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Recent changes in the status of Steller's Eider *Polysticta stelleri* wintering in Europe: a decline or redistribution?

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Summary

Steller's Eider *Polysticta stelleri* has a restricted arctic breeding range. The world population declined to *c.* 220,000 individuals in the late 1990s from an estimated 400,000–500,000 in the 1960s. The species has a limited global wintering distribution, occurring in marine habitats in north-east Europe, islands close to Kamchatka in Russia, and the eastern Aleutian Islands and south-west Alaska. European wintering numbers were estimated at 30,000–50,000 in the early 1990s, when the population was considered of favourable conservation status. Recent census data from the most important European wintering sites show annual declines of 8% in Norway since 1984, 9% in Estonia since 1994 and 22% in Lithuania since 1995, suggesting an overall 65% reduction in Europe. Counts in 1994 suggested that 30–50% of the European population wintered in Russia at that time. Current census data from Russia show similar declines along monitored sections of the Kola Peninsula wintering grounds since 1994. Accounting for trends in Russia, the current European wintering population could possibly stand at 10,000–15,000 individuals (a more than a 50% decline in 10 years), qualifying this population as Endangered under IUCN criteria. The changes in Baltic/Norwegian wintering numbers did not correlate with changes in the extent of ice-free marine waters in the Kola Peninsula/White Sea areas, but changes in annual numbers in Norway were correlated with winter North Atlantic Oscillation indices. Variation in annual numbers in the Baltic Sea correlated with projected number of juveniles among wintering birds. However, none of the possible causes discussed in this paper could fully explain the decline in Steller's Eider, confirming the need for comprehensive monitoring of the population throughout its winter range and for cohesive demographic monitoring to target effective conservation action.

Introduction

Steller's Eider *Polysticta stelleri* is classified as Globally Threatened and is, thus, a species of global conservation concern (Tucker and Heath 1994). Based on winter counts the current world population numbers *c.* 200,000–220,000 individuals, a significant decrease from the estimated 400,000–500,000 individuals in the 1960s (reviewed in Solovieva *et al.* 1998, Fredrickson 2001). It breeds from the Yamal Peninsula east to the Kolyma Delta, and in western and northern Alaska (Kertell 1991, Yesou and Lappo 1992, Nygård *et al.* 1995a, Solovieva 2000, Fredrickson 2001). On the breeding grounds, the Khatanga River (east of Taymyr Peninsula) is considered the point of separation between the subpopulations using western (Atlantic) and eastern

(Pacific) wintering grounds (U.S. Fish and Wildlife Service 2002). The species winters in three areas: north-east Europe, islands close to Kamchatka in Russia, and the eastern Aleutian Islands and south-west Alaska (Marakov 1968, Voronov 1972, Kertell 1991, Nygård *et al.* 1995a, b, Artyukhin and Burkanov 1999, Fredrickson 2001). In contrast to the common and widespread winter distribution of the two circumpolar eider species (King Eider *Somateria spectabilis* and Common Eider *S. mollissima*), Steller's Eider shows a highly clumped distribution during the wintering season. This probably reflects its specialized habitat use and diet (Bustnes *et al.* 2000, Bustnes and Systad 2001a, b, Žydelis and Esler 2005).

The European wintering population was estimated to be 30,000–50,000 individuals during 1990–1995 and was distributed between two major areas: the Barents Sea and the Baltic (Nygård *et al.* 1995a, Schäffer and Gallo-Orsi 2001). In the Barents Sea area up to 13,200 individuals have been counted in Varangerfjord, north-east Norway, and more than 16,000 individuals, between 30–50% of the European population, have been counted along the Kola Peninsula (Nygård *et al.* 1995b, Fox and Mitchell 1997). The third important wintering area is located in the White Sea, along the eastern coast of Kola Peninsula (Terskiy coast), where more than 4,000 Steller's Eiders have spent the winter period associated with polynyas (Krasnov *et al.* 2004). In the Baltic, wintering numbers rapidly increased between the late 1980s and the mid-1990s, with peak reports of 300 birds in Finland, 5,000 in Estonia, 2,000 in Lithuania and small but regular numbers in Sweden (Nygård *et al.* 1995a, Schäffer and Gallo-Orsi 2001). Recent counts in the Baltic, however, suggest that the observed population increase during the 1990s has ceased and numbers are now decreasing within their wintering areas.

The paper reviews the current status of wintering Steller's Eider population in Europe, and discusses possible causes of the observed changes in numbers and distribution.

Methods

National counts

Steller's Eiders have been monitored at their regular European wintering sites by a variety of methods which, due to logistic reasons, differed slightly between countries and years. All national counts are part of the Wetlands International Waterbird Census (Delany *et al.* 1999). In addition to national counts from Norway, Finland, Estonia and Lithuania (where Steller's Eiders winter regularly: Nygård *et al.* 1995a), winter counts from Sweden and Latvia were also reviewed, recognizing a possibility of Steller's Eiders wintering there. Recent observations of wintering Steller's Eiders in north-western Russia were also reviewed and presented.

In Varangerfjord, Finnmark County, Norway, the area from Varangerbotn to Vardø (see Figure 1 in Fox and Mitchell 1997) has been surveyed from the shore and aircraft each year since 1980 in early March as part of the national monitoring programme for seabirds (Lorentsen and Nygård 2001). Different parts of the Barents Sea and the White Sea in north-western Russia have been intermittently surveyed since the 1960s (reviewed in Nygård *et al.* 1995a). The Kola Peninsula (Eastern Murman) coast was surveyed in March–April of 1994, 1999 and from 2001 through 2005 from land along 60 km of the shoreline (central coordinates 69°07′N 36°02′E). Surveys were conducted

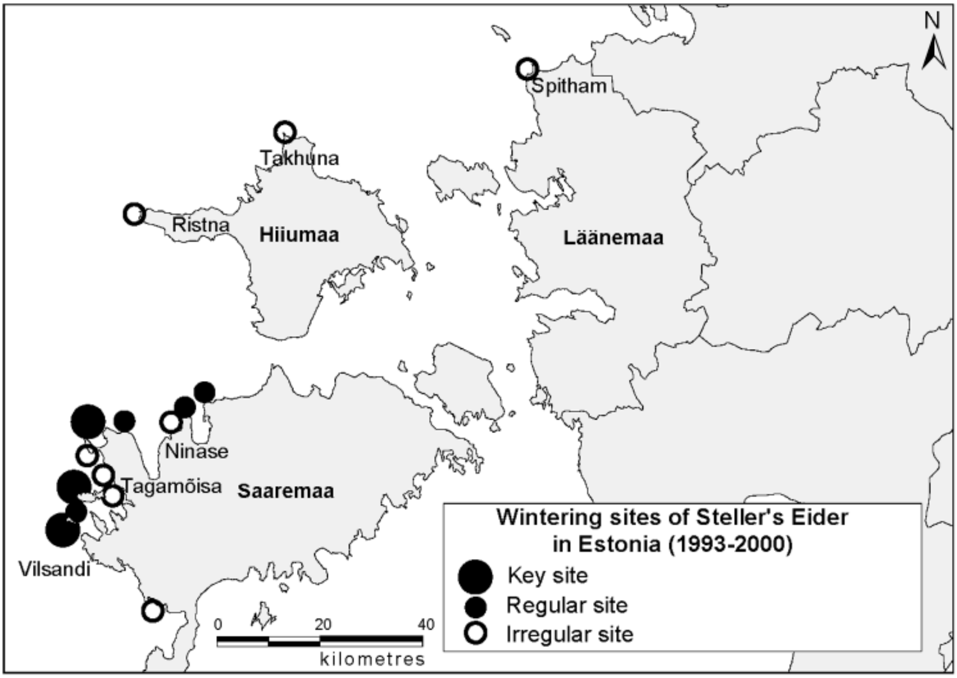

Figure 1. Winter distribution of Steller's Eider in Estonia (1993–2000).

using ×12 or ×15 binoculars covering an area up to 1 km from the shore. The first comprehensive aerial survey along the entire Murman coast of the Kola Peninsula was conducted in late March 1994 (Nygård *et al.* 1995a) and the Eastern Murman coast (the Barents Sea) and Terskiy coast of the White Sea were surveyed from helicopter in early April 2003 (Krasnov *et al.* 2004). In Finland, mid-winter boat or helicopter counts are conducted annually around Lågskär and some other parts of the Åland Islands. A standardized sample of Swedish coastal sites has been counted annually since 1971. Countrywide mid-winter surveys (including aerial counts) have been undertaken in 1971–1973, 1987–1989 and in 2004. In Estonia, coastal wintering waterbirds have been surveyed irregularly from 1967 until 1985. Thereafter mid-winter January counts at known Steller's Eider wintering sites were performed from the coast, with aerial surveys covering all potential areas in January 1993, April 1998 and April 2001. Since 1990, selected stretches or the entire Latvian coast have been surveyed in mid-January from the shore, with aerial surveys coupled to land-based counts in 1993, 1997, 1998 and 2000. A special aerial survey for Steller's Eiders took place in April 2001, when these birds are known to aggregate at herring spawning sites in neighbouring Lithuanian waters (Žydelis 2000). Waterbirds wintering in Lithuanian coastal waters have been surveyed annually since 1987, based on standardized counts from land and complete mid-winter January aerial surveys (Žalakevičius *et al.* 1995). The majority of national count data, collected prior to 1994, has already been summarized and reported by Nygård *et al.* (1995a). The wintering season, which for Steller's Eider extends from November though May, was referred to as the calendar year for January, i.e. the winter of November 1997 to May 1998, was denoted as winter 1998.

Trends in winter numbers

To detect breakpoints, indicating the start of Steller's Eider declines in national and regional counts, two separate linear regression lines were fitted to the data. Bird counts were used as response variables and YEAR, PERIOD and the interaction term (YEAR*PERIOD) were used as predictor variables. PERIOD was a categorical variable where one state indicated the period of increase in bird numbers and the other represented the period of decline. Models with all possible continuous PERIOD combinations were tested with each dataset and models with the highest r^2 values were considered as indicating the year when the trajectory of the Steller's Eider population had shifted.

Due to missing observations for some localities (1–3 of 7) in four of the 24 years between 1980 and 2003 (because of poor weather conditions in northern Norway), trend analyses, including calculation of numbers for the Norwegian data, were performed using TRIM 2.0 for Windows (Pannekoek and van Strien 1998). The statistical probability (P) of a population change was computed using Monte Carlo simulations for all data presented in this paper. By this method the linear regression slope estimated for the real dataset was compared with the corresponding slopes for 10,000 different randomized sequences of the same data values.

Trends in breeding success

One potential cause of the declines could be a reduction in breeding output and hence any time series data relating to reproductive output could be helpful in supporting this assertion. Long-term monitoring of spring migrants took place at Kummelskär, in the Gulf of Finland from 1975 until it ceased in 1995. This sequence of observations provided data on the proportions of adult males passing the site during sea-watches carried out in spring as wintering birds departed the Baltic (Pettay 1996 according to Hario 1997a and presented here). In more recent years, sex ratios have been sampled on the wintering areas in Norway (in mid-November 1996–2000 inclusive), Lithuania (mid-winter 1997–2002) and Estonia (intermittently during 1988–2001). Using the observed proportion of adult males identified in the sample (m), based on the simple assumption that the sex ratio amongst adults does not differ from parity, we infer that the proportion of adult females amongst the brown birds is equal to the number of adult males (namely m). Hence, we calculated the imputed proportion of young (j) from these counts using the formula:

$$j = (1 - 2m).$$

Given the recent finding that survival of adult male and female Steller's Eider differ in the Alaskan population (Flint *et al.* 2000), the assumption of an even adult sex ratio is unlikely to hold. However, in the absence of better data, this assumption gives some basis for the assessment of crude relative annual production using the available time series.

Environmental descriptors

There is now growing evidence that changes in climate are affecting the distribution of wintering waterfowl in the Western Palearctic, recent milder winters resulting in more extensive open water in areas north and east of traditionally used wintering areas (e.g. Švažas *et al.* 2001). Hence, changes in the extent of ice cover along the northern edge of the Kola Peninsula and in the White Sea could affect the degree to which Steller's Eider are forced west (into Norway) and south-west (into the Baltic) in winter. We used two variables to analyse the numbers of Steller's Eiders in relation to climate: (1) changes in the extent of sea ice cover in areas nearer to the breeding areas, and (2) the North Atlantic Oscillation (NAO).

Data on the extent of sea ice mapped by satellite imagery was available on the NOAA National Ice Centre web site (http://www.natice.noaa.gov/PUB/East_Arctic/ last accessed 16 June 2005, using the annual archives for the Barents and White Seas) for dates in mid-January during 1997–2003 inclusive. Imagery analysis for 7 January 1997, 12–16 January 1998, 18–22 January 1999, 17–21 January 2000, 15–19 January 2001, 21–25 January 2002 and 20–24 January 2003 were used, corresponding to data available nearest to the time of the mid-winter counts. These provide geographical data relating to the extent of sea covered by more than 50% ice based on standard algorithms to interpret infrared and visible spectra reflectance in satellite captured imagery. Steller's Eiders rarely occur far from the immediate vicinity of the coast (Fox and Mitchell 1997 and observations at all European wintering sites). Hence, we used the extent of 50% ice-free coastal waters along the Kola Peninsula as a measure of the extent of ice cover in areas outside of the known wintering areas in the Baltic and Barents Seas. In reality, the fast ice edge usually corresponded to the extent of ice-free waters, there being little sea area supporting 50–100% ice cover in the seasons examined.

The NAO reflects a North–South oscillation in atmospheric mass between the Icelandic low-pressure centre and the Azores high-pressure system (Hurrell *et al.* 2003). It has been shown to affect the population dynamics of plankton, marine fish and seabirds (Thompson and Ollason 2001). A positive NAO index is associated with a northward shift in the Atlantic storm activity, and a generally warm climate over northern Europe. Thus, it is expected that, if the Steller's Eiders prefer to winter as close to their breeding sites as possible, the numbers wintering in Scandinavia should be lower in years with mild winters. Data on the winter index (December to March) of the NAO were obtained for the years 1980 onwards (depending on which winter area was analysed) from http://www.cgd.ucar.edu/cas/jhurrell/nao.stat.winter.html (last accessed 16 June 2005).

Data analysis

Analysis of correlates of Steller's Eider numbers and selected predictor variables was conducted using an information-theoretic approach to determine the models that best fit the data (Burnham and Anderson, 2002). In a general linear model (GLM) context with logarithmic link function, Steller's Eider number was the response variable and NAO index in the current winter, NAO index in the previous winter (NAO-1), YEAR, PERIOD (consisting of pre- and post-trend breakpoint categories), number of juveniles (JUV), and interaction term between year and period (YEAR*PERIOD) were the explanatory variables. Sea ice conditions in the Barents Sea and the White Sea were not included in the modelling exercise due to the limited extent of this dataset (available only since 1997). Number of juveniles for each winter season was calculated by accepting juvenile proportions derived from observations in Finland (1980–1995), Norway (1997), and Lithuania (1998–2003). Although some waterfowl species are known as having geographically skewed sex and age ratios (Nichols and Haramis 1980), we assumed that, in the absence of better material, our dataset represents general Steller's Eider reproductive output, at least for birds observed in the Baltic Sea region. Sixty-three candidate models with all possible combinations of predictive variables were considered for predicting both Steller's Eider numbers in Norway and those in the Baltic Sea. Steller's Eider numbers in Norway and in the Baltic were analysed separately due to the different sizes of the datasets (Norway 1980–2003, Baltic 1988–2003), and possibly different patterns of species numbers occurring in those regions, as indicated by trend breakpoints (see below). Null models were also considered, and each of them included only the mean value of the response variable as intercept and the variance of the response variable. If the null model received greater support from the data than other models, it would indicate that variability in the response variable is determined by factors other than the predictor parameters analysed.

Akaike's Information Criterion corrected for a small data sample (AIC_c) was used to rank the fit of each model within a candidate set (Burnham and Anderson, 2002). ΔAIC_c was used to assess the explanatory value of each model, where ΔAIC_c was calculated as the difference between the value of the best-fitted model and each respective model in the set. AIC weights (AIC_w), indicating the relative likelihood of a model given the data and set of candidate models, were also calculated to provide a relative weight of evidence for each model (Burnham and Anderson 2002). To determine the relative importance of each explanatory variable within a candidate model set, AIC weights were summed for all candidate models containing the explanatory variable under consideration, providing a parameter likelihood value. Also, weighted parameter estimates and unconditional standard error (SE) were calculated for the explanatory variables of each analysis, based on AIC_w for all candidate models, which accounts for model uncertainty (Burnham and Anderson 2002).

Results

Trends in winter numbers

Norway

Between 1,216 and 13,755 Steller's Eiders were counted annually in Varangerfjord (70°12′N, 29°52′E) in the period 1980–2003 (some values imputed using TRIM 2.0). Overall, numbers increased from 1980 to 1984, but decreased to 2003 (Table 1). There was no statistically significant trend ($P = 0.159$) for the whole period. The initial increasing trend was reversed in 1985 (Table 1) and there has been a significant decline since then (annual decline of 7.80%, $P = 0.005$).

Russia

More than 16,000 Steller's Eiders were observed along the Murman coast of the Kola Peninsula in 1994, suggesting an estimate for Russia as high as 20,000–30,000 birds

Table 1. Numbers of Steller's Eiders recorded in key wintering sites in Europe since 1995. Earlier data reported in Nygård *et al.* (1995a).

	Norway	Russia	Finland (Lågskär)	Estonia	Lithuania
1995	9,350		221	2,430	1,250
1996	5,159		120	3,850	1,980
1997	3,431		200	2,660	2,059
1998	3,314		220	2,230	1,660
1999	1,876		80	2,100	1,490
2000	3,890		180	2,300	880
2001	3,203		50	1,500	750
2002	4,113		70[b]	1,650	400
2003	1,216	4,297[a]	30	1,600	212

[a]Survey covered the Terskiy coast of the White Sea and east Murman coast of the Barents Sea (Krasnov *et al.* 2004).
[b]In addition to these, 165 individuals have been recorded in other parts of the Åland Islands.

(Nygård *et al.*. 1995a). In 2003, 4,297 Steller's Eiders were counted, most of them along the Terskiy coast of the White Sea and only 262 individuals along the east Murman coast of the Barents Sea (Krasnov *et al.* 2004). Only a part of the Murman coast (between Savikha Bay and Dvorovoi Cape) overlapped between surveys in 1994 and 2003, but the number of Steller's Eiders observed there in 2004 constituted only 2.7% of those found in the same location in 1994 (Krasnov *et al.* 2004). Numbers of Steller's Eiders wintering along the coast of the Kola Peninsula increased between the 1970s and 1990s (Kokhanov 1979, Krasnov and Goryaev 2001). During this period, small groups of about 20 wintering Steller's Eiders were found in polynyas in the inner parts of Kandalaksha Bay of the White Sea. The peak numbers of Steller's Eiders wintering along the coast of the Kola Peninsula were observed in the mid-1990s (Nygård *et al.* 1995b), when about 20,000 ducks could have spent the winter period in the area. Since the 1990s, a decrease in numbers has been observed along the monitored shoreline section of Kola Peninsula (69°07′N, 36°02′E), where over 2,100 individuals were observed in 1994, nearly 1,800 in 1999 and only about half these numbers (range 901–1,207) in 2001–2005. Furthermore, none have been observed wintering in the inner parts of Kandalaksha Bay since winter 2002. At the same time, there has been a gradual increase in numbers of wintering ducks at some other wintering grounds. In Kola Bay, in the vicinity of Murmansk city, the number of wintering Steller's Eiders has increased by 10–13 times in recent years compared with 1999. Nevertheless, overall numbers of Steller's Eiders wintering along the Kola Peninsula continue to decline.

Finland

The Lågskär archipelago (59°50′N, 19°55′E) in Finland is a regular wintering site of Steller's Eider in the Baltic Sea, known since the late 1960s, although numbers there fluctuated between 70 and 320 birds during 1977 to 1996 (see figure 1 in Hario 1997b). It seems that the peak annual number results from continuous immigration during the winter, with numbers highest in late March–early April, depending on the extent of ice. In 2002, three new wintering flocks were discovered in the Åland Islands (in addition to the Lågskär stock), bringing the grand total to 235 wintering birds, approximately equivalent to those counted at Lågskär in peak years. Yet, in 2003, the Lågskär stock had only 30 individuals, and due to the hard-ice winter, no other localities were visited.

Sweden

A countrywide survey was undertaken in Sweden in January 2004, with three individuals counted compared with 58 in the last countrywide survey in 1989. The standard mid-winter counts during the 1990s found between zero and seven birds. Steller's Eiders are regularly reported to the official Swedish Bird Report. Unfortunately it is not always possible to separate reporting of the same individuals moving between different locations, or observations made during the winter from those undertaken during autumn and spring migration periods. The annual total number of Steller's Eiders reported in Sweden has tended to decrease since the mid-1980s (generally >250), to 34–80 in more recent years, excepting in 2000 when 156 sightings of Steller's Eiders were reported. The majority of wintering Steller's Eiders recorded in Sweden were observed on Öland and Gotland.

Estonia

Estonian coastal waters supported the highest number of Steller's Eiders wintering in the Baltic Sea. Although flocks of 100–300 birds have regularly been observed since the spring of 1975, large wintering assemblies have only formed north-west of Saaremaa Island since the winter of 1990, with peak numbers in 1992 and 1994 (5,000 and 4,800 respectively). Trend analysis indicated the year 1992 as a breakpoint in the increase and the beginning of the decline (Table 2). The Steller's Eider numbers, estimated at 3,000–5,000 individuals during the period 1991–1996, have presently declined to 1,500–2,000. There was a significant positive trend ($P = 0.002$) for the whole period (annual increase 15.1%), but a significant negative trend since 1992 (annual decline of 9.2%, $P = 0.006$).

There are two key Steller's Eider wintering sites in Estonia: Tagamõisa peninsula (58°29′N, 21°56′E) and Vilsandi archipelago (58°23′N, 21°54′E), in the north-west part of Saaremaa Island (Figure 1). At both sites, up to 2,500 individuals have been observed in peak years, but in the last 5 years numbers have fluctuated between 500 and 1,000 individuals. At a third important site – Ninase Peninsula (58°31′N, 22°13′E) – large flocks are rare (birds may simply move here from the above-mentioned key areas), but 300–500 birds have been regularly counted in recent years. Wintering sites on Hiiumaa Island are less important: at Capes Ristna and Tahkuna (58°56′N, 22°03′E and 59°03′N, 22°39′E respectively), up to 150 and 30 birds were counted respectively.

Table 2. Breakpoint years (i.e. the beginning of decline) in numbers trends of wintering Steller's Eiders in different countries and regions in Europe.

Country or region	Breakpoint	Period
Norway	1985	1980_2003
Estonia	1992	1988_2004
Lithuania	1995	1987_2003
Baltic (Estonia and Lithuania)	1994	1988_2003

A new staging site supporting up to 30 individuals was found close to Spitham Cape (Läänemaa County, 58°14′N, 23°31′E) in winter 2000.

Latvia

Since 1991, between one and 10 Steller's Eiders have been reported on 10 occasions in Latvia during winter (Celmiņš and Matrozis 1998–2004). Sightings have come from several coastal sites, most near Akmenrags Cape (56°50′N, 21°04′E), suggesting a small group may use the surrounding waters in winter. Intensive observations from the coast, aerial mid-winter surveys and a special survey in April 2001 yielded no birds (Latvian Ornithological Society unpublished data).

Lithuania

The first records of Steller's Eiders along the Lithuanian coast date back to 1969, when 11 birds were observed in the vicinity of Palanga (55°57′N, 20°52′E) (Mažeikaitė 1970, Petraitis 1991). Since then these birds have been observed annually; their numbers built up gradually, reached 400–500 in the 1980s and continued to increase during the 1990s (Nygård *et al.* 1995a, Žalakevičius *et al.* 1995, Švažas 1997). Peak numbers occurred in 1996 and 1997, when about 2,000 individuals were recorded. Since then, numbers have declined to just 220 individuals in winter 2003 (Table 1). There was no statistically significant trend ($P = 0.278$) for the whole period, but a significant decline in numbers since 1995 (Table 2; annual decline of 21.5%, $P = 0.04$). Extensive surveys have confirmed that wintering Steller's Eiders are completely restricted to a 24 km stretch of the Lithuanian coastline (see figure 1 in Žydelis and Esler 2005); the nearest other regular wintering site of this species is located 350 km north along the coast of Estonia.

Trends in breeding success

The male ratio data from Kummelskär (59°49′N, 22°50′E) showed no significant trend with time for the imputed annual production of young (Figure 2, $r = 0.26$; $P = 0.26$). The very high productivity scores obtained in 1985, 1988 and 1991, contrasted with parity in the brown/adult male bird ratios of 1986, 1987, 1989 and 1992 (Figure 2), are typical of the ''boom and bust'' production cycle described for this species (Solovieva *et al.* 1998, Quakenbush *et al.* 2004). This pattern contrasts with that of the preceding and following periods, which show lower levels of production maintained over all years. In Norway the proportion of brown birds varied between 48% in 1997 and 60.5% in 1999; the imputed ratio of young was high in 1996, suggesting that 1996 and 1999 were good production years for the Steller's Eiders wintering in Varangerfjord (Figure 2).

Environmental descriptors

According to AIC analysis, the best model (Figure 3) explaining the variation in Steller's Eider numbers in Norway was:

$$\mathrm{LogY} = 9.1\,(\pm\,0.12) - 0.04\,(\pm\,0.03)\,\mathrm{NAO{-}1} + 0.11\,(\pm\,0.04)\,\mathrm{YEAR} - 0.53\,(\pm\,0.18)\,\mathrm{PERIOD\_N} + 0.08\,(\pm\,0.02)\,\mathrm{YEAR^{*}PERIOD\_N}.$$

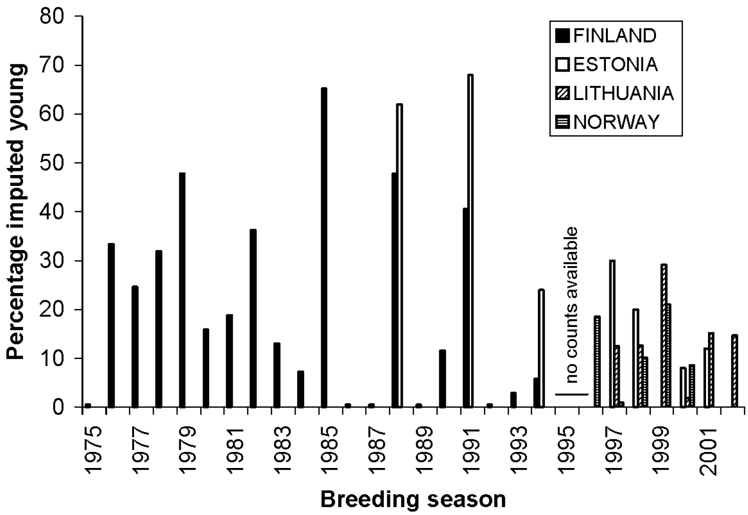

Figure 2. Estimated annual percentage of young calculated from adult male age ratios in samples taken from spring counts in Kummelskär, Finland (1975–1994; black columns), Estonia (1988, 1991, 1994, 1997, 1998, 2000, 2001; white columns), Lithuania (1997–2002; cross-hatched columns) and Norway (1996–2000; horizontal hatched columns). The year on the *x*-axis represents the relevant (i.e. previous) breeding season; hence samples from November 1996 (Norway) and January 1997 (Estonia and Lithuania) relate to the 1996 breeding season and the spring 1976 count from Finland to the 1975 breeding season.

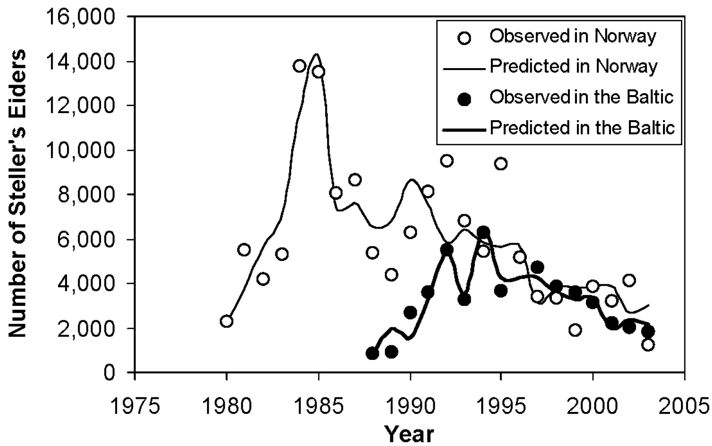

Figure 3. Best fit models (lines) explaining observed Steller's Eider numbers (dots) in Varangerfjord, Norway (thin line and open circles) and in the Baltic Sea (summed count data from Estonia and Lithuania; thick line and filled circles).

The model included three variables (YEAR, PERIOD_N, YEAR* PERIOD_N), indicating that there was an increasing trend until 1985 and a decline since then due to unknown reasons. The NAO index of the previous winter (NAO-1) was also included in the model and positively correlated with variation in Steller's Eider numbers along the trend lines. Review of the summed AIC weights of all models which included a given parameter also indicated that trend-describing variables (YEAR, PERIOD_N, YEAR* PERIOD_N) participated in models that received the best support from the data (Table 3). NAO-1 index received moderate support, with a relatively high AIC_w, but the weighted parameter estimate was not significant (Table 3). Current year NAO index and projected number of juveniles had low explanatory value according to AIC_w and weighted parameter estimates.

The best model (Figure 3) explaining the variation in Steller's Eider numbers in the Baltic Sea was:

$$\text{LogY} = 7.28\,(\pm\,0.25) - 0.08\,(\pm\,0.02)\,\text{YEAR} + 0.14\,(\pm\,0.03)\,\text{JUV\_B} - 1.04\,(\pm\,0.16)\,\text{PERIOD\_B} + 0.17\,(\pm\,0.02)\,\text{YEAR}^{*}\text{PERIOD\_B}.$$

The model included three variables (YEAR, PERIOD_B, YEAR* PERIOD_B), indicating that there was an increasing trend until 1994 and a decline since then due to unknown reasons. Projected juvenile numbers (JUV_B) received equally strong support from the data as trend variables and explained variation of Steller's Eider numbers along the trend lines. Review of summed AIC weights of all models which included a given parameter, also indicated that trend-describing variables (YEAR, PERIOD_B, YEAR* PERIOD_B) and projected juvenile numbers participated in models that received the best support from the data (Table 3). Both NAO indices had low explanatory value according to AIC_w and weighted parameter estimates.

Sea ice coverage varied considerably during the years 1997–2003 along the northern coast of the Kola Peninsula, extending from 40°39′E in 2002 to 42°19′E in 2001 (Figure 4). Remarkably, in 2001, 70% of the White Sea remained ice-free; in all other years the entire White Sea area was covered in fast ice in mid-January. There was no correlation between Steller's Eider numbers in Norway ($r_s = 0.43$, $P > 0.05$) or the Baltic Sea ($r_s = 0.04$, $P > 0.05$) and the extent of ice cover in the Barents Sea.

Discussion

Historical records suggest that during the nineteenth century Steller's Eiders were more abundant in the Baltic Sea than today; however, these birds were seemingly very rare from the beginning of the twentieth century until the mid-1960s (Nilsson 1858 quoted by Nilsson 1997, Hario 1997b). Records of Steller's Eiders in Varangerfjord,

Table 3. Summed AIC weights, weighted parameter estimates and unconditional standard errors of predictor variables (in brackets) used to explain variation of Steller's Eider numbers in Varangerfjord, Norway in 1980–2003, and in the Baltic Sea in 1988–2003.

Parameter	Barents Sea (Norway)		Baltic Sea (Estonia, Lithuania)	
	Summed AIC weights	Weighted parameter estimates (SE)	Summed AIC weights	Weighted parameter estimates (SE)
Intercept	1	8.36 (0.32)	1	7.35 (0.30)
NAO	0.13	−0.001 (0.01)	0.15	−0.01 (0.01)
NAO-1	0.67	0.05 (0.03)	0.15	0.002 (0.004)
YEAR	0.98	0.13 (0.04)	0.94	0.08 (0.02)
JUV	0.29	0.02 (0.02)	0.98	0.14 (0.03)
PERIOD	0.99	−0.90 (0.22)	0.99	−1.05 (0.17)
YEAR*PERIOD	0.99	0.19 (0.04)	0.99	0.17 (0.02)

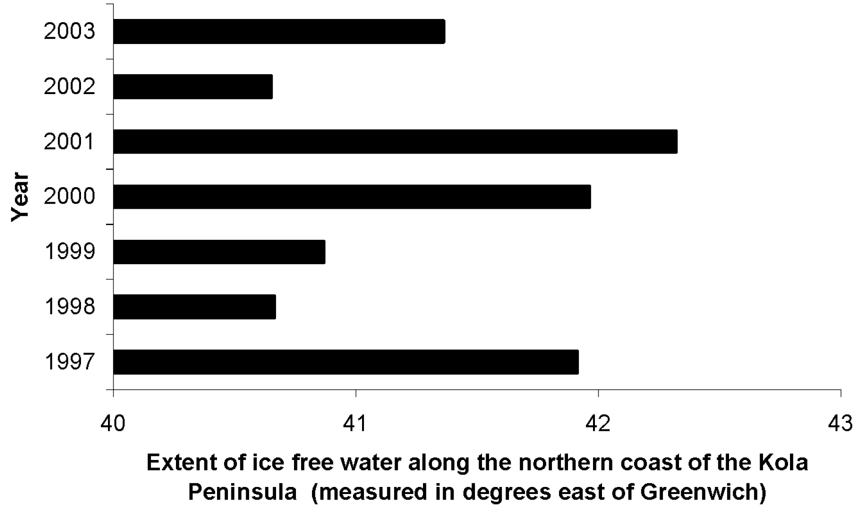

Figure 4. Extent of ice-free water in the Barents Sea, measured as the extent of open sea (>50% ice-free surface) measured along the northern coast of the Kola Peninsula in mid January 1997–2003. See Methods for a full explanation.

Norway also date back to the middle of the nineteenth century (Haftorn 1971), but it has been impossible to judge the current level of occurrence against its former status due to lack of historical data. Nevertheless, there are several suggestions that the species has been much more abundant in the past than at present, and may therefore be subject to very large-scale fluctuations in abundance over extended time periods, particularly in the Baltic.

Population changes since the 1970s

Migration counts from different points in the Gulf of Finland during 1974–1995 all confirm that, until 1986, very few (generally much less than 500) Steller's Eiders were observed leaving the Baltic in spring at a time and few were reported at the wintering areas. January 1988 saw the first count of more than 500 birds in Estonia, but numbers increased very rapidly after that. Numbers along the Lithuanian coast did not exceed 500 until 1990 and peaked generally later than those in Estonia.

What caused the sudden increase in numbers during the early 1990s in the Baltic? Although the numbers in the Varangerfjord declined slightly around 1990, there is no suggestion of a movement from Norway into the Baltic at that time. The large increase in counts at Finnish bird migration observation points in spring 1986 followed the lowest adult male ratio ever recorded in the samples from Kummelskär, which corresponded to a production of 3.75 young per adult female that year (compared with an overall mean of 0.52 during 1975–1995). Unfortunately, good counts are not available from Estonia and Lithuania in all years at that time, so it is not possible to determine numbers there at that stage. The increase from a mid-winter total of *c.* 900 in 1990 to well over 6,300 in 1994 from Estonia–Lithuania combined is hard to explain. The increase was reflected in the increase in annual counts of migrants in the Gulf of Finland from just over 1,000 to 3,000 over the same period (Hario 1997a). Despite high breeding output in 1988 (1.98 young per adult female, based on Kummelskär ratios) and 1991 (1.48), this does not explain the 3- to 7-fold increases over four seasons, so the increase in Baltic numbers was more likely to result from immigration than increased reproductive output. Following the rapid increases in the early 1990s, significant declines in wintering numbers of Steller's Eiders in the Baltic Sea, have occurred, especially at the core areas along Estonian and Lithuanian coasts (Table 1). Numbers remained relatively stable in Finnish waters, where 70–300 wintered from the 1980s until the mid-1990s (Hario 1997b). A recently discovered new wintering site in the Åland Islands maintains current stock in Finland at the same level as during the last two decades. The observed decline in the Baltic countries is reflected also in numbers wintering in Norway over the same period. According to Kokhanov (1979), no more than 2,000 Steller's Eiders wintered along the coast of the Kola Peninsula in Russia in the early 1970s, yet helicopter surveys conducted in March 1994 (Nygård *et al.* 1995b) found more than 16,000 Steller's Eiders between Savikha Bay and Skorbeevskaya Bay (Murman coast) alone. Data from the 2003 survey showed that the majority of the observed 4,000 Steller's Eiders occurred along the coast of the Kola Peninsula in the White Sea, aggregating in areas bordering on Lumbovskiy Bay (Krasnov *et al.* 2004).

Potential reasons for the recent declines

Given the global conservation status of Steller's Eider, the observed population decline at the key European wintering sites is worrying, especially because the reasons for the decline are far from clear. A number of possible causes can be proposed in an attempt to understand the observed decline. In that context, many of the threats and limiting factors considered in the EU Species Action Plan for the species (Schäffer and Gallo-Orsi 2001) should be evaluated.

It can be postulated that the recent decline is related first to an emigration of birds from the known wintering areas into new, undiscovered, wintering areas. We consider that this is unlikely within regularly surveyed regions, since it is hard to imagine that thousands of spectacular and highly gregarious birds are overlooked along the shallow and generally well monitored coasts of the Baltic Sea or elsewhere in Norway. However, there are no consistent extensive data available about Steller's Eiders wintering in Russian waters along the Kola Peninsula or in the White Sea. Therefore, the possibility remains that birds have redistributed and increased their use of undetected wintering grounds in Russia. The inter-annual distribution patterns of Steller's Eiders wintering along the Kola Peninsula are very likely affected by meteorological conditions, the distribution of polynya systems and the location of the ice edge. In winters with harsh climatic conditions, extended ice cover could force ducks to leave the White Sea and move to the coastal zone of the Barents Sea (Murman coast). As a result, Steller's Eider numbers would increase in Murman coastal waters during such seasons. The numbers of sea ducks there in 1994 (Nygård *et al.* 1995b) could be explained by such a phenomenon. Of 11 birds fitted with satellite transmitters in the Varangerfjord area, Norway in April 2001, eight returned to the same wintering area in December the same year and three individuals remained along coasts of the Kola Peninsula (Petersen *et al.* 2006). Also, this study showed that individuals migrated directly from the moulting to the wintering areas, and not by a gradual movement along the Kola coast as previously suggested. Thus, although the possibilities of a general shift of wintering areas from Norway to Russia cannot be excluded, the results from satellite tagging did not support this suggestion to any great extent.

Secondly, changes in bird survey methods and uneven coverage might also contribute to an apparent decline in overall numbers. However, in the Baltic States the waterbird census effort has generally increased since the early 1990s, involving more observers, better able to assess the numbers of birds aggregated into tight flocks and using better optical equipment. In Norway, considerable effort has been invested in ensuring that consistent methods are adhered to in support of long-term waterbird monitoring. We therefore contend that changes in survey methods and effort do not contribute to the explanation for the decline in Steller's Eider, since this species now receives increased attention from both professional and amateur ornithologists.

Typically seaducks exhibit high adult survival rates (Coulson 1984, Cooke *et al.* 2000). Estimates obtained for annual survival rates of Steller's Eider in Alaska were 0.899 for females and 0.765 for males (Flint *et al.* 2000). We assume that Steller's Eiders show strong wintering-site fidelity, since they return to relatively restricted, traditionally used wintering areas, with few individuals observed outside the known sites. Also, fidelity to moulting locations in Alaska exceeded 95% (Flint *et al.* 2000). Hence, it could be suggested that a third possible reason for the observed decline of Steller's Eiders is increased adult mortality.

If we assume that the population was discrete (i.e. not subject to immigration/ emigration), we would expect the mean annual rate of decline not to exceed *c.* 20% during years with zero reproduction. The annual decline in numbers of Steller's Eiders wintering in Lithuania (where the greatest reductions in numbers have occurred) exceeded 40% in 2000 and 2002, even though a substantial number of first-winter birds was recorded in winter 2000 (based on the brown birds in samples and actual observations and collection of first-year birds). Large reductions along the Estonian coast were observed in 1997 and 2001 (31% and 35%, respectively), the overall pattern differing from that in Lithuania. Unfortunately, we lack independent assessments of annual adult survival, nor can we gather support for our assumptions that this wintering group represents a closed population. However, if these assumptions were met, one possible explanation would be that annual adult survival falls below the level necessary to sustain the population at current levels.

Through the annual cycle, Steller's Eiders might experience increased mortality on the non-breeding and breeding quarters. Since there is no reliable information about breeding grounds, staging and moulting areas, and migration routes of Steller's Eiders wintering in the Baltic Sea, we will not speculate further about processes outside the wintering range. Survival on the wintering grounds could be affected by a number of factors, of which four are evaluated here.

(i) Habitat loss and industrial development on wintering grounds: Dramatic changes in habitat quality have not been reported at any of the regular Steller's Eider wintering sites, and neither bird starvation nor mortality outbreaks have been observed. Decline of Steller's Eiders was not mirrored among other species of sea ducks sharing the same winter habitats.

(ii) Hunting: Steller's Eiders are not hunted in any of the countries supporting the key European wintering areas. Twelve Steller's Eider individuals have been X-rayed in Lithuania and all were found to be free from shotgun pellets (Žydelis and Skeiveris 1999).

(iii) Fishing activity: Commercial fisheries can threaten Steller's Eiders by causing direct mortality due to drowning in nets. They may also displace birds from favoured habitats due to disturbance. A study undertaken in 2000/2001 in Estonia showed that gillnets might cause moderate bycatch mortality among Steller's Eiders. Although only a few cases of drowned birds have been registered so far, the number of victims was estimated at 10–50 Steller's Eiders per winter, which corresponds to 3% of the wintering stock at the maximum. The commercial gillnet fishery has become very intensive in the wintering areas of Steller's Eider along the Lithuanian coast since the mid-1990s. Since 1997, up to 20 drowned Steller's Eiders have been obtained from fishermen each year and up to 10 individuals have been collected annually during beached bird surveys and identified as gillnet victims. The total number of Steller's Eiders drowning in fishing nets per winter season is unknown, but estimates suggest that it could be as high as 10% based on the total number of birds wintering in the area (R. Žydelis unpublished data). Bird disturbance caused by commercial gillnet fishery activities in shallow nearshore waters could, however, be considered as a factor limiting habitat availability to Steller's Eiders. Commercial fisheries are not considered to threaten wintering Steller's Eiders in Norwegian, Finnish or Swedish waters.

(iv) Contamination, pollution and encounters with potential contaminants: Marine oil pollution is a potential but major threat to Steller's Eiders wintering in Estonian and Lithuanian waters. No mass mortality of this species due to oiling has been recorded so far, although a few moderate oil spill incidents have occurred in the proximity of Steller's Eider wintering sites during recent years. No information is available on contaminant levels. Lead and other heavy metals have been found in unusually high concentrations in various Alaskan eider species and in Finnish Common Eiders (Franson *et al.* 2000, Stout *et al.* 2002).

In summary, it seems likely that decreased adult survival on the wintering grounds could be a contributory factor explaining the decline of this species in some areas, but increased winter mortality cannot be fully responsible for the observed rate and magnitude of the decline.

Steller's Eiders are known to have uneven reproductive success in different years and their successful reproduction typically corresponds with seasons of high lemming numbers in the northern tundras (Solovieva *et al.* 1998, Quakenbush *et al.* 2004). Hario (1997a) illustrated a 3-year cycle of successful reproduction in the species based on observations of migrating birds along the coast of Finland in the springs of 1976–1995. It could therefore be suggested fourthly that there has been a recent reduction in reproductive success (perhaps as a result of the breakdown in the previously observed 3-year successful reproductive cycles) which has caused population decline. There was no long-term trend in the Finnish data based on the imputed production figures, which averaged 20.7% over the period 1975–1995, giving no clear reason for the original increase, nor the recent decline. The mean values for shorter runs of data presented in Figure 2 were 14.3% (Lithuania), 32% (Estonia) and 11.9% (Norway), but note that these estimates are derived from different seasons. Furthermore, we advise caution in trying to interpret long-term trends and differences in regional age ratios, given the various assumptions made in their calculations, the differences in methods and observers used in their compilation and the likely differences between different areas.

The Norwegian and Lithuanian data from very recent years suggest that this element of the population, exhibiting such low proportions of young, may not be self-supporting, based on adult survival estimates from Alaska. However, despite the high variability in annual reproductive output typical for the species, there is no clear suggestion that the poor reproductive output of recent years has been responsible for the present decrease in numbers. During the period 1992–2002, only the summer of 1999 could be characterized as a moderately successful breeding season and there were no years of high production as in 1979, 1985, 1988 and 1991. Projected numbers of juveniles among wintering birds correlated well with annual change of species numbers in the Baltic Sea, but no such relationship was found with birds wintering in Norway. Without knowledge about the relatedness of birds wintering in the Baltic and the Barents Sea, it is hard to speculate whether this indicates the presence of discrete subpopulations or strongly geographically skewed bird sex and age ratios.

There is currently no support for the suggestion that the numbers of wintering Steller's Eiders at the outermost parts of the wintering range (i.e. those in Norway and the Baltic) are related fifthly to the extent of ice in areas closer to the breeding areas. The available time series covering the extent of sea ice in the Barents Sea is unfortunately short, and data are lacking for the period of most rapid increase in Steller's Eider numbers during the late 1980s and early 1990s. However, there is sufficient variability in the available data (e.g. the huge difference between ice cover in the White Sea and Kola coasts in January 2001 and 2002) to consider that this has not been a major factor in recent years. Based on the maximum extent of ice in 2002, numbers continued to fall in the Baltic, although they stabilized in Norway. Equally, in 2001 when there was no sea ice at all along the northern Kola coast and much of the White Sea was also clear, numbers were similar to 2002 in Norway and numbers in the Baltic were not abnormally low. This would have been expected to be a season when conditions favoured very large numbers of Steller's Eider remaining in these Russian wintering areas.

The correlation between the winter NAO index and the change in numbers from one year to the next is intriguing and might indicate a shift from Norwegian (and Baltic) wintering areas to Russian wintering areas closer to the breeding grounds. At present we lack data from potential Russian wintering areas that could verify this pattern. However, since such correlations were found only for the Norwegian data and not the Baltic data, it may be suggested that the number of individuals wintering in the Baltic is dependent on the numbers (not) wintering in Norway since this site is closer to the breeding grounds. However, if that were the case, numbers in the Baltic should have become larger if the wintering conditions in Norway have deteriorated due to climate change. The patterns of decline in the different Baltic wintering areas could be taken as an indication of this since the southernmost wintering areas showed the earliest signs of decline. This is, however, not enough to explain the dramatic population decline that has been observed because this would have to be linked to either reduced recruitment or increased adult mortality, parameters which we lack for most of the time period concerned.

Concluding remarks

After a period of modest but rapid increase and favourable conservation status up to the mid-1990s in Europe, numbers of wintering Steller's Eiders have fallen by 13% per annum in the Baltic between 1994 until 2003 and by 8% per annum during 1985 to 2003 in Norway. The European wintering population was estimated to be between

30,000 and 50,000 individuals during 1990–1995, of which between 30% and 50% of the population wintered in Russian waters along the Kola coast (Nygård *et al.* 1995a). The current numbers of Steller's Eiders wintering along the entire Kola coast remains unknown; however, available data from the monitored coastal stretch in that region suggest a decline of similar magnitude. If we assume a decline of the same order along the entire Kola coasts as at the Norwegian and Baltic wintering sites (about 65% since the decline started in all areas), the current (2004) European (wintering) population could be as low as 10,000–15,000 individuals. However, it might also be argued that the decline observed in Norway and the Baltic Sea is caused by a gradual shift in wintering areas so that more birds now reside in Russian wintering areas, which are closer to the breeding grounds. As the Russian wintering grounds have not been fully surveyed during recent years we cannot exclude this possibility. Therefore, we strongly recommend that new comprehensive surveys along the entire Kola coast should be conducted to confirm the numbers and distribution of the species there.

If declines in Norway and the Baltic are indeed reflected in numbers using the Kola coasts, this would make the Western Palearctic population of Steller's Eider qualify for IUCN Endangered Status, under criterion 4 (''A … suspected population size reduction of 50% over any 10 year … period, … where the reduction or its causes … may not be understood''; IUCN 2001). These findings confirm the need for improved monitoring of the Steller's Eider population wintering in Europe. There is a particularly urgent need to conduct comprehensive surveys in Russian wintering areas to see whether the same changes in numbers and distribution have occurred there. Linkages between Steller's Eider population segments wintering in the Barents Sea and the Baltic Sea are yet to be determined, which could be done employing genetic or stable isotope analysis methods. In demographic terms, it is also important to monitor reproductive output better and to initiate monitoring of adult survival (e.g. by extensive mark–recapture schemes; Flint *et al.* 2000). It is essential to track birds throughout their annual cycle and to fill knowledge gaps about areas and timing of migration, staging, nesting and moulting. Satellite tagging and following of Steller's Eiders through their annual cycle has already been started in Norway (Petersen *et al.* 2006). Data about bird feeding ecology, habitat use, body condition and subsequent reproduction and survival have to be linked with each other to reveal mechanisms important for viability of the population. Such knowledge is vital if we are to be able to understand the precise causes of the decline, in order to undertake effective conservation actions to safeguard Steller's Eider in Europe.

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