Assessment of sustainable management of staging waterbirds in the Danish Wadden Sea

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Abstract

A large number of wildlife reserves have been established throughout Europe to protect migratory waterbirds. However, there has been little evaluation of whether they are being managed sustainably. The Danish Wadden Sea became a wildlife reserve in 1979 to manage hunting and public access to the site. This paper evaluates whether waterbirds are being managed in a sustainable manner, using the definition that bird numbers over the years should be either: 1) regulated by factors independent of human activity, or 2) be at least stable. The hypothesis was tested for 17 waterbird species, using 194 counts made from aircraft between 1980 and 2000 inclusive. The TrendSpotter programme was used to examine trends in numbers. Regression analysis with autoregressive error correction was used to assess the association between four factors (population size indices, population breeding success, plant primary production and biomass of Blue Mussel *Mytilus edulis*) thought to be affecting the numbers of waterbirds using the site each year. The results showed increasing trends in spring for Brent Goose *Branta bernicla*, Grey Plover *Pluvialis squatarola* and Bar-tailed Godwit *Limosa lapponica*, whereas numbers of Shelduck *Tadorna tadorna*, Pintail *Anas acuta*, Oystercatcher *Haematopus ostralegus*, Grey Plover, Curlew *Numenius arquata* and Common Gull *Larus canus* increased in autumn. Numbers of Brent Goose, Wigeon *Anas penelope*, Avocet *Recurvirostra avocetta*, Dunlin *Calidris alpina*, Bar-tailed Godwit, Black-headed Gull *Larus ridibundus* and Herring Gull *L. argentatus* were all stable during autumn, as was Eider *Somateria mollissima* during winter. Mallard *Anas platyrhynchos* decreased during autumn, and the trends were uncertain for Teal *Anas crecca* and Knot *Calidris canutus*. Numbers of Brent Goose, Shelduck, Wigeon, Teal, Mallard and Avocet (during autumn) and Grey Plover (during spring) in the Danish Wadden Sea were correlated either with the population index, the breeding index or the primary production index. Thus numbers of seven species appear to be influenced by factors other than human activity in the Danish Wadden Sea, and the trends of 14 species were either stable or increasing. Moreover, for the five quarry species considered, numbers in the Danish Wadden Sea were either correlated with factors outside the area (Mallard, Pintail, Wigeon and Teal) or were stable despite a decrease in the total population size (Eider). Thus it is concluded that the wildlife reserve in the Danish Wadden Sea has been managed in a sustainable manner.

Key words: conservation, sustainable management, Wadden Sea, waterbirds, wildlife reserve.

During the non-breeding season large numbers of waterbirds either pass through Europe or winter there. Many gather in large and relatively undisturbed wetland areas; however, most of these areas are also subject to recreational activities such as hunting, sailing and walking. Several studies have shown that hunting affects waterbird distribution and behaviour (reviews in Bell & Owen 1990; Fox & Madsen 1997), and that compared to other recreational activities it causes major disturbance to waterfowl (Madsen 1998). Migratory waterbirds and the wetland habitat that supports them are protected in European countries under international conventions (e.g. the Ramsar Convention) and legislation (e.g. the EU Directive on the Conservation of Wild Birds). The concept of 'sustainable use' is fundamental to these conventions and legal instruments. Since hunting is considered to be one of the main factors affecting waterbirds, wildlife reserves with non-shooting zones have been established across Europe (Moser *et al.* 1993).

Despite the establishment of wildlife reserves in recent decades, relatively few have been assessed to determine whether their management conforms to definitions of sustainable management (Madsen 1998). The aim of this study was to assess whether management of the Danish Wadden Sea Wildlife Reserve has been sustainable. This has not previously been addressed for migratory birds, which use the site for staging (Elmberg *et al.* 2006). Management of waterbirds is defined as being sustainable: 1) if human activity does not limit the waterbirds' ability to use the available food resources (Madsen *et al.* 1998), and 2) using the European Community (EC) Habitats Directive definition of 'favourable' conservation status, if the local population is stable or increasing in number and the habitat is sufficiently large to enable the population to continue within the locality on a long-term basis (Pihl *et al.* 2001a). This definition of 'favourable' conservation status was interpreted in this study by stating that the numbers of a species should be stable over a period of at least 20 years. Sustainable management on a local level implies an understanding of the interactions between waterbirds, their resources and human use of the site, from which the carrying capacity of the area is determined (van Eerden 1997). However, since it is time consuming to undertake carrying-capacity studies covering several species in large wetland areas, and therefore to identify whether carrying capacity has been reached, the definition put forward by Moser (1988) is used: 1) if the numbers of birds using a wetland site level off whereas those of the population continue to increase, it is concluded that the numbers at the site have reached carrying capacity, and 2) if both the numbers of birds using a site and the population size are increasing or are stable, the carrying capacity of the site has not been reached.

This study focuses on the management of the Danish Wadden Sea, which became a wildlife reserve in 1979 (Fig. 1a). The area is designated under the Ramsar Convention and as a Special Protection Area under the EU Directive on the Conservation of Wild Birds; management of the waterbird species on the reserve therefore should be sustainable. To examine this aim, the definition of sustainable management was adapted as follows: that bird numbers over the years should be regulated by factors independent of human activities. These factors can operate both outside the wildlife reserve (e.g. size of flyway population and breeding success) and inside the wildlife reserve (e.g. annual primary production of vegetation). Human activities take place primarily inside the reserve, affecting bird distribution either directly (e.g. hunting activities and other outdoor recreational activities) and/or indirectly (e.g. through shell fisheries and their effect on biomass and distribution of Blue Mussel *Mytilus edulis*, which are regulated by a yearly fishing quota) (Kristensen & Borgstrøm 2006). If the management of the wildlife reserve allows bird numbers to vary from year to year in relation to factors independent of human activities in the reserve, it can be concluded that the management is sustainable.

Study Area

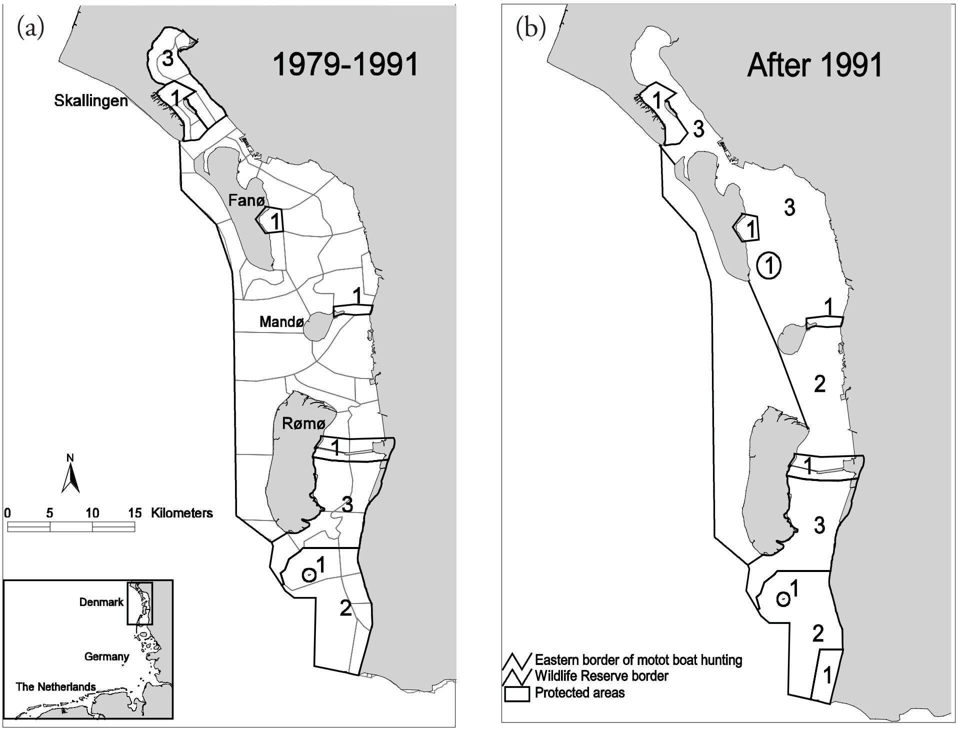
The Danish Wadden Sea constitutes the northern part of the Wadden Sea and covers an area of 850 km^2. About 60% of the area is intertidal, with a tidal amplitude of c. 1.8 m. A peninsula (Skallingen) and three major islands (Fanø, Mandø and Rømø) border the area to the west and separate it from the North Sea. Salt marshes are located along the mainland coast, on the east side of the islands and on the Skallingen peninsula (see Wolff 1983 for further details). Following its designation as a wildlife reserve in 1979, hunting and public access in the Danish Wadden Sea was controlled (Fig. 1a). In 1992, the protection of waterbirds was improved within the wildlife reserve by extending hunting-free areas and further reducing public access (Fig. 1b) (Laursen *et al.* 1997a). From 1998, all hunting in the wildlife reserve was prohibited, except on some small areas of saltmarsh along the mainland sea wall (not shown on map), and hunting of seaducks west of the islands. Independent of the wildlife regulation, the Blue Mussel fishery was regulated from 1990 (Jong *et al.* 1999). After 1993 three large areas were closed to the mussel fishery (north of Fanø, between Mandø and Rømø, and south of Rømø) and an annual quota was imposed.

Methods

Count method

A total of 194 waterbird counts were carried out within the Danish Wadden Sea from an aircraft (a Cessna 172 or Cessna 182). This counting method gives a good overview of bird numbers and distribution within a short timeframe (see below). The surveys were undertaken during the period July 1980 – December 2000. The counts were not distributed evenly through the year during the study period. From July 1980 to November 1990 a count was made each month, but from January 1991 to December 2000 the number of counts was reduced to 4–10 per year, with most counts being made in autumn and winter.

The count procedure followed the methods described for determining a 'total count' of waterbirds from aircraft (Pihl & Frikke 1992), in which the route was



Figures 1a and 1b. Maps of the Danish Wadden Sea, showing wildlife reserve areas subject to regulations on shooting and public access in, (a) 1979–1991, and (b) after 1991. Figures on the maps indicate: 1) No public access (and no shooting), 2) No shooting and 3) No hunting from motorboats. From 1998 onwards, all hunting in the wildlife reserve was prohibited except for shooting to the west of the line connecting the islands and on some small areas of saltmarsh along the mainland sea wall (not indicated in the map). To the east the wildlife reserve border follows the sea walls or, where no sea wall is present, the highest daily water line. The western border is indicated on the map. On Fig. 1a the count subsections used for the aerial surveys are also shown. The insert shows the entire Wadden Sea, which is shared by The Netherlands, Germany and Denmark; the location of the study area is indicated.

chosen so that each subsection (including all high-tide roosts and all assemblages of waterbirds) was covered by the observers. During the aerial surveys, two experienced observers (one on either side of the aircraft) identified the species of all waterbirds seen and estimated the number of each species. All observations were assigned to one of 56 geographically defined count subsections. The aircraft flew at a speed of about 100 km/h and an altitude of about 60 m. The surveys were carried out at high tide, starting 2.5 h before maximum water level, and took about 3–4 h to complete. The same route was followed during each survey and the same trained observers (eight persons) were used during the entire study period. The surveys were conducted only on days when weather conditions were good; for instance, visibility of more than 5 km, wind speed less than 25 km/h and no rain. If a survey was abandoned due to adverse weather conditions, it was resumed within one or two days. If poor weather conditions continued for more than two days, a new survey was initiated.

Species selection

A total of 17 waterbird species were included in the analysis. For 13 of these species, the accuracy of counts from aircraft has been assessed by comparing the results with those from ground counts; the difference in mean numbers recorded was < 30% (Laursen *et al.* in press). Most of the 17 species were either physically large, exhibited characteristic behaviour or occurred in large numbers, which facilitated identification. However, Curlew *Numenius arquata*, Pintail *Anas acuta*, Avocet *Recurvirosta avocetta* and Knot *Calidris canutus* were also included as their numbers were relatively high.

Trend analyses

Trends in numbers for each species were calculated using the statistical time series TrendSpotter programme (Visser 2004). The programme classifies the trends in numbers according to one of the following classes and symbols: stable (0), where the current year's figure (± 95 confidence limits) is within the previous year's figure (± 5%); moderate increase (+), where the current year's figure (± 95 confidence limits) is higher than the previous year's figure; strong increase (++), where the current year's figure (± 95 confidence limits) is higher than the previous year's figure by at least + 5%; moderate decrease (-), where the current year's figure (± 95 confidence limits) is lower than the previous year's figure; and strong decrease (- -), where the current year's figure (± 95 confidence limits) is lower that the previous year's figure by at least 5%. Uncertain (?), indicates that the variance of the current year's figure overlaps the previous year's figure (± 5%). Additionally, the programme calculated whether numbers counted in 2000 differed significantly from those counted in 1980.

The data used in the trend analyses were the average numbers counted during the summer, autumn or winter period each year, which was when most species occurred in maximum numbers on the reserve. These periods are shown in Table 1. For arctic-breeding species, whose peak counts all occurred in spring (e.g. Brent Goose

Branta bernicla, Grey Plover *Pluvialis squatarola*, Knot and Bar-tailed Godwit *Limosa lapponica*) additional trend analyses were carried out, but only up to 1995 or 1996 due to a lack of counts in subsequent years. Missing values were inserted in two cases using counts from adjacent months, if these counts were made within three days of the month in question.

Regression analysis was used to test the association between factors thought to be affecting the number of waterbirds in the Danish Wadden Sea and the annual mean number of each species in summer, autumn, winter or spring. The regression model was augmented by an autoregressive model, using the AUTOREG procedure in SAS, to control for autocorrelation in the data. Due to the relatively low number of observations (maximum n = 21 years) only four covariates were included in the analysis. These were selected on the basis that covariates should include information on population demography each year, be likely to account for annual variation in the numbers recorded, and that data for the variables selected should be easily accessible. The four variables used therefore were: the annual population size indices, the annual breeding success indices, an index for primary plant production (used for Brent Goose, Shelduck *Tadorna tadorna* and the dabbling duck species), and the yearly biomass of Blue Mussels (used for Oystercatcher *Haematopus ostralegus* and Eider *Somateria mollissima*) in the Danish Wadden Sea. Population indices up to 1998 were obtained from the International Waterfowl Census (IWC) in Northwest Europe (Delany *et al.* 1999; Ebbinge *et al.* 2002). For 1997–1999, provisional population indices have been calculated from Gilissen *et al.* (2002). Because no such annual population indices are available for waders and gulls, the midwinter Wadden Sea population index has been substituted for these species (Blew & Südbeck 2005). This index represents waders and gulls breeding throughout a large part of Northern Europe, and for some species even Siberia or Greenland/Canada, and therefore probably reflects numbers in the overall flyway population. Since the birds in the Wadden Sea are influenced by harsh winters (harsh winters being defined as those in which the mean temperature was lower than -3 °C during December, January and February, in combination with more than 15 'ice days' during which the mean temperature was below 0 °C; Blew & Südbeck 2005), such winters were excluded from the analysis.

The annual breeding success index (number of juveniles/adult females) was generated from wing surveys of wildfowl shot in Denmark during the 1982–2000 hunting season (dabbling ducks: 1 September – 31 December; diving ducks: 1 October – 28/29 February; Clausager 2002). No such information was available for Shelduck, waders and gulls, which were not included in this analysis. The primary production index, used as a measure of aquatic vegetation growth, was calculated as the sum of temperature multiplied by hours of insolation on days without clouds (i.e. radiant energy from the sun as it strikes the ground) in July and August. Sand-Jensen (1975) found a correlation between the biomass of Eelgrass (*Zostera* sp.) with insolation and temperature during summer and early autumn, and Kahlert *et al.* (2000) demonstrated a similar correlation for

Table 1. Trends calculated for 17 waterbird species in the Danish Wadden Sea during summer, autumn, winter and spring (for the period indicated) 1980–2000. *n* = number of years. Significance levels for the TrendSpotter analyses are shown.

Species	Period	Description	Trend	*P*	*n*
Wildfowl					
Brent Goose	1 Oct–15 Nov	Stable	0	n.s.	19
	16 Apr–15 May	Moderate increase	+	< 0.05	14
Shelduck	1 Oct–30 Nov	Moderate increase	+	< 0.05	21
Wigeon	16 Sep–15 Nov	Stable	0	n.s.	20
Teal	1 Oct–15 Nov	Uncertain	?	n.s.	19
Mallard	1 Nov–31 Dec	Moderate decline	-	< 0.05	20
Pintail	16 Oct–30 Nov	Strong increase	++	< 0.01	21
Eider	1 Dec–31 Jan	Stable	0	n.s.	20
Waders					
Oystercatcher	16 Oct–15 Dec	Moderate increase	+	< 0.05	21
Avocet	16 Jul–15 Sep	Stable	0	n.s.	21
Grey Plover	1 Aug–31 Aug	Strong increase	++	< 0.01	21
	1 May–31 May	Moderate increase	+	< 0.05	14
Knot	1 Apr–31 May	Uncertain	?	n.s.	17
Dunlin	1 Aug–31 Oct	Stable	0	n.s.	20
Bar-tailed Godwit	1 Aug–31 Aug	Stable	0	n.s.	21
	1 May–31 May	Moderate increase	+	< 0.05	14
Curlew	1 Aug–30 Nov	Strong increase	++	< 0.01	21
Gulls					
Black-headed Gull	16 July–30 Sep	Stable	0	n.s.	21
Common Gull	16 July–30 Sep	Moderate increase	+	< 0.05	21
Herring Gull	16 July–31 Dec	Stable	0	n.s.	21

mixed vegetation of *Ruppia* spp., pondweeds *Potamogeton* and *Zannichellia* spp. and stoneworts *Chara* spp. in shallow salt water.

Change in management regime

The wildlife management regime was improved for waterbirds in 1992 – in particular, non-shooting zones, including marine areas where Eider could formerly be hunted from motorboats (Fig. 1b), were enlarged. Therefore the quarry species (dabbling ducks) and Curlew (protected from hunting in Denmark in 1994) were analysed for significant changes in numbers between the two periods (1980–1991 and 1992–2000) by use of an unpaired *t*-test (data log transformed). The annual number of Eider was analysed in relation to Blue Mussel biomass after 1991, assuming that the birds could range freely in search of one of their favourite food items once hunting from motorboats had ceased.

Results

Trends

Trends calculated by the TrendSpotter programme based on yearly numbers in the Danish Wadden Sea from 1980 to 2000 are presented for seven species of waterfowl (Fig. 2), seven species of waders (Fig. 3) and three species of gulls (Fig. 4). Brent Goose, Grey Plover and Bar-tailed Godwit *Limosa lapponica* showed moderate increases in spring (Table 1), while Shelduck, Pintail, Oystercatcher, Grey Plover, Curlew and Common Gull *Larus fuscus* all showed moderate or strong increases in summer or autumn (Table 1). Mallard *Anas platyrhynchos* showed a moderate decline during autumn, and Brent Goose, Wigeon *Anas penelope,* Avocet, Dunlin *Calidris alpina*, Bar-tailed Godwit, Black-headed Gull *Larus ridibundus* and Herring Gull *L. argentatus* were all stable during summer or autumn, as was Eider during winter. The trends for Teal *Anas crecca* and Knot were uncertain (Table 1).

Factors affecting numbers

There was a positive correlation between Brent Goose and Shelduck numbers in autumn and the index of plant primary production (temperature x insolation; Table 2). Shelduck were also positively correlated with the flyway population index, and in total 61% of the variation was explained by the two parameters (Table 2). Mallard and Wigeon were positively correlated with the flyway population index and Avocet and Grey Plover with the Wadden Sea population numbers. Teal were positively correlated with both the breeding success index (Fig. 5) and the flyway population size index, and together these parameters explained 86% of the variation. Although not statistically significant, Pintail showed an indication of being positively correlated with the breeding success index, Knot with the Wadden Sea population numbers and Oystercatcher with the Blue Mussel biomass, but negatively correlated with the Wadden Sea population index (Table 2).

Pintail numbers during autumn were not statistically significantly correlated with the parameters tested. However, on dividing the annual Pintail numbers into three groups (high, medium and low numbers) and

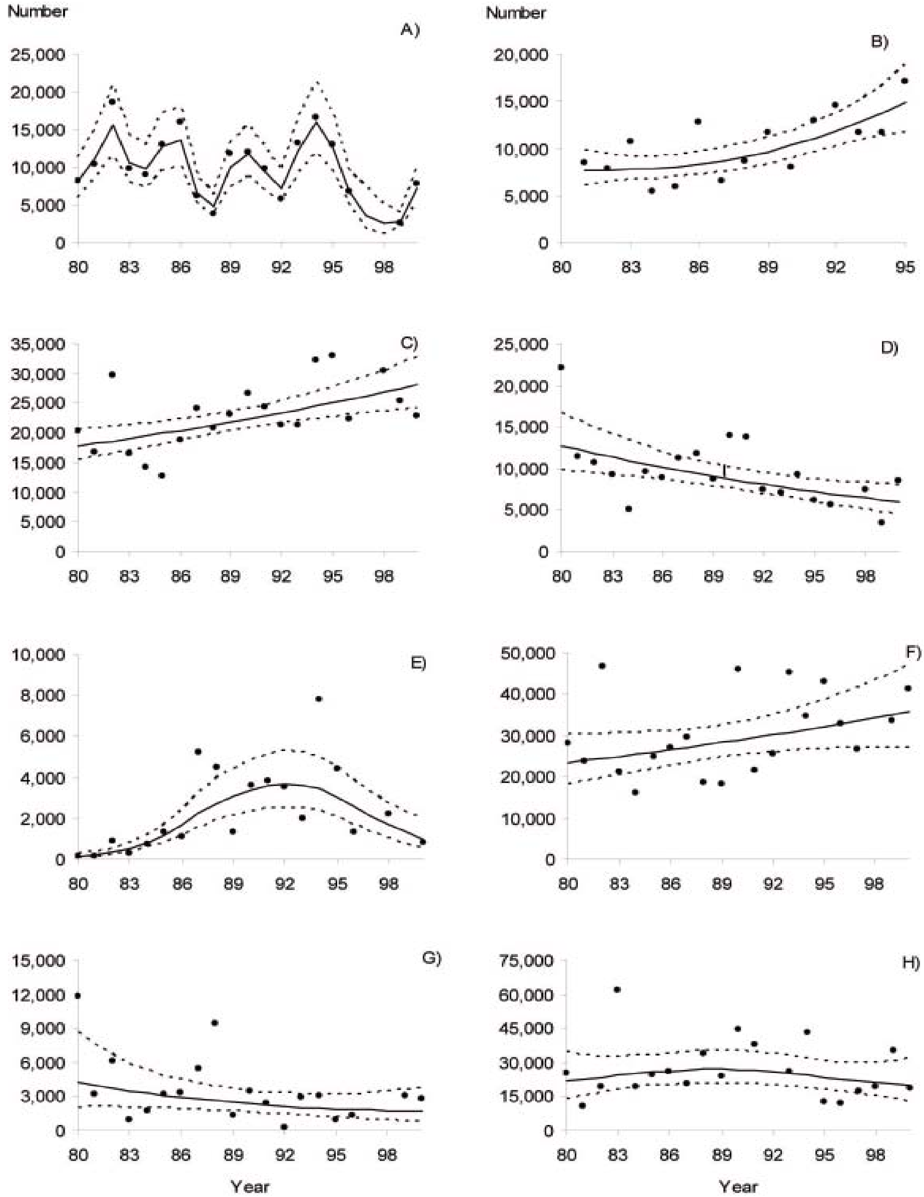
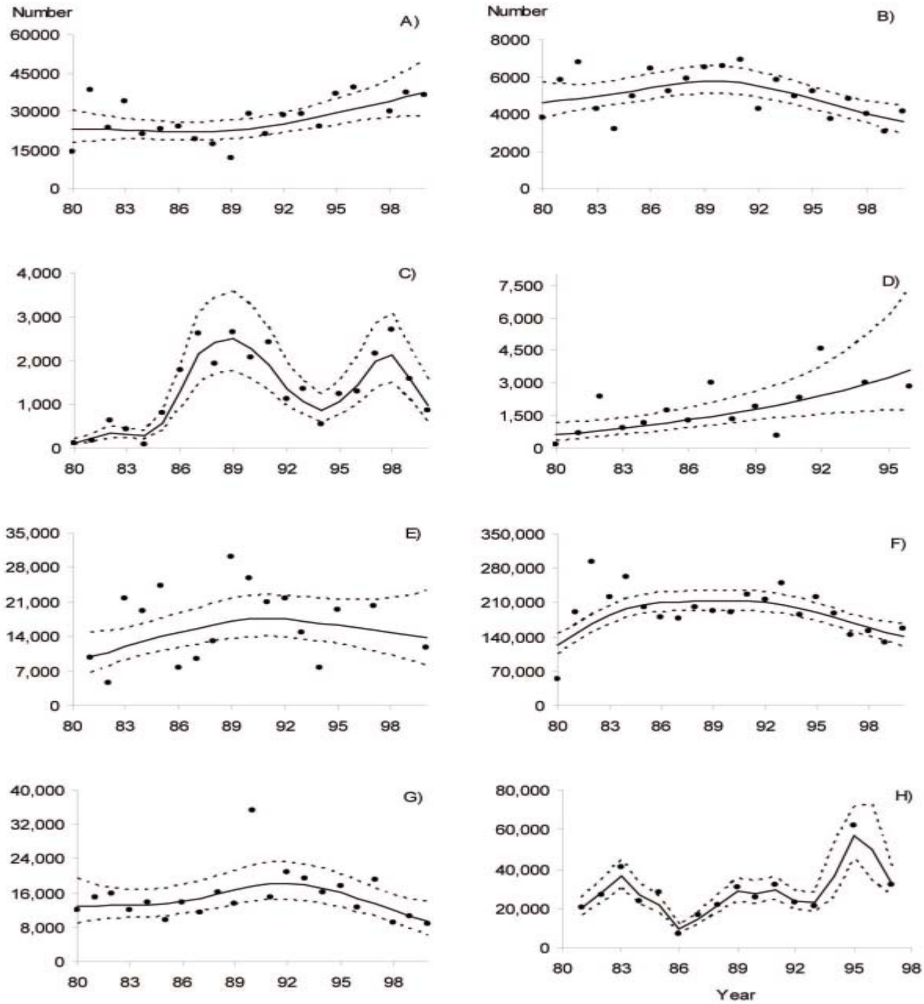


Figure 2. Mean numbers recorded each year, during periods of peak occurrence, for seven species of waterfowl counted during aerial surveys of the Danish Wadden Sea, 1980–2000. A: Brent Goose, autumn; B: Brent Goose, spring; C: Shelduck, autumn; D: Mallard, autumn; E: Pintail, autumn; F: Wigeon, autumn; G: Teal, autumn; and H: Eider, winter.



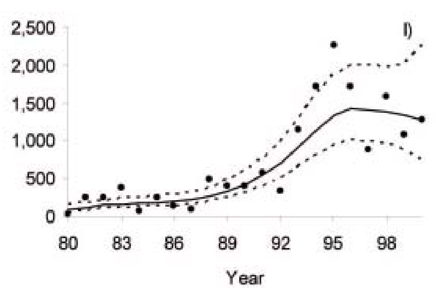


Figure 3. Mean numbers recorded, during periods of peak occurrence, for seven wader species counted during aerial surveys of the Danish Wadden Sea, 1980–2000. A: Oystercatcher, autumn; B: Avocet, autumn; C: Grey Plover, autumn; D: Grey Plover, spring; E: Knot, spring; F: Dunlin, autumn; G: Bar-tailed Godwit, autumn; H: Bar-tailed Godwit, spring; and I: Curlew, autumn.

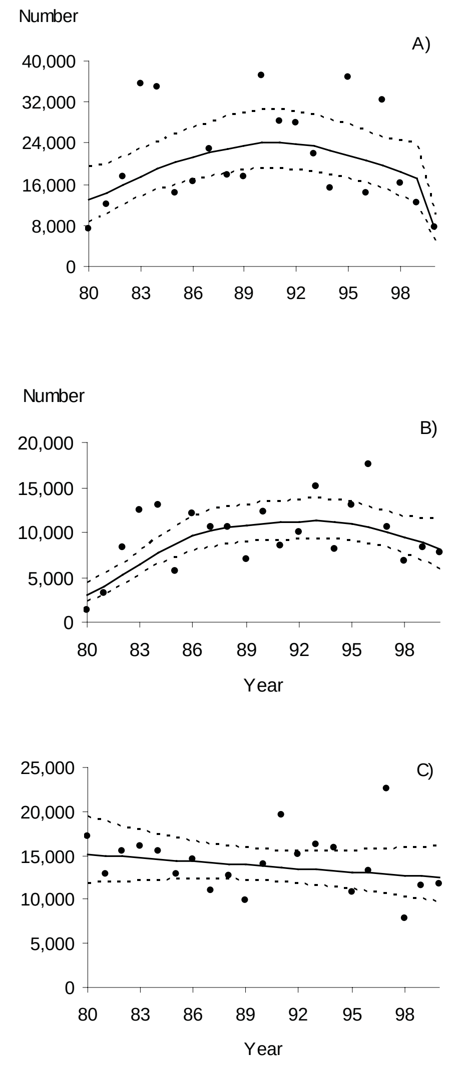


Figure 4. Mean numbers recorded, during periods of peak occurrence, for three gull species counted during aerial surveys of the Danish Wadden Sea, 1980–2000. A: Black-headed Gull, autumn; B: Common Gull, autumn; and C: Herring Gull, autumn.

testing the corresponding annual breeding index of the group with high numbers against the group with low numbers, there is a significantly higher breeding index in the first group compared to the second group (years with high Pintail numbers, average breeding index = 10.5, and years with low Pintail numbers, breeding index = 6.3; Mann-Whitney $U = 2$, $n_1 = n_2 = 5$, $P < 0.05$).

Change in management regime in 1992

Of the species examined only Curlew showed a significant increase in numbers from 1980-1991 (average $n = 273$ individuals) to 1992–2000 (average $n = 1,325$ individuals). The difference is statistically significant ($t = 5.5$, $n_1 = 11$, $n_2 = 9$, $P < 0.001$). After 1991 (when hunting from motorboats was not permitted) the Eider numbers were significantly correlated with the Blue Mussel biomass (estimate value = 244.07, $R^2 = 0.601$, d.f. = 6, $P < 0.05$)

Discussion

Waterfowl

The number of Brent Geese in the Danish Wadden Sea in autumn increased from 3,000 in 1966 (Laursen & Frikke 1984) to about 12,000 individuals recorded during the course of this study, which corresponds with an increase in the flyway population as a whole up to 1993, after which numbers levelled off (Ebbinge *et al.* 1999). The increase in population numbers up to 1993 was not reflected in the Danish Wadden

Table 2. Relative importance in autumn and spring of the plant primary production index (temperature x insolation), breeding success index, population size index (or size of Wadden Sea population) and Blue Mussel biomass for predicting the numbers of 17 waterbird species in the Danish Wadden Sea. A regression analysis with control for autocorrelation in the data was used. [x] indicates 0.1 < P > 0.05; not statistically significant.

Species	Season	Independent variable	Parameter estimate	Total R^2	d.f.	*P*
Brent Goose	Autumn	Primary production index	0.596	0.317	12	< 0.05
Shelduck	Autumn	Primary production index	1.010	0.609	13	< 0.01
		Population size index	46.650			< 0.05
Wigeon	Autumn	Population size index	70.650	0.518	9	< 0.05
Teal	Autumn	Breeding success index	1623	0.859	11	< 0.001
		Population size index	11.200			< 0.05
Mallard	Autumn	Population size index	24.800	0.444	12	< 0.05
Pintail	Autumn	Breeding success index	280.347	0.386	9	< 0.1[x]
Oystercatcher	Autumn	Blue Mussel biomass	159.796	0.392	9	< 0.1[x]
		Wadden Sea number	-0.032			< 0.1[x]
Avocet	Autumn	Wadden Sea number	1.456	0.486	10	< 0.05
Grey Plover	Spring	Wadden Sea number	0.107	0.614	9	< 0.05
Knot	Spring	Wadden Sea number	0.065	0.203	14	< 0.1[x]

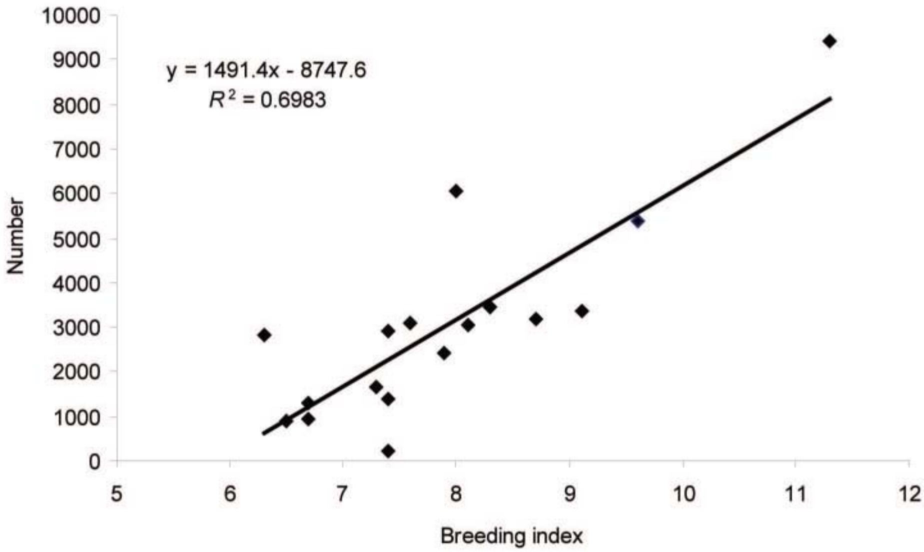


Figure 5. Mean number of Teal during autumn in the Danish Wadden Sea in relation to breeding index (number of juveniles/adult females). The trend is shown.

Sea during autumn, however, as numbers were considered to be stable during the study period. Using Moser's definition (Moser 1988), this suggests that the carrying capacity of the Danish Wadden Sea was reached before or soon after 1980. During spring Brent Goose numbers increased in the Danish Wadden, however the numbers were not correlated with the increasing flyway population.

Shelduck numbers increased from c. 18,000 individuals during 1965–1973 (Joensen 1974) to the 30,000 individuals found in this study. The Northwest Europe flyway population showed an increase from 1974 to 1987, after which it levelled off (Delany *et al.* 1999). In contrast, the number of Shelduck in the Danish Wadden Sea continued to increase up to 1995. Thus the Danish Wadden Sea count probably reflects the number of Shelduck in the flyway population, albeit that the increase at the site continued for several years after the population stabilised. The analyses also show a positive correlation between the index for primary production and the numbers of Shelduck present. This is surprising since the Shelduck's main source of food is small molluscs *Mollusca* spp. and crustaceans *Malacostraca* spp. (Smit & Wolff 1983). However, the association between Shelduck numbers and primary production could be indirect; for instance, a high level of primary production may increase the density of molluscs and crustaceans and consequently the number of Shelduck at the site.

More than 20,000 Mallard were counted annually from 1965 to 1973 (Joensen 1974), about twice the number recorded in this study, indicating a long period of decline. This may be partly attributable to a population decline, since the international midwinter counts indicate a decrease in Mallard numbers after 1983 (Monval & Pirot 1989; Delany *et al.* 1999). The results described here confirm that there has been a significant decrease in Mallard numbers counted in the Danish Wadden Sea since 1979 and that this correlates with the international midwinter counts, indicating that the number of Mallard in the Danish Wadden Sea is partly affected by factors outside the area.

About 3,000 Pintail were recorded from 1965 to 1973 (Joensen 1974), while in this study numbers varied between 5,000 and 8,000 individuals. The numbers in the Danish Wadden Sea were high from 1987 to 1995 and did not follow the trend of the Northwest Europe flyway population (Delany *et al.* 1999). The high numbers recorded from 1987 to 1995 seem to be influenced by the annual breeding success. In the Schleswig-Holstein Wadden Sea the number of Pintail was also high in the first half of the 1990s (Günther & Rösner 2000).

On average, 37,000 Wigeon occurred annually in the Danish Wadden Sea from 1965 to 1973 (Joensen 1974); this decreased to 23,000 individuals from 1980 to 1992 (except for the high numbers in 1982) and increased in subsequent years. This change in numbers in the Danish Wadden Sea reflected the trend in the Northwest Europe flyway population.

Higher numbers of Teal were counted in the Danish Wadden Sea from 1965 to 1973 than during the present study, although in both periods the annual fluctuations were high (Joensen 1974). The overall trend in the Northwest Europe flyway population also showed year-on-year variations but increased from 1987 to 1990, after which it levelled off (Delany *et al.* 1999). The flyway population index was reflected in the figures from the Danish Wadden Sea (Table 2), and the number of Teal was also highly correlated with the yearly breeding index (Fig. 5), which together explained 86% of the variation in the annual autumn numbers.

Approximately 48,000 Eiders were recorded in the Danish Wadden Sea from 1965 to 1973 (Joensen 1974), about 75% more than were counted in this study. No flyway population index exists for Eider. However, aerial surveys and counts of breeding birds indicate that the Eider population has almost halved since the middle of the 1990s (Laursen *et al.* 1997b; Pihl *et al.* 2001b; Desholm *et al.* 2003). Despite this, Eider numbers in the Danish Wadden Sea have been stable since 1980; furthermore, since 1992, when the wildlife regulations were improved by forbidding hunting from motorboats between the mainland coast and the islands, Eider numbers have been correlated with the Blue Mussel biomass. This indicates that the distribution of Eider related to the quantity of Blue Mussels, which are among their preferred food items. When the whole period (1980–2000) is taken into consideration, a correlation is not found between Eider and Blue Mussels, suggesting that before 1991 Eider had been displaced by hunting from motorboats.

Waders

The Oystercatcher population was considered by Wetlands International (2002) to be increasing. Midwinter numbers of Oystercatchers in Great Britain and the Wadden Sea have either increased or remained stable, but since the beginning of the 1990s the overall number has decreased in both areas (Pollitt *et al.* 2003; Blew & Südbeck 2005). Compared to this, it was found that Oystercatcher numbers in the Danish Wadden Sea had increased. The results also indicated a correlation both with Blue Mussel biomass and with the numbers in the Wadden Sea (although this was not statistically significant).

Avocet numbers were stable in the Danish Wadden Sea during the course of this study, while the number of birds wintering in Great Britain has shown a clear increase since the beginning of the 1980s (Wetlands International 2002; Pollitt *et al.* 2003). Avocet numbers in the Danish Wadden Sea were correlated with the Wadden Sea population index (Table 2). However, a decline in Avocet numbers has occurred in the Danish Wadden Sea since 1991, and this decline was also found in both midwinter and autumn counts there (Blew & Südbeck 2005).

The east Atlantic flyway population of Grey Plover has increased in recent years (Wetlands International 2002). The results of surveys in Great Britain since the late 1960s and in the Wadden Sea since 1980 confirm this trend (Pollitt *et al.* 2003, Blew & Südbeck 2005). The numbers in the Danish Wadden Sea are also increasing during autumn and spring, and the spring numbers were correlated with the Wadden Sea population index (Table 2).

The Knot recorded in the Danish Wadden Sea during spring belong primarily to the subspecies *islandica* (Frikke & Laursen 1992). The Northwest Europe flyway population increased between 1970 and 2000, after which it decreased (Wetlands International 2002). Knot numbers in Great Britain have declined during the past 30 years, while the Wadden Sea index has shown an increase, especially in the 1990s (Blew & Südbeck 2005). The results of these surveys indicate uncertainties in the trends of the different subspecies using different regions outside the breeding season. However, there was some indication of a positive correlation between the number of Knot counted in the Danish Wadden Sea with numbers counted on the Wadden Sea as a whole (although it is not statistically significant).

The East Atlantic flyway population of Dunlin is considered to be stable (Wetlands International 2002). This trend was also found in the Danish Wadden Sea and in Great Britain from the mid-1980s to the mid-1990s, but thereafter numbers declined (Pollitt *et al.* 2003). In contrast, the Wadden Sea population index has increased since 1980 (Blew & Südbeck 2005).

The East Atlantic flyway population of Bar-tailed Godwit is considered to be stable (Wetlands International 2002); the results from the Danish Wadden Sea also indicate this. However, the Wadden Sea population index shows an increasing trend, although with considerable annual variation, while in Great Britain the species has shown a reduction in numbers of 31% over the last 30 years (Pollitt *et al.* 2003). These contradictory results may indicate that the species is poorly covered in some of the counts.

The East Atlantic flyway population of Curlew is considered to be stable or increasing (Wetlands International 2002). In Great Britain numbers have increased since the beginning of the 1980s; in the Wadden Sea as a whole, numbers have been stable (Pollitt *et al.* 2003; Blew & Südbeck 2005), and the Danish Wadden Sea numbers have increased strongly since 1992 (Fig. 3I). There are probably two reasons for these trends. First, in 1992 shooting was banned across large tidal areas of the Danish Wadden Sea that served as roosting and feeding areas for many species including Curlew. Second, the open season was reduced in Denmark by a month in 1982 and the species became fully protected from shooting from 1994 onwards. These events increased the population, and locally also the numbers, in the Danish Wadden Sea (Laursen 2005).

Gulls

Wetlands International (2002) evaluated the Northwest European population trend for both Black-headed Gull and Herring Gull to be increasing. However, midwinter counts in the Wadden Sea as a whole show decreases in both species (Blew & Südbeck 2005), while the trend in the Danish Wadden Sea was stable. In Great Britain the breeding population of Herring Gull had decreased due to culling (to protect other species, e.g. terns *Sterna* spp., disease and a reduction in food availability through better waste management (Hagemeijer & Blair 1997). In Denmark the numbers of breeding Herring Gull have also decreased in large colonies (Grell 1998). Furthermore, the breeding population of Black-headed Gull has decreased in Denmark since the late 1980s (Grell 1998).

The Common Gull population is decreasing in northwest Europe (Wetlands International 2002), as are the numbers in the Wadden Sea as a whole. However, this study reports an increase in the Danish Wadden Sea. The breeding population of Common Gull has also declined in Europe, with the culling of breeding birds, disturbance at colonies, spread of feral American Mink *Mustella vison* and reduction in dumped waste all contributing to this decline (Hagemeijer & Blair 1997).

Overall, this study shows that Shelduck, Pintail, Oystercatcher, Grey Plover, Curlew and Common Gull numbers have increased in the Danish Wadden Sea during the study period, that Brent Goose, Wigeon, Eider, Avocet, Dunlin, Bar-tailed Godwit, Black-headed Gull and Herring Gull numbers have remained stable (although Brent Goose and Bar-tailed Godwit numbers have increased in spring), and only Mallard numbers have decreased. The trends for Teal and Knot were evaluated as being uncertain. The annual numbers of Brent Geese, Shelduck, Wigeon, Teal, Mallard, Avocet and Grey Plover correlated significantly with one or more parameters defined as being independent of human activities (e.g. flyway population, breeding success, primary production). In addition, there was evidence that Pintail numbers were influenced by breeding success, and indications that numbers of Oystercatcher and Knot in the Danish Wadden Sea were influenced by the population numbers in the Wadden Sea as a whole or by Blue Mussel biomass. Black-headed, Common and

Herring Gulls showed no correlation with the parameters examined, but their trend in the Danish Wadden Sea was either stable or increasing while the breeding population reported from the countries surrounding the Wadden Sea was decreasing. Quarry species are of special interest because of the major regulation of hunting activities in the wildlife reserve. Quarry species' numbers were correlated with factors outside the Danish Wadden Sea (for Mallard, Pintail, Wigeon and Teal) or were stable despite a decline in total population size (Eider). After 1991, when large no-shooting zones were established, in the Danish Wadden Sea the number of Curlew increased and Eiders were distributed in relation to Blue Mussel biomass. The analyses found that 14 of the 17 species examined were either stable or increasing in number and that only one species (Mallard) was decreasing. In addition, seven species were regulated by parameters independent of human activities in the Danish Wadden Sea and among these was the only declining species. Thus it seems that, with the administrative adjustments made in 1992 and 1998, the management of the wildlife reserve in the Danish Wadden Sea is currently sustainable.

Acknowledgements

We wish to thank Johnny Kahlert and Tony Fox for comments and suggestions on an early draft of this paper, and Erik van Winden, SOVON, for the trend calculations. Thanks also to Kim Fischer, Lars Maltha Rasmussen, Jeppe Ebdrup, Niels Knudsen, Erik Overlund and Svend Rønnest for participating in the aerial surveys.

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