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Habitat preferences and factors affecting population density and breeding rate of Steller's Sea Eagle on Northern Okhotia

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Abstract. Distribution of Steller's Sea Eagles *Haliaetus pelagicus* was studied along the coastline of the northern part of the Sea of Okhotsk in surveys of 1991-1998. Every breeding territory was classified by a number of qualitative factors describing the character of the coast, type of vegetation cover, various characteristics of the tidal zone, presence of human settlements and distance to the nearest river with salmon spawning grounds. PCA analysis revealed that the strongest environmental gradient in the territorial preferences of Steller's Sea Eagle was associated with the type of the coast (low coast vs. cliffs). The second axis was associated with the type of littoral zone (stone littoral vs. no littoral). The third factor was associated with the type of vegetation (forest/creepy pine cover vs. no plant cover). Separate multiple regression analyses were conducted of the densities of territorial pairs in the portions of coastline classified by factors with the strongest environmental gradient revealed by the PCA. These showed that along low coast eagles breed in higher densities in coastal fragments with vast littoral zones and were to lerant of human presence including commercial fishing activities. In contrast, along cliffy coastline eagles preferred places in close proximity to sea-bird colonies, and were not able to coexist with human settlements including cabins occupied by small groups of fishermen. These differences in habitat preferences and tolerance of humans were explained by fundamental differences in hunting strategy at low coasts with vast littoral zones and at cliffy coasts with narrow littoral zone.

INTRODUCTION

Due to its limited distribution (a narrow strip around the coasts of the Sea of Okhotsk) Steller's Sea Eagles *Haliaetus pelagicus* was listed in the Red Data Book of the Russian Federation (Eliseev 1985) and in Appendix 2 (threatened species) of CITES. Although it is the largest sea eagle in the world and an endemic to Russia, it has attracted little attention by raptor

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researchers. The numbers and distribution of Steller's Sea Eagle have been studied in the Kamchatka Peninsula (Lobkov 1986, Lobkov & Neifeldt 1986) and also in the northern Primorie (Babenko *et al.* 1988, Masterov 1992). Both studies dealt with river or lake-dwelling eagles, whereas the majority of the Steller's Sea Eagles in the Northern Okhotia breed not along the rivers, but along the sea coast (Potapov *et al.* 1995). Except for a few observations of breeding birds (Leito *et al.* 1991), there is no information on the distribution and numbers of the Steller's Sea Eagle in the coastal zone, and in particular in the north-western part of the Okhotsk Sea, which has been suspected of being the stronghold of the species (Lobkov 1988). We have made an effort to survey Steller's Sea Eagle throughout the whole breeding range in the northern part of the Okhotsk Sea (Potapov *et al.* 1995, 2000). This survey has been given some urgency with plans for oil exploitation and other large-scale developments (e.g. increased timber harvest, and increased fishery exploitation).

In this study our aims were:

1. To determine and classify habitats around nest-sites of Steller's Sea Eagle breeding along the northern coast of the Okhotsk Sea.
2. To determine important factors affecting the density, occupancy and breeding rate of Steller's Sea Eagle in various coastline habitats.

METHODS

Steller's Sea Eagles were counted during coastal surveys undertaken by motorboat and on foot. The surveys were conducted June-August between 1991 and 1998. During these surveys Steller's Sea Eagle territories were identified, and, if possible, occupancy and reproductive success were determined.

The area surveyed is shown in Figure 1 and Table 1. A total of 145 nests were recorded along 1852 km of coastline.

The data were analyzed in the following steps:

1. To determine the most favorable combination of factors at coastal breeding habitats.
2. To classify the entire coastline according to the dominant environmental factors revealed by the first step.
3. By use of stepwise multiple regression, identify factors with the most predictive power for the density of territorial pairs of Steller's Sea Eagle in various segments of coastline.
4. To identify factors with the most predictive power for the breeding rate in various segments of the coastline.

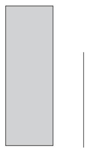

Fig. 1. The coastline and the rivers within the study area.

Table 1. Dates and portions of coastline surveyed.

Year	Months	Place	Means of surveys
1993	26-28 May	Koni peninsula, Umara Island	Motor-boat, boat
	24 Jul. - 3 Aug.	Koni peninsula	Motor-boat, boat, on foot
1994	11 Jun.	Staritskogo Peninsula	Motor-boat
	27 Jun. - 3 Aug.	Coastline from Tauy estuary to the Shestakova peninsula, portions of coastline from Yama estuary to Taygonos peninsula	Motor-boat
	10 Aug.	Gertnera Bay coastline, Staritskogo peninsula	Motor-boat, on foot
1995	24-25 Jun.	Rechnoy Bay - Umara island coastline	Motor-boat
	30 Jul.	Staritskogo peninsula	Motor-boat
	13-14 Aug.	Koni peninsula, Odyan Bay	Motor-boat
1996	31 May	Staritskogo peninsula	Motor-boat, on foot
	2-10 Jul.	Odyan Bay, Koni peninsula	Motor-boat, boat
	15-26 Jul.	coastline from Tauy estuary to point Enken	Motor-boat, boat
	7-12 Aug.	Motykley Bay	Motor-boat, on foot
1997	3 Jun.	Staritskogo peninsula	Motor-boat
	20 Jun., 10 Jul.	Odyan bay and Koni peninsula	Motor-boat
	14-17 Jul.	Odyan Bay	Motor-boat
	1-4 Jul.	Coastline from Tauy Estuary to Gavantsa cape	Motor-boat
	18-27 Jul.	Coastline from Sheltinga bay to Okhotsk sea port, Umara and Spafariev islands, Motykley Bay	Motor-boat, boat
	31 Jul., 1 Aug.	Odyan Bay	Motor-boat
	9-15 Aug.	Yama river	Motor-boat, rafting
	22-30 Sep.	Chelomdja and Tauy rivers	rafting
1998	2 Apr. - 18 May	Talan island	on foot
	12-17 Jun.	Lisyanskiy peninsula	on foot, motor-boat, boat
	13 Jul.	Staritskiy peninsula, Nedorasumenia Island	motor-boat
	14-18 Jul.	Lisyanskiy Peninsula, Spafariev island	Motor-boat
	30-31 Jul.	Umara island, Odyan Bay	Motor-boat
	1 Aug.	Onatsevicha peninsula - Shestakova cape	Motor-boat
	5 Aug.	Lisyanskiy peninsula	Motor-boat
	9 Aug.	Lisyanskiy peninsula - Izmailova Cape	Motor-boat
	10 Aug.	Talan Island, Khmitievskiy peninsula	Motor-boat
	12 Aug.	Motykley Bay	Motor-boat

Nest site habitat analysis

Habitats surrounding nest locations on the seacoast were described by a number of qualitative factors:

1. character of the coast at the nest site:
   - cliffs
   - mountain slope
   - low coast)
2. type of vegetation:
   - Siberian Larch *Larix daurica* cover ("forest" thereafter)
   - Creepy Pine *Pinus pimula* cover

• no vegetation, which in this study means either tundra or steppe-like communities, wide gravel terrace with no bushes, or vast bog with no trees

3. type of littoral zone:
   • no littoral zone
   • vast mud-stone littoral zone (with many stones emerging at low tide)
   • vast sandy stone littoral zone (more than 0.5 km wide),
4. other factors:
   • presence of sea-bird colonies in the proximity of the nest
   • turbidity of sea water at the nest-site (turbid or transparent)
   • presence of rivers and their estuaries at the distance less than 2 km.

In combination these environmental factors were features of the coastal landscape from which the eagles were able to choose. Stochastic environmental factors which acted simultaneous on all closely situated nests (e.g. weather) were not considered in this study. The data were subjected to principal component analysis (PCA) as a way of summarizing inter-correlated variables and identifying dominant environmental gradients of the coastline at nest-sites. Nest-sites were then grouped according to the results of the ordination.

Territorial density analysis

The entire coastline surveyed was classified into segments of variable length according to the factors identified by the PCA as dominant environmental gradients. The length of these coastline segments varied from 10 to 103 km. The density of the eagles territories (i.e. territorial pairs per 10 km of coastline) was measured for every segment of the classified coastline on a computer map (GISWare 1997).

The coastline segments classified according to dominant environmental factors were described by environmental factors used for nest habitat description (above). In addition, density of active fisheries (fishermen's cabins or camps occupied all summer) per 10 km of coast, minimum distance from the segment to the nearest settlement, minimum distance to a river or river estuary, number of rivers per 10 km of coastline in the segment, and the abundance of large stones on the littoral zone (many or few) were included in the analysis.

The densities of Steller's Sea Eagle territories in various segments of the coastline were classified by these factors, and analysed separately for the coast types classified by the factors determined by the PCA using multiple regression. This analysis was carried out in order to determine the factors with the most predictive power for Steller's Sea Eagle territory density within a particular portion of coastline. Similar analysis was performed for occupancy (ratio of the number of breeding pairs to the total number of territorial pairs in particular segment) and breeding rate (average number of fledglings seen per nest for a particular segment). In the case of occupancy only nests observed for a period of not less than 3 years were included in the analysis. The average occupancy per nest was then calculated for particular portions of coastline.

The statistical analysis was performed using Statistica and StatView packages.

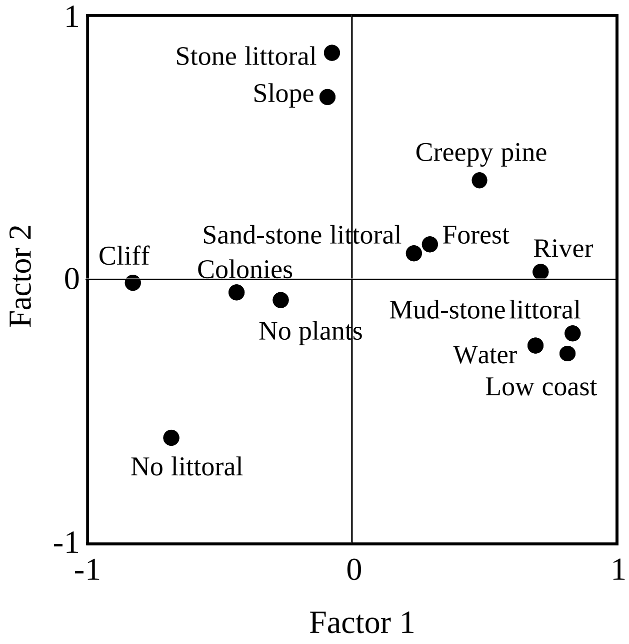

Fig. 2. Principal component analysis (PCA) of variables measured at Steller's Sea Eagle nest sites along the coastline in north Okhotia.

RESULTS

Environmental patterns at nest sites

The strongest environmental gradient (Factor 1) was associated with the type of coastline (cliffy coasts vs. low coast) and explained 32% of the total variance in environmental data (Fig. 2). The ordination indicated the following gradation of the factors: cliffy coast, no littoral zone, bird colonies, no plants, sand-stone littoral, turbid water, river/river estuary, mud stone littoral, low-coast. The second dominant environmental gradient (Factor 2) was somewhat asymmetrical and covered types of littoral (stone littoral vs. no littoral) and explained 15% of the total variance (Fig. 2). The third environmental gradient included vegetation categories "forest - creepy pine - no plants" and explained 12% of the variance (Fig. 3).

Territorial density of the Steller's Sea Eagles in various coastline types

Because the strongest environmental gradient determined by the PCA was "Low coast type - Cliffs" (Fig. 2), the territorial densities in the portions of coastline classified by these two characteristics were subjected to multiple regression analysis separately.

The multiple regression procedure (Table 2) included the factors "presence of sea-bird colonies" and number of fisheries per 10 km of the coastline in the model, but left out other factors including presence of slope, presence of low coast portions, lack of littoral, presence of stones at the littoral, lot or little stones at the littoral, turbid water, mud-stony littoral, number

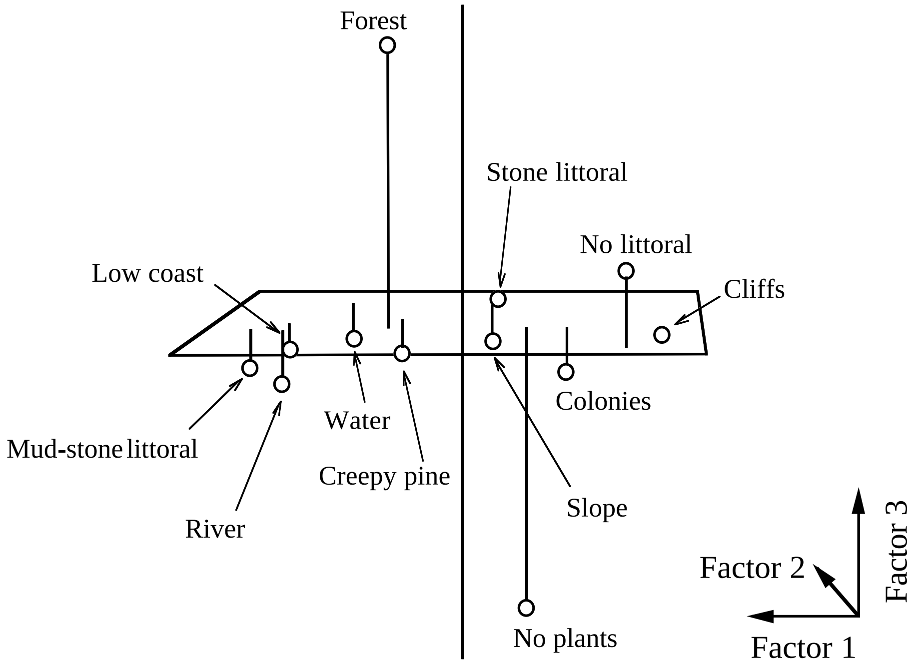

Fig. 3. First three axes revealed by the principal component analysis of Steller's Sea Eagle nest sites on the coastline in north Okhotia.

of rivers/river estuaries per 10 km of the coastline. This revealed that in cliff-dominated segments the numbers of territorial Steller's Sea Eagle pairs were negatively correlated with the number of fisheries and positively correlated with the number of sea bird colonies.

The stepwise regression model for the "low coast" included only the presence of vast mud-stony littoral as a significant and positive factor. In such places eagle density did not show any significant association with density of fisheries, density of rivers/estuaries, presence of other types of littoral (stony, sandy or insignificant littoral), proximity to settlements, or the presence of fishermen's camps.

Occupancy and breeding rate of the Steller's Sea Eagles in various coastline types

Average occupancy of territories (aggregating both coastline types) showed significant and negative association with turbid waters (Table 3). Other factors showed no influence on occupancy. Occupancy of nests analysed separately for low coast and cliffy coastline showed that no recorded factors had significant association with occupancy.

Average number of fledglings per nest along particular coastline segments showed significant negative association with water turbidity (Fig. 3). Other recorded factors such as type of coastline, littoral, presence or absence of forests, settlements, or fisheries proved to have non-significant correlation. The average number of fledglings per nest showed negative association with the presence of many stones in the littoral zone in the segments of cliffy

Table 2. Results of multiple regression of factors influencing breeding density of Steller's Sea Eagles on the sea coast. Separate analyses were performed for 'Low coast" and "Cliffs" types of coastline. Variables rejected by the procedure for "Cliff Coastline" are: presence of slope, low coast, absence of littoral zone, absence of stones at the littoral, many stones at littoral, presence of sandy-stone or muddy-stone littoral, water turbidity, density or rivers/estuaries per 10 km and proximity to settlements. Rejected variables for "Low coast" are: presence of slope, absence of littoral zone, many stones at littoral, presence of sandy-stone littoral and fisheries/fishermen's camps density, proximity of settlements, density of rivers/ estuaries per 10 km of coastline.

		Cliff Coastline		
R	R^2	Adj. R^2	Residual	
0.62	0.383	0.322	0.822	
		Analysis of Variance		
Source	DF	SS	MS	*F* -test
REGRESSION	2	8.42	4.21	6.229
RESIDUAL	20	13.527	0.676	
TOTAL	22	21.954		
		Variables in Equation		
Variable:	Coefficient	Std. Err.	Std. Coeff.	*F* to Remove
INTERCEPT	0.663			
Sea-bird colonies	1.259	0.452	0.488	7.746
Fisheries/km	-0.528	0.251	-0.368	4.401
		Low coast		
R	R^2	Adj. R^2	Residual	
0.764	0.585	0.589	0.681	
		Analysis of Variance		
Source	DF	SS	MS	*F* -test
REGRESSION	1	5.889	5.889	12.68
RESIDUAL	9	4.177	0.464	
TOTAL	10	10.066		
		Variables in Equation		
Variable:	Coefficient	Std. Err.	Std. Coeff.	*F* to Remove
INTERCEPT	0.101			
Muddy-stone littoral	1.521	0.427	0.765	12.689

coasts, and positive association with presence of vast mud-stone littoral in the low coast segments (Table 4). Other factors, like presence of settlements, fisheries, sand-stone littoral and type of vegetation, were found not to be significant by the step-wise regression procedure.

DISCUSSION

Steller’s Sea Eagle breeding sites in this study were grouped by the results of the PCA ordination along three main environmental gradients: the type of coast (cliffs vs. low coast associated with vast mud-stony littoral zone and turbid waters), type of littoral (stone littoral vs. no littoral) and type of vegetation gradient (forest-creepy pine - no plant cover). The strongest environmental gradient explaining most of the variation was the type of coast. Indeed, the breeding ecology of the Steller’s Sea Eagle in these two categories of coastline was

Table 3. Results of multiple regression of factors influencing breeding performance of coastal Steller's Sea Eagles. Coast types were aggregated.

Occupancy, all coast types				
R	R^2	Adj. R^2	Residual	
0.38	0.147	0.127	0.094	
Analysis of Variance				
Source	DF	SS	MS	*F* -test
REGRESSION	1	0.064	40.064	7.254
RESIDUAL	42	0.374	0.009	
TOTAL	43	0.0438		
Variables in Equation				
Variable	Coefficient	Std. Err.	Std. Coeff.	*F* to Remove
INTERCEPT	1			
Water turbidity	-0.111	0.041	-0.383	7.254

Breeding rate, all coasts				
R	R^2	Adj. R^2	Residual	
0.576	0.332	0.309	0.376	
Analysis of Variance				
Source	DF	SS	MS	*F* -test
REGRESSION	1	2.049	2.049	14.425
RESIDUAL	29	4.119	0.142	
TOTAL	30	6.169		
Variables in Equation				
Variable	Coefficient	Std. Err.	Std. Coeff.	*F* to Remove
INTERCEPT	0.633			
Water turbidity	-0.521	0.137	-0.576	14.425

Table 4. Results of multiple regression of factors influencing breeding performance of coastal Steller's Sea Eagles. The analysis was performed separately for "Low coast" and "Cliffs" types of coastline.

Breeding rate, cliffs				
R	R^2	Adj. R^2	Residual	
0.506	0.256	0.215	0.411	
Analysis of Variance				
Source	DF	SS	MS	*F* -test:
REGRESSION	1	1.046	1.046	6.194
RESIDUAL	18	3.039	0.168	
TOTAL	19	4.85		
Variables in Equation				
Variable:	Coefficient	Std. Err.	Std. Coeff.	*F* to Remove
INTERCEPT	0.762			
Many stones	-0.479	0.192	-0.506	6.194

Breeding rate, low coasts				
R	R^2	Adj. R^2	MS	
0.752	0.566	0.519	0.113	
Analysis of Variance				
Source	DF	SS	MS	*F* -test:
REGRESSION	1	0.149	0.149	11.768
RESIDUAL	9	0.115	0.013	
TOTAL	10	0.264		
Variables in Equation				
Variable:	Coefficient	Std. Err.	Std. Coeff.	*F* to Remove
INTERCEPT	0			
Mud-stony littoral	0.242	0.07	0.752	11.768

fundamentally different. Eagles nesting on cliffs obtained most of their food from sea-bird colonies, from the sea surface or at the surf-line, whereas eagles living on low coast fed primarily on the vast littoral during low tide, taking small-size prey from puddles. Lobkov & Neifeldt (1986) mention that Steller's Sea Eagles on the coastline of Kamchatka breed on cliffs without a vast littoral zone or on the forested low coast of western Kamchatka, which at least locally has a large littoral zone. Although they provide no quantitative data, their description indicates a situation similar to the one we observed.

Lobkov (1986) noted that coastal Steller's Sea Eagles on Kamchatka are associated with river estuaries. Distribution of nesting eagles in North Okhotia showed a different pattern. Nesting eagles were found on the coastline far away from the river estuaries. The PCA did not reveal the proximity of estuaries as an important factor in determining the density of eagle territories

Simple hierarchical separation of nesting habitat into 'low coast' and 'cliffs' followed by more detailed separation on the basis of habitat preferences shown by eagles would give a straightforward method for habitat classification in GIS models.

Different factors influenced the population depending upon whether the coast was predominantly cliffs or low coast. For the cliffy coasts the most important factor was the presence of sea-bird colonies, while a limiting factor was the density of active fishing camps. Major parts of such coastlines had no estuaries of large, salmon-spawning rivers, and few estuaries of small salmon runs, and as a result eagles fed primarily on sea birds and sea fish. In addition, a small littoral zone meant that eagles had limited access to small sea fish that are trapped in small puddles left at low tides. Active fisheries (which were mostly located at river estuaries) with a lot of boats and people, kept eagles away from these places which have an abundance of pre-spawning salmon.

In contrast, along low coast with a vast littoral zone Steller's Sea Eagles seem to ignore people and perch on large rocks that emerge at low tide. Walking on these mud-flats is difficult for humans, but the abundance of small shallow puddles with land-locked fish (mainly flounders *Pleuronectus* sp. and sticklebacks *Gastrosteus* sp.) makes this habitat perfect for eagles. Within such habitat eagles might breed in close proximity to settlements, in spite of numerous cases of nest robbery and constant disturbance caused by motorboats at high tide. In addition, the results of this study show that in the low coast type of habitat the number of fledglings per nest is relatively high at nests which have access to vast littorals, whereas small littoral and sandy-gravel beach predetermine low breeding rate. Strictly speaking, vast mudflats are habitats where Steller's Sea Eagles could share the coastline with humans with little conflict, provided that direct human access to the nests is limited.

Occupancy seemed not to be determined by any of the environmental factors we measured, when the two types of coast were analysed separately. However, analysis of the whole data set revealed a negative association between occupancy and high water turbidity. In places with turbid waters occupancy was low or less stable in the years in which we made observations.

Breeding rate was generally lower in low coast segments. In such habitats the best performance was demonstrated by eagles breeding in proximity to vast mud-stony littoral. In cliff coast segments breeding rate was best in segments with narrow littoral zone without big boulders, suggesting small boulder size made it difficult to hunt at the surf line. It appears that the optimal size of boulder should be of the size of the eagle itself, and that the best beaches for eagles were covered in medium to large ball-shaped rocks with some shoals close to the shore that become exposed at low tide.

The results of this study suggest that it is important to limit human activity of eagles at fishing camps during the eagle breeding season in close proximity to cliff coast with dense seabird colonies, because it is there that eagles are most susceptible to disturbance. In these areas the protection of nest sites only is not sufficient to ensure successful breeding. In contrast, the protection of nest sites of eagles breeding close to mud flats is crucial to the maintenance of the breeding rate in such habitats.

CONCLUSIONS

1. Steller's Sea Eagles habitats on the coast can be classified into two general landscape features "cliffs" and "low coast" according to the results of the PCA ordination.
2. Territory density of Steller's Sea Eagles in "cliffy" coastline was negatively correlated with numbers of fishing camps and positively correlated with the presence of sea-bird colonies. In "low coast" the presence of vast mud-stony littoral was positively correlated with territory density.
3. There were no factors that we examined that affected occupancy of territories in either low coast or cliffs, but high water turbidity was negatively correlated with occupancy for both coast types combined.
4. The highest number of fledglings per nest was along segments of low coast with vast mud-stony littoral, and in cliffy coasts segments with little or no littoral without big boulders. Generally the breeding rate along cliffy coast was higher than along 'low coast'.

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