Photo: Martin Stock. Migratory birds.

Wadden Sea Quality Status Report

Migratory birds

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1. Introduction

The Wadden Sea is of great importance as a staging, wintering and moulting area for migratory birds along the East Atlantic Flyway. For more than three decades, the Trilateral Wadden Sea Cooperation has monitored the numbers of 39 populations of 34 migratory waterbird species. The monitored species breed in a large part of the Northern hemisphere, including Greenland, Canada, Fennoscandia and Russia, but also in the Wadden Sea (see Koffijberg *et al*., thematic report Breeding birds). They spend the winter along the coasts of Western Europe, the Mediterranean and Africa (see Van Roomen *et al*., thematic report East Atlantic Flyway). For nine of the 34 monitored migratory species, the Wadden Sea can be considered as the most important site during any period in their annual cycle (staging, moulting, or wintering), as more than 50% of their flyway population use the Wadden Sea at these stages within their annual cycle. Another 14 species use the Wadden Sea with more than 10% of their flyway population (Blew *et al*., 2017; Kleefstra *et al*., 2019).

This chapter on migratory birds provides an update of the migratory bird chapter in the Quality Status Report (QSR) of 2017 (Blew *et al*., 2017) and summarizes the results of the latest Expert Group Migratory Birds (EG MB; formally known as Joint Monitoring of Migratory Birds) progress report with data from 1987/1988-2019/2020 (Kleefstra *et al*., 2022).

2. Status and trends

2.1 TMAP monitoring scheme migratory birds

The Trilateral Monitoring and Assessment Program (TMAP) is organized, coordinated and carried out by different institutions in the three Wadden Sea countries Denmark, Germany and the Netherlands, and involves a network of many professional and volunteer counters. The trilaterally organized bird counts were initiated in 1980 and in 1987/1988 a revised and improved counting scheme was established, which has been the basis of the trilateral monitoring efforts ever since.

Monitoring of 34 migratory waterbird species in the Wadden Sea has taken place for 33 years now. The monitoring conducted by the EG MB, consists of (a) at least five synchronous, total counts of all waterbird species per year: in January (mid-winter count), May, September and November, and a fifth in another different month each year, (b) frequent (bi-monthly to monthly) spring tide counts of waterbirds at 60 sites, (c) aerial counts of Eider in winter and for Shelduck during wing moult (July/August) in Germany and by boats in the Netherlands. At present, a total of 594 counting units from the Wadden Sea are included in the analyses. These surveys allow reliable estimates of numbers, phenology and population trends. For a more detailed description, see Kleefstra *et al.* (2022).

We present the trends for 34 waterbird species that are considered important in a Wadden Sea context and occur in sufficiently large numbers to allow analyses on numbers and trends. A small number of species that only occur in low numbers or for which the trilateral survey scheme does not retrieve representative data (e.g. Purple Sandpiper), has been excluded from the analyses (for a more detailed explanation see Rösner *et al.,* 1994 or Blew & Südbeck, 2005). Trends are also calculated for ten different subspecies of five of these 34 species (originating from different breeding regions) since the subspecies can be separated by different periods of their presence in the Wadden Sea area during the year. Trends for subspecies are calculated for Common Ringed-Plover, Red Knot, Bar-tailed Godwit, Redshank and Turnstone.

Despite a large dataset with long-term monitoring data, coverage is not always complete. In order to avoid any impact of varying coverage on numbers and trends, UINDEX (Bell, 1995) was used to account for missing counts in the dataset by estimating bird numbers for missing counts (imputing) taking site, year and month into account (Underhill & Prys-Jones, 1994). Sites were classified into four different Wadden Sea regions which are assumed to have similar patterns in abundance: Denmark, Schleswig-Holstein, Lower Saxony (including Hamburg) and the Netherlands. The counted and imputed values for each month were added to yearly averages for the respective “bird-years”, covering the period from July to June of the following year, as is usually done for waterbird reporting schemes. TrendSpotter was used to calculate so-called “flexible trends”, which are particularly suitable to deal with time series with different periods of decreasing, stable or increasing numbers (Visser 2004, Soldaat *et al*., 2007). We report trend estimates for the last 33 years (1987-2020) and the last ten years (2010-2020) to assess long-term and short-term developments. In order to allow a comparable assessment of changes in annual numbers between species, trends have been categorized in a standardised classification, based on the average annual change in numbers in the respective periods and their 95% confidence limits (see Hornman *et al.,* 2020; Kleefstra *et al.,* 2022 for details). They range from strong increases of >5% per annum (++) to similar strong decreases (--); with the classification of stable and fluctuating numbers in-between. These so-called "fluctuating" trends usually reflect species with strong annual variation in abundance and large 95% confidence intervals around the average annual change.

The given trends reflect the use of the Wadden Sea by the respective bird species and therefore indicate the status of the migratory bird populations of the East Atlantic Flyway population in the Wadden Sea (see thematic report East Atlantic Flyway). The trends only give an impression of the changes of overall estimated annual numbers of bird species in the Wadden Sea, correcting for the strong intra-annual variation in abundance. To indicate abundance, we also defined periods of winter, spring, breeding, moulting, and autumning per species and calculated maximum estimates for each period (the average of the three maximum estimates during each period). Estimates of which more than 50 % of the numbers were imputed were excluded in these latter analyses.

2.2 Trends per species

Long-term trends over the last 33 years (1987/1988-2019/2020) showed increasing numbers for seven species, stable numbers for 14 species and a decline in numbers for 13 species declined (Figure 1). The short-term trends over the last ten years of the monitoring period (2010/2011-2019/2020) showed an increase for ten species, stable numbers for 14 species, a decline for seven species while for three species no clear short-term trends could be determined (Figure 1).

Comparisons between the long- and short-term trends showed that six species increased in both periods (Eurasian Spoonbill, Barnacle Goose, Northern Pintail, Northern Shoveler, Great Ringed Plover, and Sanderling). Great Cormorants increased in the long run, but numbers were stable over the last ten years. Populations of six species decreased both in the long- and the short-term: Common Shelduck (based on high-tide roost counts), Mallard, Eurasian Oystercatcher, Pied Avocet, Dunlin, and Spotted Redshank. The numbers of most other species that declined in the long run, stabilized over the last ten years, except for the Ruff, which increased slightly since 2010.

Of the 14 species with stable long-term trends, eight species also showed stable numbers over the last ten years (Grey Plover, Northern Lapwing, Bar-tailed Godwit, Whimbrel, Eurasian Curlew, Common Redshank, Black-headed Gull and Common Gull), while three species showed an increase over the last ten years, namely Eurasian Wigeon, Common Teal and Ruddy Turnstone, and numbers of Common Greenshanks started to decline. Trends of Eurasian Golden Plover, Kentish Plover, and Curlew Sandpiper are not significant over the short-term period.

Species	33 year trend 1997/98 - 2019/20	10 year trend 2010/11-2019/20	Flyway trend 2011-2020
Great Cormorant	↑↑	→	↑↑
Eurasian Spoonbill	↑↑	↑↑	↑↑
Barnacle Goose	↑↑	↑	↑
Brent Goose	↓	→	→
Common Shelduck	↓	↓	↓
Eurasian Wigeon	→	↑	→
Common Teal	→	↑	→
Mallard	↓	↓	↓
Northern Pintail	↑	↑	↑
Northern Shoveler	↑	↑	↑↑
Common Eider (29y trend)	↓	→	—
Eurasian Oystercatcher	↓	↓	↓
Pied Avocet	↓	↓	→
Common Ringed Plover	↑	↑	X
C. p. psammodroma	↑	↑	→
C. p. hiaticula	→	→	→
Kentish Plover	↓	—	—
European Golden Plover	→	—	X
Grey Plover	→	→	↓
Northern Lapwing	→	→	↓
Red Knot	↓	→	X
C. c. islandica	↓	→	↓
C. c. canutus	→	→	—
Sanderling	↑	↑	→
Curlew Sandpiper	→	—	↓↓
Dunlin	↓	↓	↓
Ruff	↓	↑	X
Bar-tailed Godwit	→	→	X
L. l. lapponica	→	→	↓
L. l. taymyrensis	→	→	↓
Whimbrel	→	→	→
Eurasian Curlew	→	→	→
Spotted Redshank	↓	↓	—
Common Redshank	→	→	X
T. t. totanus	↓	↓	→
T. t. britannica	↓	↓	↓
T. t. robusta	→	→	↑
Common Greenshank	→	↓	—
Ruddy Turnstone	→	↑	X
NE Canada and Greenland	↑	↑	→
Fennoscandia and NW Russia	→	→	—
C. Black-headed Gull	→	→	↓
Common Gull	→	→	↓
European Herring Gull	↓	→	↓
Great Black-backed Gull	↓	→	→

↓↓ strong decrease ↓ moderate decrease → stable — uncertain

Figure 1. 33-year and ten-year trends of 34 species and their flyway trends (QSR report "East Atlantic Flyway"). For five species with separate populations ('subspecies') the overall trends are shown on top and the subpopulation trends below. Flyway trends were calculated over the most recent ten years from the period 2011-2020 and presented as categorized as "increase", "decrease" and "stable".

2.3 Comparison of the maximum estimated numbers for three decades

In addition to the trends over the entire year, we provide the estimated maximum numbers for each of the three decades in the period 1989/1990-2019/2020 (Table 1). This gives an impression of absolute population numbers and the order of magnitude of the changes in abundance over a long period and the over a shorter period (1999/2000-2019/2020) when it comes to the numbers present.

The most numerous species in the first ten years of the period were (in order of maximum numbers) Dunlin, Eurasian Oystercatcher, Black-headed Gull, Red Knot, Eurasian Wigeon, Bar-tailed Godwit, Common Eider, Eurasian Curlew, European Herring Gull and Brent Goose, with numbers over 230,000 (Brent Goose) up to more than 1,104,000 birds (Dunlin). In the last decade, the ten most numerous species were Dunlin, Barnacle Goose, Black-headed Gull, Eurasian Wigeon, Eurasian Oystercatcher, Red Knot, Bar-tailed Godwit, Eurasian Curlew, Common Shelduck and Brent Goose, with numbers over 175,000 (Brent Goose) up to almost 870,000 birds (Dunlin). Of these 'top ten species' for the period 1989/1990-1998/1999 the majority showed a remarkable reduction in maximum numbers with 25,000 up to almost 250,000 individuals that were 'lost': Dunlin (-234,355 = -21%), Eurasian Oystercatcher (-246,674 = -43%), Red Knot (-64,716 = -19%), Bar-tailed Godwit (-25,839 = -9%), Common Eider (-120,456 = -43%), Eurasian Curlew (-31,446 = -11%), European Herring Gull (-93,763 = -40%) and Brent Goose (-55,095 = -24%).

Of the 34 species in Table 1, most declined in abundance over a long period. Fifteen of these species showed a decline of 15% or more. Nine species showed an increase of 15% or more in the long term. In the short-term, the picture is slightly more positive; only seven of the species showed a decrease in abundance of 15% or more, while all species that increased in the long-term, also did so in the short-term. The eight species of which numbers changed for the better were Kentish Plover, Brent Goose, Dunlin, Red Knot, Common Eider, Ruff, Common Gull and Common Redshank. Species that showed an increase in abundance of 15% or more over the short period, instead of the long period, are Black-headed Gull and European Golden Plover. Species that showed such an increase over the long period, but not over the short period, were Great Cormorant and Northern Lapwing.

Four species showed a strong increase in abundance over the long period as well over the short period: Eurasian Spoonbill, Northern Pintail, Barnacle Goose and Sanderling. Compared to the period 1989/1990-1998/1999 there were 6.7 times more Eurasian Spoonbills in the Wadden Sea in the period 2009/2010-2018/2019. For Northern Pintail, Barnacle Goose and Sanderling there were respectively 2.5, 2.2 and 1.9 times more. Other species that showed an increase of more than 25% in abundance in both periods were Common Teal, Common Ringed Plover and Northern Shoveler.

Only one species, the Pied Avocet, showed a decrease in abundance of more than 25% in both periods. Other species that showed a decrease of 15% or more in both periods are Spotted Redshank, Curlew Sandpiper, Eurasian Oystercatcher, Great Black-backed Gull, European Herring Gull and Mallard.

In species for which subspecies were distinguished, both subspecies of Common Ringed Plover showed an increase in abundance. Both subspecies of Ruddy Turnstone showed quite stable population numbers, while numbers of both subspecies of Bar-tailed Godwit decreased slightly. The only two species for which the subspecies showed clearly different trends are the Red Knot and the Common Redshank. The *islandica* Red Knots decreased considerably over the long period (-24%), but their abundance did not change much during the last ten-year period (4%). The abundance of the *canutus* Red Knot decreased over both periods, with respectively -12% and -19%. The *totanus* Redshank numbers showed a slight decrease over both periods of respectively -17% and -12%, while the robusta Redshanks showed a strong decrease in both periods of respectively -34% and -27%.

Summed up and divided into species groups, the results were clearly negative for waders and gulls. The sum of all duck species showed a slight increase, while the group of geese and the group of cormorants and spoonbills showed a strong increase.

Table 1. Comparison of the maximum estimated numbers of migratory birds in the international Wadden Sea, for three decades in the period 1989/1990-2019/2020.

					Late minus early estimates			
Euring	**Soort**	**1989/1990-1998/1999**	**1999/2000-2000-2009**	**2009/2010-2019/2020**	**long**	**short**	**long in %**	**short in %**
1440	Eurasian Spoonbill	929	2563	6283	5353	3720	576	145
1670	Barnacle Goose	224340	313213	502442	278101	189229	124	60
1890	Northern Pintail	18468	29302	45859	27391	16557	148	57
4970	Sanderling	21809	27038	41556	19748	14518	91	54
1840	Common Teal	34189	30928	45083	10894	14155	32	46
4700	Common Ringed Plover	27252	30180	39428	12176	9248	45	31
1940	Northern Shoveler	5603	6213	7809	2206	1597	39	26
5820	Black-headed Gull	448791	400204	481017	32226	80813	7	20
4850	European Golden Plover	126626	102509	120457	-6169	17948	-5	18
4770	Kentish Plover	750	469	534	-216	65	-29	14
1730	Common Shelduck	222903	223701	243537	20634	19836	9	9
5380	Whimbrel	2696	2575	2720	24	145	1	6
1680	Brent Goose	230444	171034	175349	-55095	4315	-24	3
5610	Ruddy Turnstone	8398	8409	8599	201	190	2	2
1790	Eurasian Wigeon	337489	331666	335905	-1584	4239	0	1
4860	Grey Plover	127607	124046	122439	-5168	-1607	-4	-1
4930	Northern Lapwing	70766	92783	87908	17143	-4875	24	-5
5120	Dunlin	1104151	938531	869796	-234355	-68736	-21	-7
4960	Red Knot	340197	305365	275482	-64716	-29883	-19	-10
2060	Common Eider	282177	180199	161721	-120456	-18478	-43	-10
5170	Ruff	6013	2996	2678	-3335	-318	-55	-11
5340	Bar-tailed Godwit	290574	297028	264736	-25839	-32292	-9	-11
5410	Eurasian Curlew	280743	280480	249297	-31446	-31183	-11	-11
720	Great Cormorant	14971	23134	20274	5303	-2860	35	-12
5480	Common Greenshank	21129	23156	20008	-1121	-3148	-5	-14
5900	Mew Gull	207179	180908	155813	-51366	-25095	-25	-14
5460	Common Redshank	79297	77586	66460	-12837	-11126	-16	-14
1860	Mallard	135418	114408	96084	-39334	-18324	-29	-16
5920	European Herring Gull	232189	167824	138425	-93763	-29399	-40	-18
6000	Great Black-backed Gull	15429	10372	8357	-7073	-2015	-46	-19
4500	Eurasian Oystercatcher	574604	408647	327929	-246674	-80718	-43	-20
5090	Curlew Sandpiper	8808	9314	7305	-1503	-2009	-17	-22
5450	Spotted Redshank	17605	14740	11284	-6322	-3456	-36	-23
4560	Pied Avocet	44089	38788	26518	-17570	-12270	-40	-32
4702	Common Ringed Plover (*psammodroma/tundrae*)	26338	29957	39451	13113	9494	50	32
4701	Common Ringed Plover (*hiaticula*)	4993	4356	5013	20	657	0	15
5611	Ruddy Turnstone (Greenland & NE Canada)	8031	8135	8575	544	440	7	5
4962	Red Knot (*islandica*)	345892	254347	264050	-81842	9704	-24	4
5612	Ruddy Turnstone (Scandinavia - Western Russia)	6326	6952	6271	-55	-681	-1	-10
5341	Bar-tailed Godwit (*taimyrensis*)	297317	299736	269571	-27747	-30165	-9	-10
5342	Bar-tailed Godwit (*lapponica*)	138686	148265	130770	-7916	-17495	-6	-12
5461	Common Redshank (*totanus*)	76420	72242	63551	-12869	-8691	-17	-12
4961	Red Knot (*canutus*)	249453	270298	218994	-30459	-51303	-12	-19
5462	Common Redshank (*robusta*)	39501	35368	25990	-13511	-9378	-34	-27
Sum	Cormorant en Spoonbill	225270	315776	508724	283455	192949	126	61
Sum	Geese	40277	56340	87416	47139	31076	117	55
Sum	Ducks	866116	794204	937866	71750	143662	8	18
Sum	Waders	3786869	3332502	3062053	-724816	-270449	-19	-8
Sum	Gulls	645106	471489	373036	-272070	-98453	-42	-21
Sum	Total	5563637	4970311	4969095	-594543	-1216	-11	0

2.4. Wadden Sea trends in a flyway perspective

A comparison between the ten-year Wadden Sea trends and the East Atlantic Flyway trends (Figure 1; also see QSR report [East Atlantic Flyway]) can help in evaluating if local or global drivers were causing changes in numbers using the Wadden Sea. For example, if a species performs worse in the Wadden Sea than it does at the scale of the entire flyway, the decrease in abundance might most likely be caused by conditions in the Wadden Sea. Previous analyses of the trends of migratory and wintering birds in the Wadden Sea until the season 2010/11 showed that numbers declined faster within the Wadden Sea than at the scale of the Flyway, especially among benthic feeding species (e.g. van Roomen *et al*., 2015). More recently, however, Bregnballe *et al.* (2018) showed that, based on Wadden Sea trends up to 2016/2017, this pattern has changed, with more of these benthic-feeding species now showing stable or positive trends at the Wadden Sea scale compared with the scale of the Flyway. This suggests either a larger population increase at the scale of the flyway or a relatively slow population decrease in the Wadden Sea. Quite a few benthic eating species showed more negative trends at the Flyway scale compared with the Wadden Sea scale (Figure 1). This especially concerned Curlew Sandpiper, but also Common Ringed Plover (C.h. *psammodroma/tundrae*-subspecies), Grey Plover, Sanderling, Bar-tailed Godwit (both subspecies), Eurasian Curlew and Ruddy Turnstone (Greenland & NE Canada populations) that were doing better in the Wadden Sea than in the flyway. The gulls also were doing better in the Wadden Sea than in the flyway. Of the benthic eating species, only two subspecies of the Redshank showed a more positive trend on the Flyway level compared to the Wadden Sea (*robusta* and *totanus* from Britain & Ireland/Britain, Ireland, France).

Trends of plant-eating species seemed to differ less between the Wadden Sea and the Flyway, although trends of Brent Goose, Eurasian Wigeon and Common Teal tended to be slightly more negative on the Flyway level (Figure 1). Trends of fish-feeding species were positive for Great Cormorant and Eurasian Spoonbill, with the Cormorants seeming to do better on a Flyway level than in the Wadden Sea.

3. Assessment

The targets for migratory birds in the Wadden Sea Plan ([CWSS, 2010]) are:

- stable or increasing numbers and distribution considering that abundance of species is in line with prevailing physiographic, geographic and climatic conditions
- breeding, feeding, moulting and roosting sites supporting a natural population
- undisturbed connectivity between breeding, feeding, moulting and roosting sites
- fluctuations in food stocks determined by natural processes
- habitat, food stocks and connectivity between habitats supporting a favourable conservation status

3.1 Development of trends

Figure 1 showed the long term (33 years) and the short term (ten years) trends for 34 species. The question is how these trends developed; did the number of species with a negative trend become larger over the years, or did that apply to species with a positive trend? Comparing the trends published in the Quality Status Reports of 2004, 2009, 2017 and 2022 gives an indication of how bird numbers developed and if the number of species with a negative trend changed over the years, and if species with a positive trend continued to increase. The result showed (Figure 2):

- The number of species with a negative long-term trend went up from five to 16 in the first three QSRs, but now dropped once again to 13 species, while the number of species with a positive trend did not change substantially: eight in 2004, eight in 2009, six in 2017 and seven in 2022. The same is true for species with stable numbers: 15 in 2004, 12 in 2009, 12 in 2017 and 14 in 2022.
- The short-term trends show fewer changes, apart from the QSR from 2004. The number of increasing, stable and decreasing species were pretty consistent in the QSR's of 2009, 2017 and 2022.
- In comparison with the QSR of 2017 more species show an increase in the short and long term, while the number of decreasing species went down in the long term (but not short term).

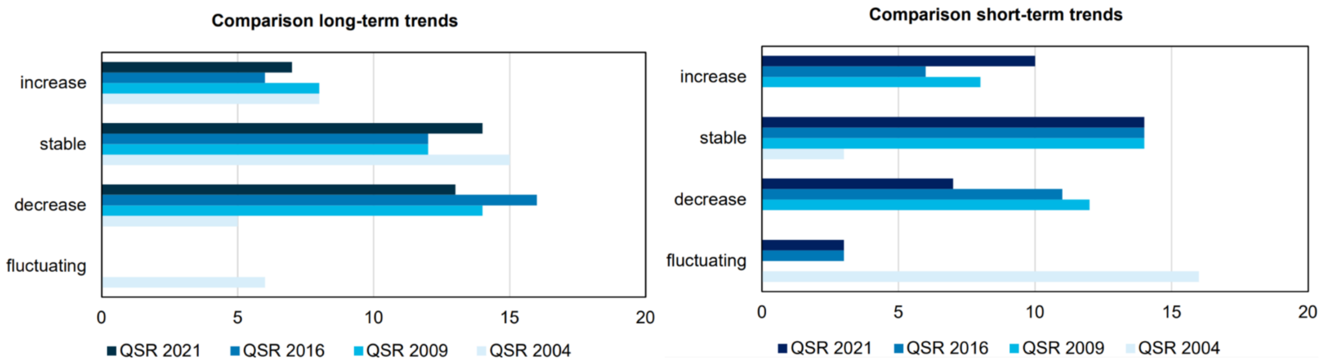

Figure 2. Overview of long- and short-term trends in migratory birds in the Wadden Sea as presented in the different QSR chapters. Non-significant trends have been categorised as "fluctuating".

3.2. Feeding, roosting, and moulting sites

3.2.1. Feeding sites

The issue of feeding sites is closely related to the evaluation of the target "Fluctuations in food stocks determined by natural processes" (CWSS, 2010) and is discussed in Chapter 3.3.

3.2.2. High tide roosts

Nearly 20 years ago, a review of bird distribution, protection, and potential sources of anthropogenic disturbance at high-tide roosts had been published by Koffijberg *et al*. (2003). Blew *et al.* (2017) provided an overview of conclusions published in former QSR's, based on the review by Koffijberg *et al*. (2003):

- recreation has an impact on many high-tide roosting sites, and this is expected to get even worse, as more people visit the Wadden Sea and for longer periods in spring and autumn;
- hunting of waterbirds has been phased out (e.g. Eurasian Curlew in Denmark, Laursen, 2005). Nevertheless, hunting of other birds and small mammals close to roosting sites still occurs (saltmarshes,

inland roosting sites);
- knowledge of the effects of civil and military air traffic (e.g. Vliehors at Vlieland, NL) must be assessed further.

Blew *et al*. (2017) stated that the quality of high tide roosts cannot be sufficiently assessed, as the most recent evaluation goes back to 2003 (Koffijberg *et al.,* 2003), while factors such as tourism and infrastructure (e.g. wind parks) have changed. This conclusion still holds, and a new evaluation is urgently needed. Still, some progress has been made on the national level. In the Netherlands, high-tide roost analyses with the aim to identify bottlenecks and opportunities for improvement of roosts has been carried out, by examining how the supply and quality of the roosts relate to the location of profitable foraging areas (Folmer *et al.,* 2021) and disturbances by recreationists (e.g. dog owners, photographers and bird watchers, Ens *et al.,* 2021). During bird counts on high tide roosts in the Netherlands, natural and unnatural potential sources of disturbance and the resulting disturbances have been started to be recorded in a standardized manner to allow the analysis of its developments.

The impact of civil and military air traffic has now been assessed in more detail as well. Van der Kolk *et al.* (2020a, 2020b) investigated how disruptive, different types of flying aircraft are for staging Oystercatchers on Vliehors at the island of Vlieland in the Dutch Wadden Sea. The effect of jet fighters appeared to be relatively small, while large transport aircrafts caused a lot of disturbance to the birds. One should bear in mind that these findings do not necessarily apply to other waterbird species. In the German Wadden Sea civil and military air traffic is by far the largest cause of bird disturbance (pers. comm. K. Günther). The extent of disturbance has intensified since the "permitted low-flight altitude" for civil airplanes in Germany was reduced from 600 to 150 meters in 2014, according to the European law following the "Standardised European Rules of the Air" (SERA).

With regard to the status of roosting sites, Blew *et al*. (2017) added and discussed two additional issues:

- potential (natural) disturbance from Peregrine Falcon and White-tailed Eagle
- insufficient counting coverage of remote roosting sites

Van den Hout *et al*. (submitted) showed that Peregrine Falcons increased stronger and are present in higher densities in the eastern part of the Dutch Wadden Sea than the western part. A comparison of the Peregrine-low period (1975-1980) and high period (1981-1996) revealed that Red Knots and Bar-tailed Godwits occurred more in the western part of the Dutch Wadden Sea in the latter period. This tendency was lacking in both the smaller (e.g. Sanderling and Dunlin) and the larger species (e.g. Eurasian Curlew and Eurasian Oystercatcher), which are outside the mass range of prey preferred by Peregrines. Within a seasonal context, patterns were even clearer. During autumn, when Peregrine numbers increased, both Red Knots and Bar-tailed Godwits, but not the smaller and larger species (such as Sanderling and Eurasian Curlew), shifted from the east to the west to avoid predation risk.

The potential (natural) disturbance of White-tailed Eagles has not been studied yet in the Wadden Sea, but with the growing breeding populations in the north of Germany (Krüger *et al.,* 2010), Denmark (Skelmose & Larsen, 2020) and the Netherlands (van Rijn *et al.,* 2019) it is obvious that their presence in the Wadden Sea is increasing, which has been confirmed by movements of tagged White-tailed Eagles in the Netherlands (Werkgroep Zeearend Nederland, 2021).

As for the insufficient counting coverage of remote roosting sites, Blew *et al*. (2017) already elaborated on the consequences of missing data from outer sands in Lower Saxony and Schleswig-Holstein on the established total numbers of birds on high tide roosts. The intention is to regularly carry out three to five aerial counts around the high tide of the outer sands in the Schleswig-Holstein area from 2021 onwards.

Not only insufficient coverage is a point of attention, but the quality of the counts as well. Precise counting of birds can be challenging in some of the areas that are used by large numbers of waterbirds roosting at high tide. In Denmark, the quality of counting results from a number of volunteer counters who cover important counting areas was assessed. Their counts did not reach the standard that Aarhus University deemed sufficient to ensure a satisfactory provision of information about the number of waterbirds present. In the future, more professional and trained bird counters are needed to ensure that the most important areas are counted by sufficiently qualified ornithologists

3.2.3 Moulting ducks

The Wadden Sea and adjacent areas in the North Sea are of great international importance for Common Shelduck, Common Eider and Common Scoter, which gather for their wing moult between May and September. During this period the moulting ducks are not able to fly, and the birds are extremely vulnerable to predators and human disturbance and therefore congregate in remote places. For Common Shelduck the entire European population uses the Wadden Sea to moult. Thus, the Wadden Sea countries have a great responsibility for the protection of these species. However, the species' moulting behaviour and phenology differ, thus the management and also monitoring requires a species-specific approach.

The most important moulting sites for **Common Shelduck** are situated within the southern Schleswig-Holstein Wadden Sea in the outer Elbe estuary (Kempf, 2007; Kempf & Kleefstra, 2013) and the central Dutch Wadden Sea (Kleefstra *et al*., 2011; Kempf & Kleefstra, 2013). In the German Wadden Sea the number of moulting Shelducks increased from about 180,000 in the late 1980s to an average of 206,000 in the period 1996-2002 (range 195,000-219,000). Thereafter, numbers steadily declined to an average of 155,000 in 2003-2009 (range 130,000-183,000). This could be interpreted as a decline in the Northwest European Shelduck population, if it was not for the increase of moulting Shelducks in the central part of the Dutch Wadden Sea, growing from several thousand during the 1990s up to over 50,000 after the year 2000 (Kempf & Kleefstra 2013). While the number of moulting Shelducks in the German Wadden Sea stabilized at an average of 157,600 individuals in 2014-2019 (range 143,830-181,140; N. Kempf, unpublished data), their average number in the Dutch Wadden Sea grew to 69,000 in 2014-2019 (range 45,000-96,000; R. Kleefstra & WaddenUnit, unpublished data). Moulting Shelducks are not consistently counted in the Danish Wadden Sea. Birds counted during aerial counts in summer are registered as moulting and have increased from 3,500 in the 1990s to 13,000 after the year 2000 (Laursen & Frikke 2013), but seem to have decreased in recent years (2900 in 2013, 2200 in 2019; N. Kempf unpublished data).

While the aerial counts of moulting Shelducks are guaranteed in the German Wadden Sea, the monitoring of moulting Shelducks in the Netherlands is still not part of the national Network Ecological Monitoring (NEM) and is currently only performed as a volunteer initiative. In Denmark, targeted counts of moulting shelducks are even lacking.

Common Eiders moult from July until the end of August and early September. The ducks prefer areas with low disturbance levels, rich in shellfish stocks and roosting sites on sandbanks. The moulting populations in the German and Danish Wadden Sea added up to 170,000-230,000 individuals in the 1990s, but showed a steep decline since 1994 in the major moulting sites in the North Frisian Wadden Sea (Scheiffarth & Frank, 2005).

Moulting Eiders are not monitored trilaterally, as they cannot easily be distinguished from non-moulting birds. Only in Schleswig-Holstein and Lower Saxony/Hamburg aerial counts are conducted each August. In the Wadden Sea of Lower Saxony, this resulted in an average of 68,000 counted individuals in the period 1987-2020 (range 35,330- 101,496), fluctuating without a clear trend, although the average over the last ten years (59,500 in 2011-2020) is lower than the average in the years before (72,000 in 1987-2010; G. Scheiffarth, unpublished data). Numbers of moulting Eiders in Schleswig-Holstein have not been published yet, while no (recent) data exist from the Danish and Dutch Wadden Sea.

Common Scoters have the longest moulting period (June to October) because immature birds, males and females moult consecutively. Moulting centres of Common Scoter in all three Wadden Sea countries have been identified during the late 1990s. Denmark and Schleswig-Holstein supported larger numbers than Lower Saxony/ Hamburg and the Netherlands (for Schleswig-Holstein see Hennig & Eskildsen, 2001; Deppe, 2003), but as actual data are lacking there is no clear overview possible. Disturbance effects of both offshore windfarms and ships (including maintenance traffic to offshore windfarms) have been shown, with flight distances for approaching boats of more than 2000 m (Bellebaum *et al.*, 2006, Schwemmer *et al.*, 2011; Dierschke *et al.* 2016). Recent studies have been carried out in all Wadden Sea areas as part of assessments for offshore wind farms and sand extraction.

3.3 Trends per food group

To assess population developments for species grouped according to both their main food and feeding sites, Laursen *et al.* (2010) introduced indicator groups, which were also used in the 2017 QSR (Blew *et al.*, 2017) and progress reports (Kleefstra *et al.*, 2019). Blew *et al.* (2017) used it to evaluate the target "Fluctuations in food stocks determined by natural processes", closely linked to targets "Feeding, moulting and roosting sites supporting a natural population" and "Undisturbed connectivity between feeding, moulting and roosting sites". It needs to be mentioned though that some species are difficult to classify into one dietary group because some species are omnivores to a certain extent and their diet varies seasonally and between different feeding sites. The Spotted Redshank, for instance, is here classified as fish-eating (Table 2) but also hunts insects, worms, crabs as well as shrimps, and their decrease in the Dollard-estuary seems to be related to the lower availability of mud shrimps (*Corophium volutato*r; Prop *et al*., 2012).

Figure 3 shows the trend indexes of six indicator groups in the period 1987/1988-2019/2020. The fish- and plant-eating groups showed a moderate increase over the long term, but over the short term, the trends of these groups are respectively stable and uncertain. The omnivorous- and shellfish-groups show a moderate decrease over the long term, the trends for these groups are respectively uncertain and stable over the short term, although it only contains one omnivorous species (Great Black-backed Gull). The worms/benthos- and the other invertebrates-groups both show a stable trend over the whole period. Table 2 shows the list of species per indicator group.

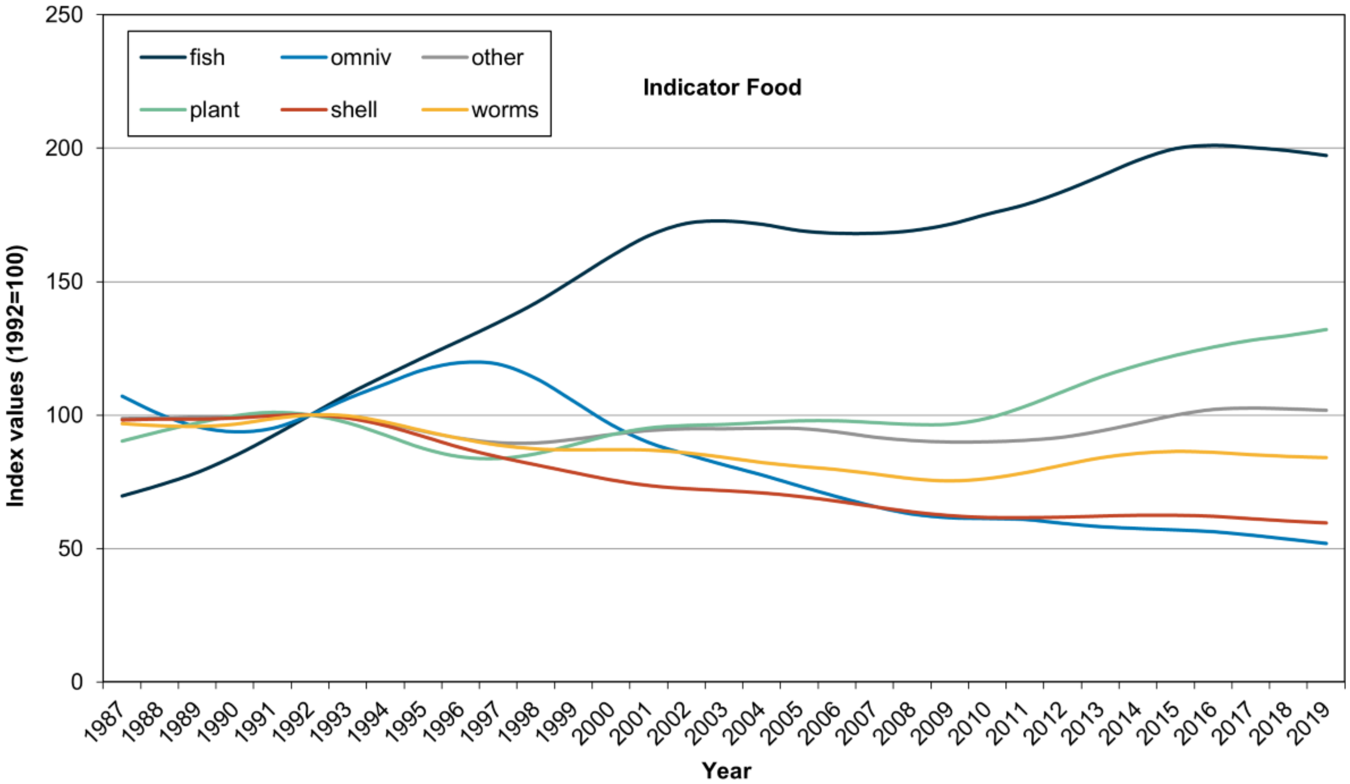

Figure 3. Trends of indicator groups, based on prey choice (food), in the period 1987/1988-2019/2020.

Shellfish	Worms/Benthos	Fish	Other invertebrates	Plants	Omnivorous
Common Eider	Pied Avocet	Spotted Redshank	Common Shelduck	Brent Goose	Great Black-backed Gull
Eurasian Oystercather	Dunlin	Common Greenshank	Whimbrel	Mallard	
Herring Gull	Kentish Plover	Great Cormorant	Eurasian Curlew	Eurasian Wigeon	
Red Knot	Eurasian Golden Plover	Eurasian Spoonbill	Common Redshank	Common Teal	
	Grey Plover		Ruddy Turnstone	Barnacle Goose	
	Northern Lapwing		Black-headed Gull	Northern Pintail	
	Curlew Sandpiper		Common Gull		
	Ruff		Northern Shoveler		
	Bar-tailed Godwit				
	Great Ringed Plover				
	Sanderling				

Table 2. Lists of species per indicator group, based on the main food per species. Colours indicate trends and refer to long-term trends in Figure 1.

Figure 4 shows the trend indexes of four indicator groups over types of feeding habitat in the period 1987/1988-2019/2020 (average trend of all species within each group). Both the beach and the offshore group as well as the tidal area-group show on average stable trends over the whole period. The group of coastal grassland birds showed a moderate decrease in the first years, then a stable trend for almost 14 years, but over the last ten years the trend is uncertain. The salt marsh group shows a moderate increase over almost the whole period, but the trend over the last six years is uncertain.

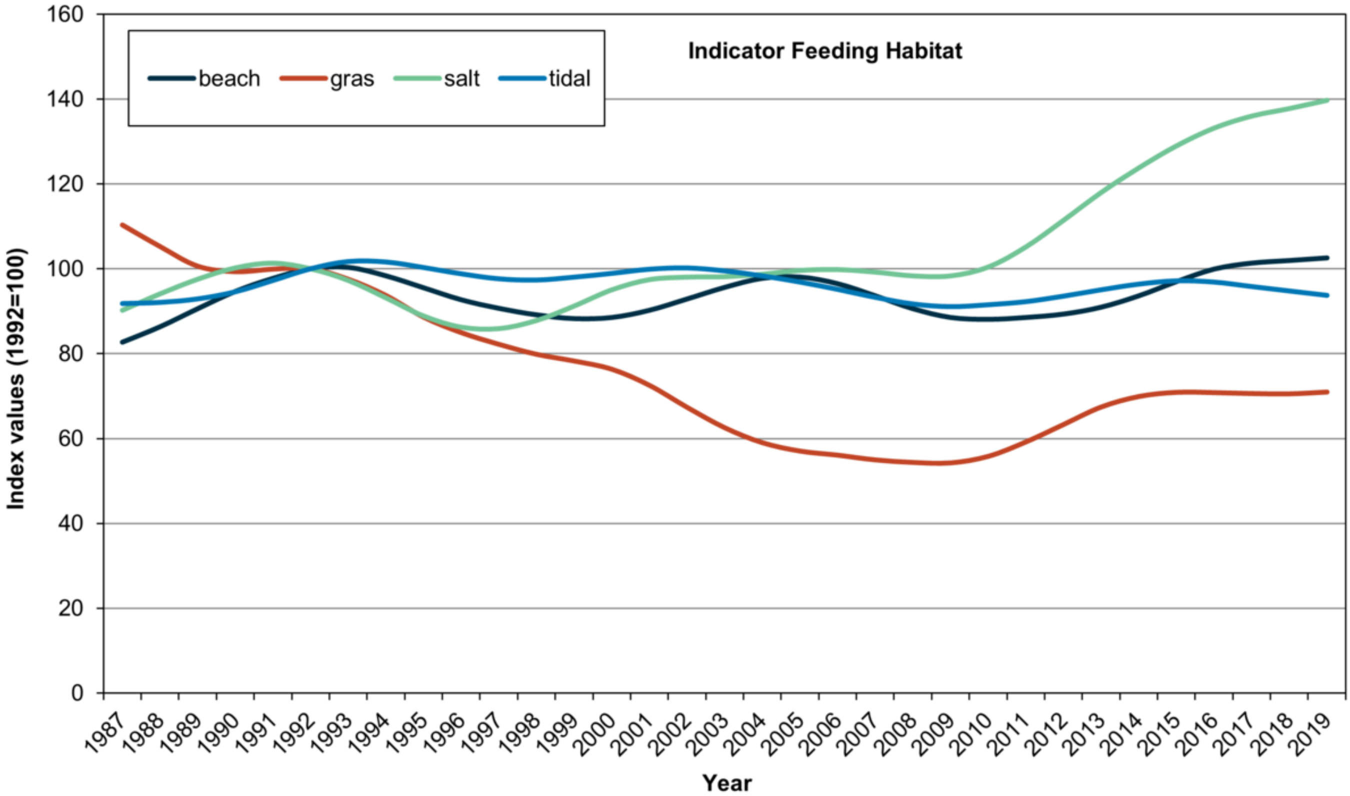

Figure 4. Trends of indicator groups, based on feeding habitat, in the period 1987/1988-2019/2020.

3.3.1 Plants

The plant indicator group contains six species, namely Barnacle Goose, Dark-bellied Brent Goose, Eurasian Wigeon, Common Teal Mallard and Northern Pintail. This group showed an overall moderate increase since the late 1980s but has changed into a fluctuating trend more recently as species within the group show contrasting developments. Although this group of species is doing well, varying extents in different Wadden Sea countries exist. For example, numbers of Eurasian Wigeons decline in the Dutch Wadden Sea and Common Teals decrease in the area of Lower Saxony (Kleefstra *et al.*, 2022).

3.3.2 Fish

The group of fish-eaters consists of four species (Great Cormorant, Eurasian Spoonbill, Spotted Redshank and Common Greenshank), of which the Spotted Redshank and Common Greenshank are debatable species because their diet is broad and does not only include fish. The long-term trend shows a moderate increase that stabilized over the last ten years. Great Cormorant and Eurasian Spoonbill showed strong increases since the late 1980s, but the short-term trend of Great Cormorants is less positive (stable) in almost all Wadden Sea areas, apart from the Danish part. Spotted Redshanks and Common Greenshanks both declined over the last ten years, mainly in Lower Saxony and the Netherlands. As mentioned before, in the Dollard-estuary the decline of the Spotted Redshanks seems to be related to a decreased availability of mud shrimps (*Corophium volutator*), while numbers of Common Greenshanks increased in the Dollard at the same time due to more ragworms (*Hediste diversicolor*) being available (Prop *et al.,* 2012). This indicates that both species do not completely rely on fish. It should also be noted that many fish-eating birds, like egrets, grebes and terns, are not part of the joint monitoring of migratory birds.

3.3.3. Shellfish

The group of shellfish eating birds contains four species (Table 2), which all have declined in the long-term, also associated with considerable losses (20% or more, Table 1) in absolute numbers. Over the last 15 years, the trend of the indicator group seems to stabilize (Figure 3), with stable short-term trends of Common Eider, Red Knot and Herring Gull. As the only member within this group, Eurasian Oystercatcher continued its decrease.

The long term decline of all shellfish feeding species is closely related to shrinking food stocks. The quantity and quality of bivalves as blue mussel and cockle was seriously affected by fishery management in the different Wadden Sea regions (Piersma & Koolhaas 1997, Kraan *et al*. 2004, Scheiffarth & Frank, 2005; Ens *et al*., 2009; Laursen *et al.,* 2009 & 2010). With depleted food stocks and no alternative food available or of low quality, this had an immediate effect on the number of Common Eider (Ens & Kats, 2004), and the condition and survival of Eurasian Oystercatchers (Verhulst *et al.,* 2004) and Red Knot (Kraan *et al*., 2008). This also makes Eurasian Oystercatchers vulnerable to severe winters (Schwemmer *et al*., 2014). Even though the food stock is recovering (Baltic Tellin, cockles), the recovery of the shellfish eating bird populations is lagging behind and numbers only recently started to stabilize. Further restrictive conditions that hinder population recovery might be found in the breeding grounds (e.g. suggested by Van Gils *et al.,* 2016) as well as the wintering grounds (Leyrer *et al*., 2016). For Herring Gull, mussel fishery may provide only part of the explanation for the lower numbers at high tide roosts, as this omnivorous species also make use of other food.

3.3.4 Omnivorous

This group contains only one species: the Great Black-backed Gull. Its decline cannot be explained by the issue of “food availability” (Blew *et al.,* 2017). The population trend appears to be decreasing on an international scale (BirdLife International, 2021).

3.3.5 Worms / Benthos

The group of worms/benthos feeding birds consists of 11 species, namely Pied Avocet, Common Ringed Plover, Kentish Plover, European Golden Plover, Grey Plover, Northern Lapwing, Sanderling, Curlew Sandpiper, Dunlin, Ruff and Bar-tailed Godwit, and thus 11 of the total number of 19 wader species. Seven of these species use tidal areas, while three species, namely Golden Plover, Northern Lapwing and Ruff (mainly) use coastal grasslands as their feeding habitat. Sanderlings use many different types of tidal flats and beaches, depending on the time of the year (Loonstra *et al.*, 2016).

In fact, this indicator group has an overlap with the group of other invertebrate feeders, since several species from the invertebrate group also forage on worms to a certain extent (e.g. Common Shelduck, Whimbrel, Eurasian Curlew, Common Redshank, Ruddy Turnstone, Black-headed Gull and Common Gull).

The composite indicator trend of this group is stable in the long and the short term. Ens *et al.* (2009) pointed out that most species of this group were declining in Germany and thus in the central part of the Wadden Sea, while trends in the Dutch Wadden Sea were stable and increasing (Van Roomen *et al.*, 2012). The contrasting trends between regions and tidal basins within the Wadden Sea suggest that causes for their declines are mainly to be sought within the Wadden Sea itself and could be related to food availability. Interestingly, the Wadden Sea regions where negative trends of benthivorous waterbirds predominate are characterized by large tidal amplitude, whereas areas, where bird numbers have generally increased, are characterized by a small tidal amplitude (Laursen *et al.*, 2009). Still, the migratory bird trends for most of these species are contrasting between the Dutch Wadden Sea and the rest of the Wadden Sea. Kleefstra & Schekkerman (2019) described that the Frisian mainland coast in the central part of the Dutch Wadden Sea has become one of the most important stopover sites for Curlew Sandpipers in the Wadden Sea and that it is one of the worm/benthos feeding species of which numbers declined in the German Wadden Sea in summer and autumn, while numbers in the (central part of) the Dutch Wadden Sea increased. High densities of mud shrimps have been suggested to explain this pattern. Looking at all species of which trends contrast, it is interesting to analyse the relationship with differences in local food availability within the Wadden Sea regions.

3.3.6 Other invertebrates

The indicator group of species feeding on "other invertebrates" consists of eight species: Common Shelduck, Northern Shoveler, Whimbrel, Eurasian Curlew, Common Redshank, Ruddy Turnstone, Black-headed Gull and Common Gull. Like the "worm/benthos-group", the trend of the group is stable in the long and short term. Only the Common Shelduck shows a moderate decrease, based on high tide roost counts (not based on counts of moulting Shelducks). The Northern Shoveler is the only species in the group that increased, mainly due to positive trends in Wadden Sea areas of Schleswig-Holstein and the Netherlands.

Blew *et al.* (2017) already stated that the food "other invertebrates" separates this group from the "worms/benthos-group", but it includes species that use a large variety of prey as well as a variety of bird taxa, such as ducks, waders and gulls. This variety makes an assessment of this group difficult. Common Shelduck, Whimbrel, Eurasian Curlew, Common Redshank, Ruddy Turnstone and Common Gull showed similar contrasting trends as the worms/benthos indicator group. This also seems to be related to food availability. An analysis of wintering and migrating Eurasian Curlews in the Netherlands also shows a more positive trend in the Dutch Wadden Sea and Delta than elsewhere in the Wadden Sea and it is suggested that total numbers mainly increased due to favourable foraging conditions with good supplies of prey species such as soft-shelled clam, ragworms and lugworms (Kleefstra *et al.*, 2021).

4. Recommendations

Blew et al. (2017) already stated that the current monitoring of migratory birds is well developed to keep track of changes of most migratory bird populations in the Wadden Sea. Now, after 33 years of monitoring, these data are of great value to detect trends of species (and groups), which is important for conservationists, managers and policy makers, aiming to protect migratory birds within the Wadden Sea. Blew et al. (2017) also gave a long and extensive list of recommendations, which is still up to date. Summarizing the previous chapters, we have the following recommendations for monitoring and research:

Monitoring:

- The quality of the high tide roost counts is a permanent point of attention. In Denmark more professional bird counters are needed in future to ensure that all the important areas are counted by qualified people. In Germany and the Netherlands, there is training needed to improve the quality and quantity of counts by volunteer counters. This could be done by organizing courses to learn about counting birds on high tide roosts, especially what is needed to ensure coverage and quality. A trilateral strategy for improvements on the quality (and quantity) of count data is needed.
- Fish-eating bird species have been underexposed to date. It is recommended to also look at the trends at the trilateral level for fish-eating species such as Lesser Black-backed Gull, Sandwich Tern, Common Tern and maybe egrets.
- Regarding moulting ducks in the Wadden Sea and adjacent areas in the North Sea, the main point of concern is that the available data on moulting ducks are incomplete, because a trilateral monitoring of all three species of moulting ducks is not guaranteed in the current monitoring program. All Wadden Sea regions should ensure annual monitoring of moulting ducks within the framework of their national migratory bird monitoring, contributing to the trilateral monitoring of moulting ducks in the international Wadden Sea.
- Regular counts of the German outer sands are needed to improve the quality of the trend assessments and should be integrated in the trilateral monitoring program for migratory birds.
- Recording disturbance is important for several research goals (Polwijk *et al.,* 2018):
  To calculate how the occurrence of waterbird disturbance varies among locations and within years. Different factors probably play a role in different seasons: recreational pressure is highest in summer. In winter, natural causes, such as Peregrine Falcons, may cause more disturbance.
  To find out how birds' responses to disturbance sources vary throughout the season. Do they get used to the disruptor? Will birds avoid areas with a lot of human activity?
  With this information, the long-term effects of anthropogenic disturbance on waterbirds can be studied.

Research:

- A new evaluation/analysis of the quality of high tide roosts is needed, with anthropogenic disturbance evaluated, and the quality of roosts in relation to feeding sites analysed. This will also require trilateral data on food availability, comparable with an intertidal benthic survey programme such as SIBES (NIOZ, 2018). It also advocates combining bird counts with the simultaneous assessment of (sources of) disturbance.
- The effects of civil and military air traffic (e.g. Vliehors at Vlieland, NL) must be assessed further on species other than Eurasian Oystercatcher, for instance, Bar-tailed Godwit and Eurasian Curlew, for which Vliehors is an important high tide roost. Research on the effects of air traffic is recommended on a trilateral level as there are indications from the Netherlands that there are effects on bird distribution. We further recommend that the 600-meter “allowed low-flight altitude” level should be implemented again in Germany, at least above protected areas such as National Parks and Nature protection areas
- By investigating where birds go and why, we can possibly better identify whether and how they can deal

with threats such as the sea-level rise and habitat destruction (feeding sites, high tide roosts). Tracking programmes are needed for protection and analyses purposes, as research initiatives by NIOZ, and the University of Kiel have shown.

- We still see strong contrasting trends between the Wadden Sea areas, for instance when it comes to several species in the indicator groups “Worms/benthos” and “Other invertebrates”. This deserves further attention, in which the relationship between high tide roosts and food availability plays a major role.
- Climate change affects bird population trends, distribution and survival and reproduction, but receives little research attention. A complication is that climate change affects migratory birds in all areas and in all periods within a migratory bird’s annual cycle in numerous ways. Those effects are often cumulative but are usually studied in isolation (Reneerkens, 2020). Within the Wadden Sea itself, two main threats are sea-level rise and the increase in frequency and intensity of heat waves (Reneerkens, 2020). Depending largely on the speed and scale at which it occurs, sea-level rise will lead to the loss of tidal flats in the Wadden Sea, which are an essential foraging area for large numbers of birds. There is also clear evidence that more frequent and intense heat waves can lead to mass mortality of shellfish (Beukema & Dekker, 2020; Suyderbuyk *et al.,* 2021). Blew *et al*. (2017) already named several recommendations for monitoring fluctuation in food stocks, also their effects of a changing climate should be monitored in the light of the migratory bird monitoring.
- A continuation of long-term, in-depth studies of demography (survival, reproduction and emi- and immigration) using colour-ringed individuals, perhaps extended with studies on a few extra species, can give insight into where and when along the East-Atlantic Flyway populations may run into trouble, and what may be causing this. This should better ecologically explain, and perhaps even predict, the population trends in the Wadden Sea and may lead to effective conservation action, if necessary.

5. Summary

Standardized high tide roost counts were used to assess changes in abundance of 34 waterbird species (some with sub-populations) in the Wadden Sea. Since the start of the monitoring scheme in 1987/88, population trends of seven species have increased, 14 remained stable and 13 declined. Over the last ten years, the number of increasing species went up to 14, while 14 species remained stable, seven were in decline and three remained to fluctuate. Species showing (continued) increases were Eurasian Spoonbill, Barnacle Goose, Northern Pintail, Northern Shoveler, Great Ringed Plover and Sanderling. Long- and short-term trends were decreasing for Common Shelduck, Mallard, Eurasian Oystercatcher, Pied Avocet, Dunlin and Spotted Redshank. In some cases, these declines came with a considerable reduction in maximum numbers, e.g. -43% in Eurasian Oystercatcher. Overall, a larger number of migratory bird species increased over the past ten years and fewer species were in decline.

From a flyway perspective, the results revealed stable (or even increasing) trends in the Wadden Sea compared to the flyway. This is in contrast to previous analysis which had indicated faster declines within the Wadden Sea than on the flyway level, notably for benthic-feeding species. Species that show more positive trends in the Wadden Sea compared to the flyway level are, for example, Grey Plover, Sanderling, Bar-tailed Godwit and Eurasian Curlew. Pied Avocet is one of the species showing pronounced declines in the Wadden Sea (also as a breeding bird) while being stable at the flyway level. It requires further research to understand what is causing these differences.

One major issue affecting bird abundance in the Wadden Sea includes disturbances at high tide roosts, by humans, predators or air traffic at low altitudes. In addition, species feeding mostly on benthic prey showed pronounced declines over the entire data series, albeit recent stabilisation which suggests that previous bottlenecks in food resources were less limiting, but not sufficient to aid full recovery. With respect to (human) disturbances, it is recommended to include records of disturbance in survey designs and repeat the review of high tide roosts done in the early 2000s. The lowered flight altitude for aircraft in the German Wadden should be reconsidered, at least in the designated National Park areas. More detailed studies on population demography and the spatial relationship between roosting numbers and food resources are needed to understand the patterns of increase and decrease in population trends and the usage of roosting areas within the Wadden Sea (in combination with global issues like climate change and sea-level rise). These studies are needed to develop adequate conservation action and measures. Improvement of the monitoring data quality, e.g. through better coverage of outer sands in the German Wadden Sea and more comprehensive surveys of moulting Shelduck and sea ducks in The Netherlands and Denmark, is needed to keep track of the success of measures being implemented.

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