First Symposium on Steller's and White-tailed Sea Eagles in East Asia pp. 45-57, 2000
UETA, M. & MCGRADY, M.J. (eds)

Numbers and current status of the population of Steller's Sea Eagle on Sakhalin Island

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Abstract. A predictive model of spatial distribution of nesting territories of Steller's Sea Eagle *Haliaeetus pelagicus* was constructed using GIS. A habitat map was created by vectorization of satellite imagery into unequal area polygons, grouped according to geobotanical and landscape characteristics. Logistic regression was used to model presence of a territory in a polygon. Using this method the model predicted that 434 potential nesting territories exist on Sakhalin. Evaluation of bird numbers was carried out using counts along line transects of varying length. After estimating linear density using jack-knife resembling, the density was extrapolated to unsurveyed fragments of coastline on the basis of similarity of their landscape characteristics. The total estimated number of birds for Sakhalin is 560 birds. Population age-structure estimation of the fraction of adult birds on Sakhalin was 64.2%. Mortality from fledging to maturity was estimated at 75.8%, with average annual mortality of juveniles reaching 25%. Average reproductive success for territorial pairs on Sakhalin was 0.795 fledgling per pair (N = 70). Estimated population growth rate using Leslie matrix model was -0.0024, indicating a slow decline in the Sakhalin eagle population. Because of this even a relatively small decrease in survival or fertility could lead to a rapid decline in the population size.

INTRODUCTION

The breeding range of the Steller's Sea Eagle *Haliaeetus pelagicus* includes the Okhot seacoast, Kamchatka, Lower Amur River, Sakhalin Island and Kuril Islands. Remoteness and difficult access to these areas has probably contributed to population stability. These same factors make this species one of the least studied birds of prey in the Palearctic. Lobkov (1988) estimates the Steller's Sea Eagle population to be 7,000-7,500 birds. On Sakhalin the breeding range of Steller's Sea Eagle includes shoreline and the lower reaches of rivers in the northern part of the island, from Tyk Bay in the north-east to the Terpenia Cape in the east (Fig. 1).

Northern Sakhalin and the adjoining sea shelf is the principal oil and gas province of the Russian Far East region. In 1997 preparations were made for large scale development of shelf

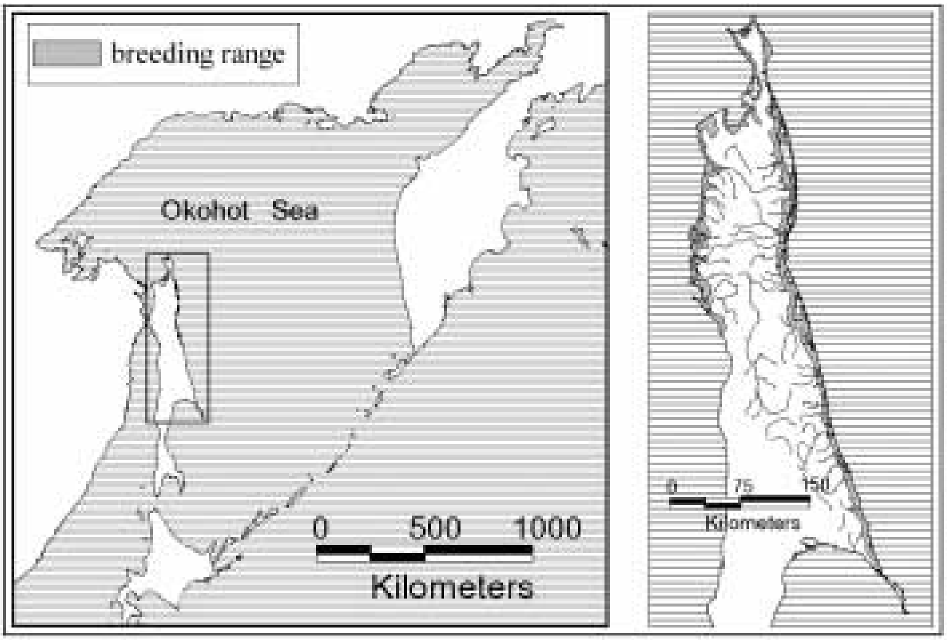

Fig. 1. Breeding range of Steller's Sea Eagle on Sakhalin.

fields by Exxon, SADECO, Marathon Oil, Mitsui Bussan, McDermott, Shell, and Mitsubishi. It is estimated that full development of the field will occur over 25-30 years. Ten off-shore drilling platforms will be established, each sinking up to 200 wells. Pipelines will cross 625 km of sea bottom and 700 km of dry land. Gas and oil will be transported along the shore by shuttle tankers making up to 120 runs per year. Severe environment and complicated seismic and ice conditions in the region increase the possibility of accidents, like drilling rig collisions, pipeline ruptures, and tanker wrecks similar to the Exxon Valdez accident.

Environmental pollution and habitat deterioration may destroy trophic chains of shelf and wetland ecosystems. Most endangered species inhabiting seaside areas participate in the trophic chains of marine ecosystems and are vulnerable to occasional fluctuations in amount of available food caused by technogenic deterioration of this environment (Terborgh & Winter 1980, Diamond 1984, Pimm 1984). This is especially true for the Steller's Sea Eagle, which occupies the upper level of the seaside trophic pyramid.

The absence of basic information on the recent status of the Steller's Sea Eagle population and its habitats in Sakhalin does not allow for an objective evaluation of the potential impact of oil development on this vulnerable species. This study evaluates the population numbers and demography of the Steller's Sea Eagle at Sakhalin, and develops a model of spatial distribution of principal breeding habitats.

Evaluation of population status requires knowledge of not only numbers, but also sex and age ratios, mortality in different age classes, mean life expectancy, and reproductive success.

Deficiencies in these data sets mean that only a preliminary assessment of the Steller's Sea Eagle population can be made.

METHODS

Population numbers were evaluated using line transect counts in 1997-98 and aerial surveys in 1989-91. Birds and nests were assigned to the following categories:

- adult birds: older than 5 years in definitive plumage
- immature: less than 5 years old with different extent of brown in plumage
- nest territory: area within 400 m of the nest. The nest territory included the active and all old nests belonging to the pair. If the pair was breeding, the active nest was used as the territory centre.
- territorial pair: pair of adult eagles occupying a nesting territory. In any one year, these included successfully breeding pairs, as well as pairs that failed, and pairs for whom the result of breeding was unknown.
- successfully breeding pairs: pairs that successfully raised eaglets to the late nestling stage.

Counts were carried out along line transects of constant width and varying length that covered segments of the shoreline and lower reaches of rivers. Preliminary surveys revealed that 85% of 140 eagle nests on the Lower Amur and on Sakhalin were located within 300 m of shoreline, and were distributed within distance categories in the following proportions: 0-100 m - 53%; 101-200 m - 19.5%; 201-300 m - 12.5%. The remaining 15% were found up to 1300 m from the shore. Relative to the forest edge nests were distributed in the following way: 0-50 m - 71%; 51-100 m - 14%; 101-150 m - 7%; the remaining 8% of nests were found at a distance 151 to 350 m from the forest edge.

Eagle numbers: Adult and immature birds were usually observed along the shoreline, near the forest edge, or on single trees, stones and poles. Accordingly, number of birds (nests) per kilometre of shoreline was chosen to evaluate the linear density of eagles. Adult birds and nests were easily located from boat or aircraft. During surveys on foot, undercount was related to forest cover and terrain features which obscured the observer's view of eagle, and was not related to the distance these were from the transect. Accordingly, a 250 m buffer on either side of the transect line, (which encompassed at least 90% of nests), was used for density estimates. The total length of transects was 908 km.

Nest counts: To estimate density and spatial distribution of nest territories, shoreline habitats were delineated from satellite imagery. Habitats were treated as potentially suitable if they fell within a 3 km buffer of the seashore, or within 1 km of the lower stretches of rivers and their floodplains > 3 km from the mouth. Vectorization was carried out using MapInfo Professional 4.1, creating a habitat map comprised of unequal area polygons, grouped according to geobotanical and landscape characteristics (Fig. 2). In total, 5 principal groups of habitats were distinguished:

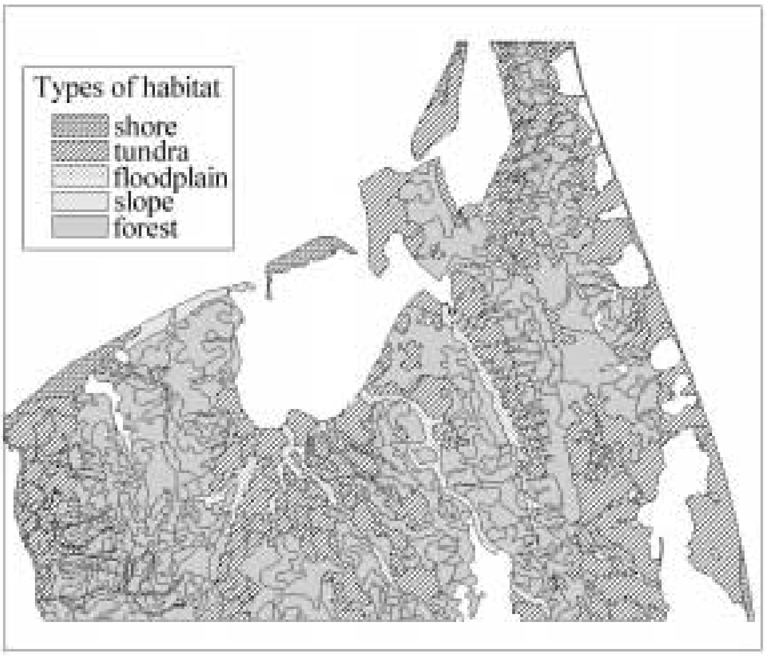

Fig. 2. Principal groups of Steller's Sea Eagle habitats on Sakhalin.

1. forest-like habitats, 7 types:
   - larch forest *Larix gmelini* with Marsh Tea *Ledum palustre*, mosses and lichens, L1
   - larch forest with rhododendron (Lapland Rhododendron *Rhododendron lapponicum*), L2
   - larch forest with Japanese Stone Pine *Pinus pumila*, L3
   - larch forest with Yeddo Spruce *Picea jezoensis*, marsh tea and mosses, L4
   - larch forest with Yeddo Spruce and Khingan Fir *Abies nephrolepis*, L5
   - larch forest with Erman's Stone Birch *Betula ermani*, L6
   - burnt logged woodland, L7
2. tundra-like habitats, 3 types:
   - mar' with dwarf-shrubs, lichens, small lakes, sedge-tussocks *Carex elata*, M1
   - seaside sand tundra, M2
   - larch and birch forest tundra, with Dwarf Birch *Betula nana*, M3
3. floodplain, 3 types:
   - non-forest floodplain (rock, meadow, shrub), F1
   - non-forest floodplain with larch belts on terraces, F2
   - poplar floodplain, F3
4. shoreline habitats, including hill slopes and seaside rocks, 3 types:
   - rocks, S1
   - tundra-like or meadow-like slopes, S2
   - spruce and larch forest on sandy and rocky cliffs, S3
5. spits (incl. sand spits in bays, tidal spits and small islands), SH

Location of nests and nest territories were determined using GPS. Linear density of nest territories was assessed by determining shoreline length for every habitat type within each count, and then estimating density and its error using jack-knife resembling techniques (Tukey 1958, Efron 1982) with counts as sample units.

A predictive model of the spatial distribution of nest territories was constructed using logistic regression to model presence of territory within a particular polygon from continuous (polygon area, perimeter, coastline length, length of a border with floodplain) and categorical (habitat types) predictors. Continuous predictors were log-transformed to normalise their distribution. Coefficients for logistic regression were derived from models constructed in areas which were thoroughly surveyed, and census adequacy was close to absolute.

Prior to bird counts the shoreline of north-east Sakhalin was split into a series of non-overlapping transects, each of which covered easily definable fragments of coastline. Birds observed in the course of the surveys were assigned to these fragments. After estimating linear density using a jack-knife approach, coastline transects were placed into one of 5 categories according to density. This classification was used for further extrapolation of density in unsurveyed areas and in estimating the total number using the following formulae from Coli (1979) for estimating standard error:

$$SE = \sqrt{\sum_h z_h^2 / n_h \times s_{Dh}^2}$$

where s_{Dh}^2 = density variance in the surveyed fragments, z_h = total area of category h, n_h = number of fragments in category h. A correction for underestimation was introduced by regressing density index on absolute density and then evaluated in the areas that were surveyed more than once.

RESULTS AND DISCUSSION

Number and spatial distribution of nest territories

Evaluation of nest numbers and modelling of their spatial distribution was made separately for 3 groups of polygons. The first group included polygons adjacent to coastline. The second, polygons within 3 km from the coast, but separated from it by other polygons. The last group was represented by polygons adjacent to floodplain habitats.

To make results of logistic regression more interpretable we reduced the number of habitat categories. The occurrence of each of the 17 initial habitat types within the nesting territories was examined. If a habitat type did not occur in more than 10% of the territories, then it was aggregated into a group called ‘select’. This resulted in the following groups of habitats: forest (L1, L2, L4), tundra (M1, M2, M3), floodplain (F1, F2, F3), shore cliffs (S2) and “Select” (Table 1). Overall the model was significant (χ^2 test, $P < 0.001$, McFadden’s Rho-Squared = 0.294).

As the number of polygons without nests was substantially larger than the number of inhabited polygons, the model, adjusted to include all available observations, tends to predict absence in a satisfactory way, but will not adequately predict presence. To resolve this problem we used Cohen's κ for calibrating the threshold probability value that best reduces the adjusted probability values to 0 (nest absence) or 1 (nest presence) (Guisan *et al.* 1998). The selected threshold value is the one that provides the best κ between adjusted and observed probability values from the calibration dataset. The best κ for above model was 0.595 (ASE = 0.006), and corresponded to a threshold probability of 0.36. Classification of calibration dataset using this probability yielded results presented in Table 2.

Results of logistic regression for polygons not adjacent to shoreline are presented in Table 3. Overall the model was significant (χ^2 test, $P = 0.008$, McFadden's Rho-Squared = 0.110). The best κ for the above model was 0.255 (ASE = 0.123), and corresponded to a threshold probability of 0.175. Classification of calibration dataset using this probability yielded results presented in Table 4.

Results of logistic regression for the 3rd group of polygons (floodplain habitats) are presented in Table 5. Overall the model was significant (χ^2 test, $P \leq 0.001$, McFadden's Rho-Squared = 0.255). The best κ for the above model was 0.504 (ASE = 0.103), and corresponded to a threshold probability of 0.385. Classification of calibration dataset using this probability yielded results presented in Table 6.

Results of nest distribution modelling for areas other than the training sample are presented at Figure 3. Given that threshold probabilities were 0.36, 0.175 and 0.385 for three groups of habitat patches, the model predicts the number of nest territories to be 233 in the 3 m seaside zone, and 33 within the floodplain zones of the northwest. As the dependent variable in the logistic model was binary and accepted only presence or absence values, a correction was necessary to account for multiple nest territories within a small fraction of patches. The correction coefficient (ratio of the total number of nests in a training sample to the number of patches with nests) was 1.33 for shoreline habitats, and 1.35 for floodplain habitats. Therefore, the total number of nest territories of Steller's Sea Eagles on Sakhalin, after correcting for census incompleteness, is estimated at 434.

We also evaluated eagle nest numbers by extrapolating count data for the total area of suitable habitats. Nest density values by habitats estimated from count data using jack-knife resembling are presented in Table 7. The total

Table 1. Logistic regression results for polygons bordering shoreline.

Independent variable	*P*
CONSTANT	0.000
Lg polygon perimeter	0.006
Lg length of coastline	0.001
floodplain habitat	0.729
forest habitat	0.213
tundra habitat	0.759
shoreline cliffs and terraces	0.045

Table 2. Classification of calibration dataset using adjusted threshold probability of 0.36 (adjacent to shoreline)

Actual Choice	Actual total	Predicted Choice		% of correctly predicted
		polygons without nest	polygons with nest	
polygons without nest	144	122	22	84.7
polygons with nest	64	15	49	76.6

number estimated in this way was 339 territories, situated along sea coasts. The number nests' sites in the floodplains of North-Western Sakhalin was estimated at 47.

The spatial distribution of Steller's Sea Eagle nest sites in Northern Sakhalin is presented in Fig. 4. Not all territories were permanently occupied. Census data revealed that 31.5% of nest sites had been deserted during the study period while the rest (68.5%, including 40.7% of the total that were successful) remained occupied throughout. Also, the proportion of occupied territories differed between coastline regions (Table 8). Low occupancy rates in Nabil, Nyivo, Piltun, and Pomr' Bays are probably be due to the impact of human activities along the shore and habitat differences (Masterov & Zykov 1992).

Table 3. Logistic regression results for polygons not adjacent to shoreline.

Independent variable	*P*
CONSTANT	0.000
Lg polygon perimeter	0.009
Combined "Select" habitat	0.130

Table 4. Classification of calibration dataset using adjusted threshold probability of 0.175 (not adjacent to shoreline).

Actual Choice	Actual total	Predicted Choice: polygons without nest	Predicted Choice: polygons with nest	% of correctly predicted
polygons without nest	170	160	10	94.2
polygons with nest	12	8	4	50.0

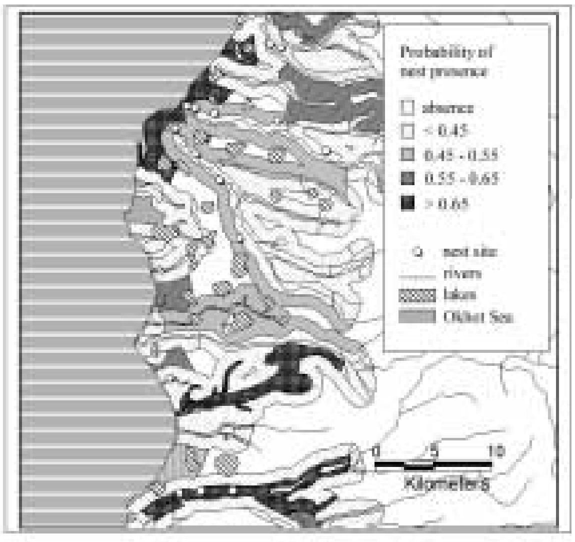

Fig. 3. Predicted distribution of eagle nests and their actual locations for a fraction of studied territory.

Table 5. Logistic regression results for the polygons adjacent to floodplain.

Independent variable	*P*
CONSTANT	0.000
Lg polygon area	0.000
Floodplain habitat	0.023
Combined "Select" habitat	0.104

Table 6. Classification of calibration dataset using adjusted threshold probability of 0.385 (adjacent to floodplain).

Actual Choice	Actual total	Predicted Choice: polygons without nest	Predicted Choice: polygons with nest	% of correctly predicted
polygons without nest	213	209	4	98.1
polygons with nest	23	13	10	56.5

Bird numbers

Bird count data were obtained in different years and during different periods within the breeding season, and required pre-processing to form a homogenous sample. Mean density of eagles during autumn counts (September and October) were significantly lower than the average for a summer months (June, July and August) (0.026 ± 0.018 and 0.112 ± 0.012 birds / km, respectively, $P < 0.05$). These were excluded from our analyses. However, density indices for summer counts in 1990 (June and August) and 1991(June and July) did not differ (0.152 ± 0.010 and 0.112 ± 0.012 birds / km, $P > 0.05$), and these were pooled.

To estimate bird density indices from individual shoreline fragments were grouped into categories (Table 9), which stratified the coast according to eagle density Each transect was assigned to one of the density categories, and these could include a number of different types of landscape. So, different landscapes could have similar densities, and thus fall within one density category. Extrapolation to unsurveyed fragments of coastline was based on the similarity of their landscape and geo-morphological characteristics to surveyed areas, and allowed unsurveyed areas to be assigned to a density category. The total estimated number of birds for the shoreline at northeast of Sakhalin (2197.4 km) after correcting for count incompleteness is 551.2 (SE = 33.48).

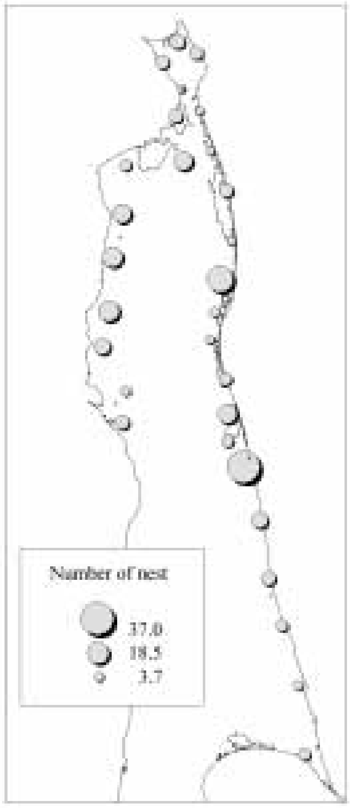

Fig. 4. Spatial distribution of Steller's Sea Eagles nest territories in Northern Sakhalin.

An additional correction was introduced by dividing all counts by the number of observations made during relatively favourable and relatively unfavourable conditions and then estimating the mean density between these groups. Estimated density (Y) was related to observed density (X) according to the equation:

$$Y = -0.029 + 1.014 \times X$$

using this method, the number of birds in north-east Sakhalin was estimated at 559. The spatial distribution of Steller's Sea Eagles in Northern Sakhalin is presented in Figure 5.

Demographic structure of population

The age structure of the population was assessed as the ratio of adult and immature birds in counts. In 10 counts, we observed 480 eagles. Adults comprised 64.19 ± 11.18(SE)%, of the population and immatures comprised 34.81 ± 12.61(SE)%. The age ratio was constant

Table 7. Nest density values (by habitats) estimated from count data using jack-knife resampling.

Habitat	Length of shoreline (km)	Linear density (nests/km of shoreline)	SE
non-forest floodplain (rocky, meadow, bushy), F1	67.56	0.372	0.0157
non-forest floodplain with larch belts on terraces, F2	56.98	0.154	0.0128
poplar floodplain, F3	37.84	0.261	0.0060
larch forest (with marsh tea, mosses and lichens), L1	122.78	0.130	0.0027
larch forest (with rhododendron), L2	80.68	0.312	0.0155
larch forest (with dwarf Siberian pine), L3	22.29	0.344	0.0069
larch forest (with Yeddo spruce, marsh tea and mosses), L4	6.26	0.407	0.0701
larch forest (with spruce and fur) L5	40.26	0.562	0.0063
larch forest (with Erman's birch) L6	4.49	0.000	0.0000
burnt wood and logged wood	2.75	0.000	0.0000
mar' (with dwarf-shrubs, lichens, small lakes, sedge-tussocks), M1	295.21	0.112	0.0039
seaside sand tundra, M2	519.14	0.154	0.0024
larch and birch forest tundra, with dwarf birch, M3	110.56	0.163	0.0049
rocks, S1	155.70	0.075	0.0039
tundra-like or meadow-like slopes, S2	68.86	0.634	0.1092
spruce and larch forest on sandy and rocky cliffs, S3	0.13	0.000	0.0000
seas spits (incl. Spits in bays, tidal spits and small islands), SH	713.28	0.050	0.0080

Table 8. The fraction of inhabited territories in different coastline regions.

Coastline region	fraction of inhabited nests (%)	Coastline region	fraction of inhabited nests (%)
Lunski Bay	16.0	Piltun Bay	5.4
Nabil Bay	7.1	Baikal Bay	16.0
Nyivo Bay	5.4	Pomr' Bay	3.6
Chaivo Bay	7.1	Schmidt Peninsula	25.1
sealine from Ratmanova Cape to Lunski Bay			14.3

Table 9. Shoreline categories according to difference in eagle density.

Category	Density range	Number of transects	Average density / 1 km of coastline	Variance of density	Length of coastline, km
1	0.001-0.100	10	0.076	0.0009	459.5
2	0.11-0.20	10	0.150	0.0009	422.4
3	0.21-0.50	26	0.306	0.0040	491.1
4	0.51-1.50	14	0.983	0.1420	102.2
5	>1.51	4	6.609	21.3360	13.3

throughout the reproductive period and similar between years (Table 10). Lobkov & Neifeldt (1986) provided similar values for the proportion of immature birds in Kamchatka - from 33.3% to 38%.

Average reproductive success per territorial pair in Sakhalin was 0.795 fledgling/pair (N = 70). Reproductive performance of successfully breeding pairs was 1.409 fledgling/pair (N =

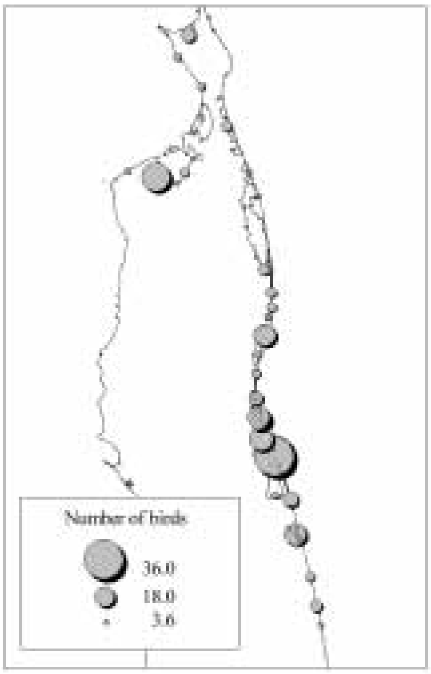

Fig. 5. The spatial distribution of Steller's Sea Eagles in Northern Sakhalin.

Table 10. Age structure in different reproductive periods and years.

Period	Adults (%)	Immature birds (%)
May-June	60.78	39.22
July-August	60.27	39.73

Year	Adults (%)	Immature birds (%)
1990	61.62	38.38
1991	69.23	30.77

36). The sex ratio in eagle broods was 1:1 (Masterov 1998).

Mortality of immature birds was estimated assuming acquisition of complete adult plumage at the age of five years (Belopolski 1939). The ratio of adult to immature birds can be represented by the equation:

$$2S_{ad}^4 / Br(S_{ad}^4 + S_{ad}^3 \times S_{im} + S_{ad}^2 \times S_{im}^2 + S_{ad} \times S_{im}^3 + S_{im}^4) = 64.2 / 34.8\ (1.8448),$$

where S_{ad} is the survival rate of adults, Br is the reproductive success (0.795 fledgling / pair); S_{im} is the survival rate of immature birds.

Adequate information about mortality of adult Steller's Sea Eagles is absent, but in Bald Eagles it varies between 5 and 9% (Bowman *et al.* 1995). Adult birds' mortality can be approximately obtained from general equations relating mortality and average number of chicks per brood (Paevski 1985).

$Y = 7.48 \times x + 3.06$, $r = 0.96$ (Paevski 1985), where x is average brood size.

According to this equation mean annual mortality of adult eagles may be about 9%, and from knowledge of annual survival rate of adults (0.91) and reproductive success (0.795 fledgling/pair), we can calculate the survival of immature birds from fledging to 5 years of age to be about 24.2%. Then annual survival (S_{im}) during first five years will be $S_{im}^5 = 0.242$, which gives S_{im} = 75% and average annual mortality of juveniles - 25%.

Annual mortality of young White-tailed Eagles was 27% in Scotland (Green *et al.* 1996), which is also close to our estimates. Gerrard *et al.* (1978) showed that mortality of Bald Eagle

Table 11. Reproductive performance (number of female fledglings per female) and mortality of Steller's Sea Eagle in different age groups.

	Age (year)								
	0-1	2-3	4-5	6	7-8	9-10	11-12	13-14	15
Reproductive performance	0	0	0	0.300	0.398	0.398	0.398	0.398	0.380
Survival (%)	0.75	0.75	0.75	0.91	0.91	0.91	0.91	0.91	0.90

Table 12. Population growth rate and sustainable age structure according to Lesli model.

Growth rate	Sustainable age structure (%)				
	1 years	2 years	3 years	4 years	Adult
-0.0024	17.5	13.3	9.9	7.3	52

chicks was 71.5% in the first year, 50.9% in the second, and 35% in the third. Overall, only about 10% of Bald Eagle fledglings survive to maturity (Stalmaster 1987).

Average longevity of birds in natural conditions is an important demographic characteristic which can be evaluated from body mass using generalised allometric equations (Lindstedt & Calder 1976, Paevski 1985). Mean life expectancy of Steller’s Sea Eagles is 15 years.

Using a Leslie matrix model (Usher 1972), demographic structure of a population can be estimated using reproductive performance parameters, in the case of Steller’s Sea Eagles: the number of female fledglings per female and the survival rate for different age groups (Table 11). The natural logarithm of the main eigen value of the Leslie matrix (L) characterises the population growth rate, while the corresponding eigen vector (V) characterises the sustainable age structure (Table 12). The main eigen value of the Leslie matrix for Steller’s Sea Eagles on Sakhalin is somewhat less than 1 (0.997) which indicates a slow decrease of the population size at a rate of -0.0024.

Human-related habitat deterioration, pollution, and increasing disturbance may cause decreases in reproductive success and survival of birds. Even relatively small decreases in survival and fecundity in a population with low growth rate can lead to rapid decreases in numbers (Usher 1976). This puts emphasis on the creation of protected territories (natural refuges) in places where breeding sites of Steller’s Sea Eagles are concentrated.

Research carried out on the Bald Eagle demonstrated that a protected area within 800 m of the nest improved reproductive performance. And that all kinds of human activities, including recreation, should be reduced in the vicinity of the nest through out the whole breeding period, including the courtship period (Anthony & Isaacs 1989). In the case of Steller’s Sea Eagles on Sakhalin this period corresponds to 20 March - 10 September. Also, development in the autumn-winter period, such as logging, and pipe-line and road construction should not be allowed within 400 m of the nest site (Grubb & King 1991). Disturbance effects not only nesting, but also feeding of eagles. Additional energy expenditures due to disturbance avoidance may lead to the reduction in the amount of food brought to chicks, a reduced rate of nestling development and decreased reproductive success (Masterov 1992). To avoid these effects undisturbed zones should be created around principal feeding localities within a radius of 450 m (Knight 1984).

ACKNOWLEDGMENTS

Scientific and financial support was provided by Research Center Wild Bird Society of Japan and NEC.

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