs	1979	13	13	3	17	1.31
Dusty	1984	8	8	5	6	0.75
Cayton	1974	17	16	7	17	1.06
North Shore	1970	21	20	9	12	0.60
South Shore	1970	19	17	14	0	0.0
Pit Rim	1970	21	20	7	14	0.75
Pit 3 Powerhouse	1988	4	4	2	4	1.0
Pit 5	1972	18	17	6	18	1.06
Pit 6	1970	12	8	6	3	0.38
No. of occupied territories	-	-	140	62	-	-
Young per monitored occupied territory	-	-	-	-	114	0.81
% of occupied territories successful	-	-	55.7	-	-	-

ONS[a] = Occupied, not successful

25% of the original 16 have died over the 4.63-year average period. This equates to an adult mortality rate of 5.4% of breeding adults per year, and a survivorship rate of 94.6% (Table 2).

Juvenile Survivorship

I based juvenile survivorship estimates in the PRSA on radiotelemetry monitoring of two cohorts of eagles fledged from Lake Britton in 1989 and 1990. Of one cohort of six fledglings radiotagged in 1989 at Lake Britton, four birds were located the following year and a fifth was located in 1991. Seven additional fledglings were radiotagged in 1990 and five of them were located a year later. Combining the survival rates of the two cohorts yields a survival rate of 76.9% (10 of 13) for the first year of life (Table 2). This figure is very similar to that reported by McCollough (1986), over twice that reported by Gerrard *et al.* (1978), but less than the 100% survivorship of

Table 2. Estimated and observed life table parameters for Bald Eagles in the PRSA (Jenkins 1992).

Population	*Estimate*		
Reproduction			
Age at first breeding	5 years		
Percent of adult with 0 young	62/140	=	44.3
Percent of adult with 1 young	41/40	=	29.3
Percent of adult with 2 young	36/140	=	25.7
Percent of adult with 3 young	1/140	=	0.71
No. young per female with young	114/78	=	1.46
No. female young per female with young	57/78	=	0.73
No. young per adult	114/140	=	0.81
No. young per adult	57/140	=	0.41
Survival			
Annual survival of first-year birds	10/13	=	76.9%
Annual survival rate of breeding adults (See text)		=	94.6%

first year birds reported by Buehler *et al.* (1991). This 76.9% survival rate is a conservative estimate, because it ignores the potential of transmitter loss or failure and the possibility that fledglings were missed on aerial surveys over northern California and southern Oregon.

For the purposes of the model, I assumed that survivorship of birds between one and five years old increases linearly until the adult value is reached. Accordingly, I used an 80.4% survivorship rate for second-year birds, 84.0% for third-year birds, 87.5% for fourth-year birds, 91.1% for fifth-year birds, and 94.6% for birds older than five years.

Population Model

Using the empirical reproductive and survivorship values described above, I developed a model of the PRSA Bald Eagle population. Use of these values, beginning with 10 breeding pairs, produces the results illustrated in Figure 2. The number of breeding pairs initially declines slightly because no recruitment to population begins until year six. Thereafter, the population increases steadily, doubling to 20 breeding pairs after about 20 years. The total population, including all age classes, does not suffer an initial decline and doubles much more rapidly than the number of breeding pairs, as expected.

Figure 2. Outcome of an age-specific population model for PRSAxBald Eagles using empirical estimates of survivorship and reproduction (Jenkins 1992).

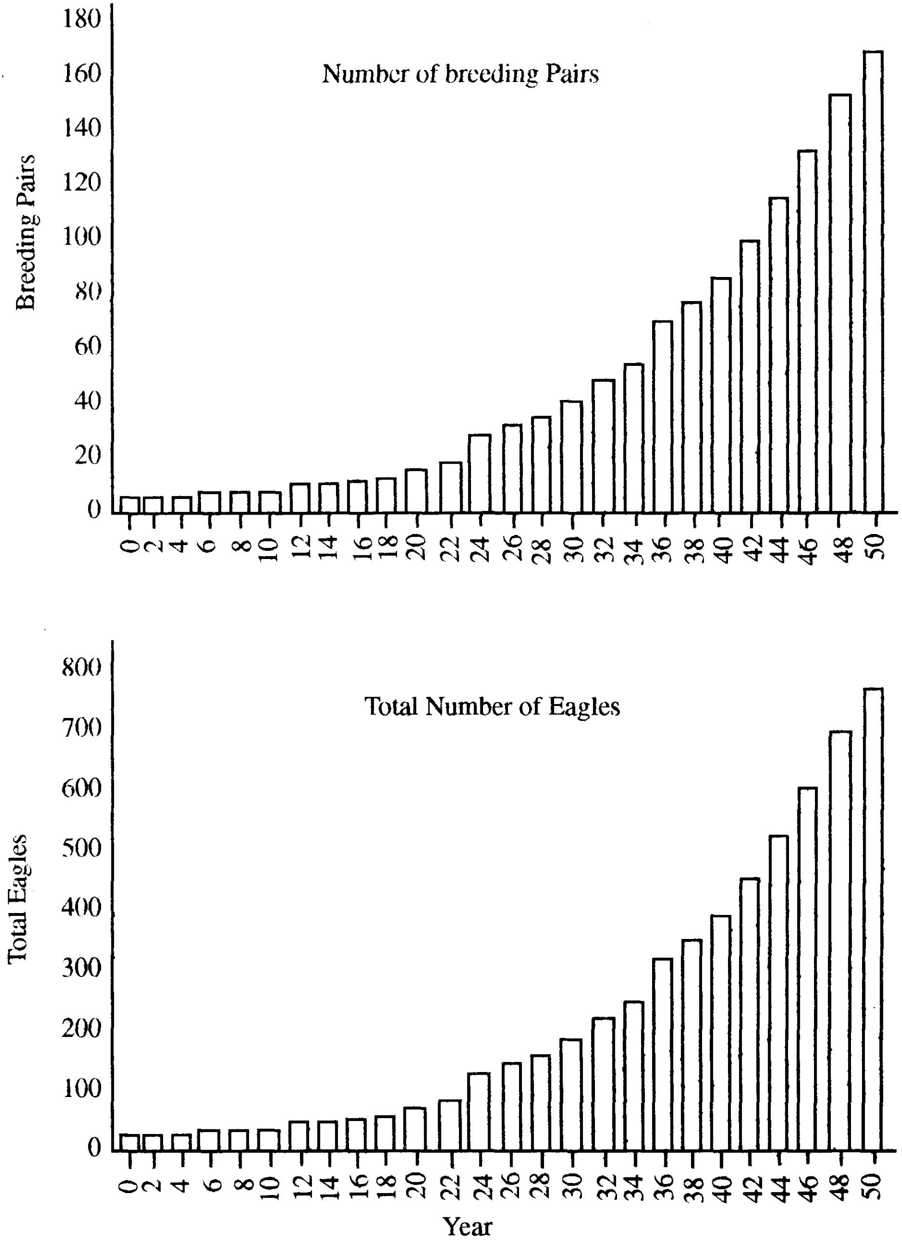


Table 3. Outcome of various parameter adjustments of the age-specific population model beginning with ten nesting pairs of Bald Eagles.

Parameter Adjustment	*Outcome*
Halve survival of first year birds or halve productivity	14 pairs at 30 years 21 pairs at 50 years
Halve survivorship of first two age classes	6 pairs at 30 years 5 pairs at 50 years
Halve survivorship for all nonbreeding age classes	2 pairs at 30 years 0 pairs at 50 years
Reduce adult survivorship of 94.6% to 80%	3 pairs at 30 years 2 pairs at 50 years

DISCUSSION

I have purposely kept this model simple and emphasized empirical data on the PRSA Bald Eagle population. The few assumptions that were necessary to run the model were made with the most conservative estimates that seemed reasonable. Therefore, the model represents what would conservatively be expected in this population assuming that habitat is not a constraining factor. Habitat will be a constraining factor at some point, as the PRSA is probably already nearing its carrying capacity for breeding pairs of Bald Eagles.

The model produces several revealing insights into the population ecology of PRSA eagles. For instance, halving the survival estimate for the first year of life produces a population that increases relatively slowly to 14 breeding pairs at 30 years and 21 breeding pairs at 50 years (Table 3). Halving the reproductive output for the population produces the same result, as both parameters equally affect the number of first-year birds in the population. Halving survivorship throughout the first two nonbreeding age classes produces a declining population that drops to six nesting pairs after 30 years and continues to decline to fewer than five pairs after 50 years. Halving the survival rate for all nonbreeding age classes reduces the population to five pairs in 13 years and to fewer than one pair after 47 years (Table 3).

Adult survivorship appears to have an even greater effect than first-year survivorship on the results of the model. Reducing calculated adult survivorship from 94.6% to 80% produces a population that declines rapidly to only three nesting pairs after 16 years and two pairs at 32 years. This decline is rapid partly because of the assumption of no nonbreeding age classes existing in year zero, but even assuming some birds in these age groups ultimately produces the same result. This outcome tends to support the accuracy of the empirical adult survivorship parameter. Clearly the PRSA breeding Bald Eagle population has increased over the past 20 years (Figure 1), and an adult survivorship value near the estimated value appears necessary to achieve this growth.

The sensitivity of this population model to survivorship emphasizes the importance of maintaining and enhancing high-quality habitats for nonbreeding birds as well as resident adults. Because nonbreeding birds are often excluded from nesting territories by resident eagles, it may be necessary to look for opportunities for such enhancement beyond traditional nest territory management plans. These results also indicate the importance of winter habitat management to enhance survivorship for all age classes, in areas of significant wintering Bald Eagle populations.

Obviously, sufficient habitat does not exist in the PRSA to accommodate the number of breeding eagles that could be produced by this population, as illustrated in Figure 2. However, the movement and dispersal of these birds around northern California and southern Oregon could provide recruitment to a population expanding into former habitat. For the past 15 years, such an expanding population appears to have existed in California (Jurek 1990). The results of this analysis indicate the importance of maintaining suitable expansion habitat for breeding Bald Eagles in areas within the former breeding range of the species. Given the population parameters exhibited by the PRSA breeding eagles, further increases in California's breeding Bald Eagle population can be expected.

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REFERENCES

BUEHLER, D.A., J.D. FRASER, S.K.D. SEEGAR, G.D. THERRES & M.A. BYRD 1991. Survival rates and population dynamics of Bald Eagles on Chesapeake Bay. *J.Wildl. Manage* 55: 608-613.

DETRICH, P.J. 1985. *The status and distribution of the Bald Eagle*. M.Sc. thesis. California State University, Chico.

GERRARD, J.M., D.W.A. WHITFIELD, P.GERRARD, P.N. GERRARD & W.J. MAHER 1978. Migratory movements and plumage of subadult Saskatchewan Bald Eagles *Can. Field-Nat.*92: 375-382.

GRIER, J.W. 1980. Modeling approaches to Bald Eagle population dynamics. *Wildl. Soc. Bull.* 8: 316-322.

HODGES, Jr., J.I. 1982. Bald Eagle nesting studies in Seymour Canal, Southeast Alaska. *Condor* 84: 125-127.

HOLLAND, R.F. 1986. *Preliminary descriptions of the terrestrial natural communities of California*. California Department of Fish and Game, Nongame-Heritage Program. Sacramento, California. 155 pp.

JENKINS, J.M. 1992. *Ecology and behavior of a resident Bald Eagle population*, Ph.D. dissertation,

University of California, Davis.
JUREK, R.M. 1988. *Bald Eagle five-year status report.* Calif. Dept. of Fish and Game, Nongame Bird and Mammal Section, Sacramento, California. 15 pp.
JUREK, R.M. 1990. *California Bald Eagle breeding population survey and trend, 1970-90.* Unpub. Admin. Report, Calif. Dept. of Fish and Game, Nongame Bird and Mammal Section. Sacramento, CA. 16 pp.
McCOLLOUGH, M.A. 1986. *The post-fledging ecology and population dynamics of Bald Eagles in Maine*. Ph.D. dissertation. Univ. of Maine. Orono. 105 pp.
POSTUPALSKY, S. 1974. Raptor reproductive success: Some problems with methods, criteria, and terminology, pp. 21-31. *In* F.N. Hamerstron, Jr., B.E. Harrell & R.R. Olendorff [Eds.], *Management of Raptors.* Raptor Res. Found., Vermillion, S.D.
SWENSON, J.E., K.L. ALT & R.L. ENG 1986. Ecology of Bald Eagles in the greater Yellowstone ecosystem. *Wildl. Monogr.* 95: 1-46.
THELANDER, C.G. 1973. *Bald Eagle reproduction in California,* 1972-1973. California Department of Fish and Game, Wildl. Manage. Br. Admin. Rept. No. 73-5. 17 pp.
U.S. FISH AND WILDLIFE SERVICE 1986. *Recovery plan for the Pacific Bald Eagle.* U.S. Fish and Wildlife Service, Portland, Oregon. 160 pp.

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