FLIGHT ALTITUDES OF COASTAL BIRDS IN RELATION TO WIND DIRECTION AND SPEED

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Krüger, T. & Garthe S. (2001): Flight altitudes of coastal birds in relation to wind direction and speed. Atlantic Seabirds 3(4): 203-216. *During systematic sea watches carried out between 1 September and 15 November 1999 on the East Friesian island of Wangerooge, observations were recorded of the flight altitude of coastal birds in relation to wind direction and speed. In Red-throated Diver* Gavia stellata, *Common Eider* Somateria mollissima *and Common Scoter* Melanitta nigra *the proportion of birds flying into the wind low over the water (0-1.5m) increased with wind speed. On the other hand, in the same species, the number of low-flying birds decreased in inverse proportion to the speed of a tail wind and the ratio of birds flying at greater altitudes increased (1.5-12m and 12-25m respectively). Irrespective of wind speed, the proportion of individual birds flying low into the wind was highest in Red-throated Diver, Shelduck* Tadorna tadorna, *Common Eider and Common Scoter. This pattern is repeated at a higher level in Sandwich Tern* Sterna sandvicensis *and Common/Arctic Terns* S. hirundo/paradisaea. *In contrast, in tail winds, the greatest proportion of birds of these species invariably flew at the highest levels. Comparisons of flight altitudes reveal that these species fly noticeably higher in tail winds. This behaviour can be explained in terms of economy of effort on migration. The present study also reveals that diurnal movement of the observed species takes place mainly at a low flight altitude (up to 25m, occasionally up to 50m, rarely higher) above sea level. This demonstrates potentially adverse effects on birds from construction of proposed offshore wind farms. The data indicate that, to be of any value in the assessment of the potential disturbance of the wind farms to North Sea migrants, flight altitude records must be viewed against the background of the meteorological situation as a whole.*

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INTRODUCTION

Little is known about the flight altitudes of coastal birds migrating through the southern North Sea, and even less about their relation to meteorological parameters. Statements about flight altitudes based on sea-watch observations have generally been vague; scattered information about species migrating at a particular height may be found in Berndt & Drenckhahn (1974), Camphuysen & van Dijk (1983), Nehls & Zöllick (1990) and Temme (1995). Although radar observations have improved our understanding of bird migration over the North Sea substantially (Lack 1963; Jellmann 1979; Buurma 1987), they have not been able to provide clear information on low-level migratory movement until very recently; radar equipment used to date is mostly accurate only at heights above (50) 100-300 m, and it is often not possible to identify birds to species level using radar (Williams & Williams 1990; Berthold 2000). For a long time the intensity of low-level migratory movements over the sea generally were thought - aside from the moult migration of Shelduck *Tadorna tadorna*- to be of minor importance (*cf.* Jellmann 1979, 1987, 1989). Major improvements in radar technology now enable exact measurements of flight altitudes (e.g. Dirksen *et al.* 1996, 1998). However, such studies have been carried out so far only at selected locations, usually to inform environmental issues such as wind energy utilization.

The purpose of the study described here was to examine the flight altitudes of the most common coastal birds and seabirds by field observations of visible migration and to identify the influence of the meteorological parameters wind direction and speed.

METHODS

Visible migration of coastal birds and seabirds was studied on 52 days between 1 September and 15 November 1999 on Wangerooge Island, Germany. Wangerooge is located in the southern North Sea (German Bight; 53°47'N 07°54'E) and constitutes the easternmost of the East Frisian islands. Observations followed common sea watching methods (Camphuysen & van Dijk 1983) using a telescope (Swarovski, AT 30x80 HD). We excluded all common gull species from the observations (*Larus argentatus, L. fuscus, L. marinus, L. canus, L. ridibundus*) because it was impossible to distinguish between true migration and frequent local movements between resting and feeding sites. The method of sea watching has been proved suitable for describing and analysing migratory behaviour (e.g. phenology, influence of wind) of birds along the coast and at sea (e.g. Camphuysen & van Dijk 1983, Platteeuw *et al.* 1994). It is not the purpose of this study to assess all birds flying during day and night, which could be done much more comprehensively by radar studies.

In order to study whether wind direction and wind speed influence directly the flight altitude of migrating birds, all individuals passing Wangerooge were allocated to one of several pre-arranged flight levels. Because the estimation of flight altitude is difficult in general and because "observers nearly always overestimate the height of migrating birds" (Thienemann 1931, see also Gätke 1900, Lucanus 1923), a simple but accurate schema had to be devised (Fig. 1):

- Birds flying low over the water were allocated to the lowest level *(low)*. The upper limit of this level was about 1.5 m. In light winds and relatively calm seas it was easy to identify this level. In these conditions, the birds often flew so low over the

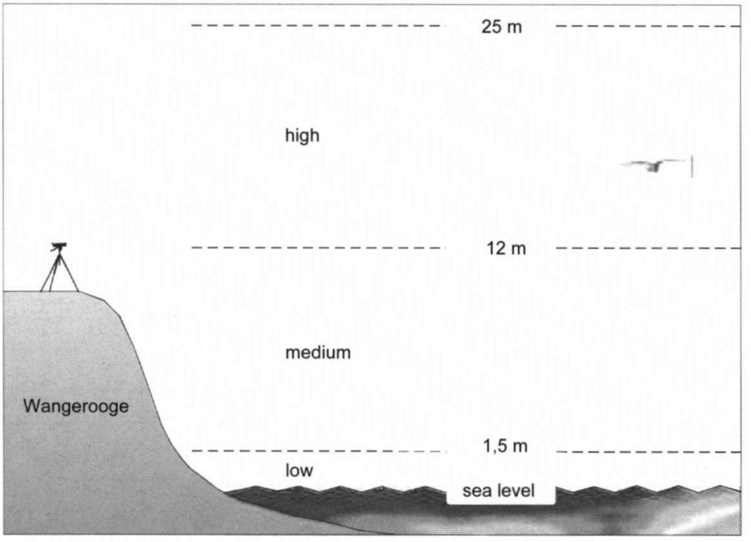


Figure 1. Allocation of flight altitude above the sea surface to various pre-determined levels.
Figuur 1. Verdeling van vlieghoogte in hoogteklassen ten opzichte van het zeeoppervlak.

surface that the reflection of their wingtips in the water was clearly visible at considerable distances. In rougher or stormy seas, high waves frequently forced the birds to leave their low trajectories for at least part of the time. To be sure of a correct flight altitude allocation, the observers were obliged to follow the flight paths over longer distances in order to distinguish between a *medium* flight altitude and a tendency towards a *low* trajectory.

- The upper limit of the next higher level *(medium)* was at eye-level for the observers and thus encompassed the space from about 1.5 m to 12 m a.s.l. This categorised all those birds that were not clearly flying "low" and yet not flying above eye-level (= side view). Birds in flight above eye-level, and thus viewed at an angle from below, were allocated to a third level *(high)*, whose upper limit was assigned to about 25 m.
- A further category *(very high)* was established for birds flying even higher, at flight altitudes > 25 to 100 m.
- The levels low, medium and high lay all within the telescope's field of vision. The observations were regulary interrupted by searching the sky for very high-flying birds with a binocular (Zeiss 10x40). As a rule, birds passing >3 km away were excluded from flight altitude assessments as these could not be estimated accurately.

Table 1. The correlation (r) between the percentage of birds passing Wangerooge in autumn 1999 and wind speed, grouped according to wind direction and flight altitude. Correlation coefficient r is in italics where p< 0.05 (cf. Fig. 2).
Tabel 1. Correlatie (r) tussen het aandeel vogels dat Wangerooge in het najaar van 1999 passeerde en de windsnelheid, gegroepeerd naar windrichting en vlieghoogte. Correlatiecoëfficiënt r is cursief indien p < 0.05 (cf. Figuur 2).

	Headwind	**Tail wind**
	Low	Low
Red-throated Diver	0.295	*-0.720*
Common Eider	0.550	*-0.770*
Common Scoter	0.223	*-0.668*

To minimise distortion of the results through other meteorological factors, rainy, hazy and foggy days during the period of the investigation were excluded from the evaluation (*cf.* Bruderer 1971). In order to correlate the observed migration with the wind, measurements of wind speed and wind direction were taken from a meteorological station on Minsener Oog (8 km E of Wangerooge; Wasser- und Schiffahrtsamt Wilhelmshaven, Abt. Gewässerkunde). During the study, the main migration direction was west. Consequently, winds from SW-NW are defined as headwinds, those from SE-NE as tail winds.

RESULTS

Flight altitudes in relation to wind speed and direction

Red-throated Diver *Gavia stellata* During headwinds, most Red-throated Divers migrated low over the water (range: 60-100%; Fig. 2). The proportion of low-flying birds increased with increasing wind speed, and was up to 100% beyond speeds of 10.8 m s^{-1}. High-flying individuals were seldom recorded in headwinds and even then the breezes were only light.

During light tail winds, the greatest percentage of Red-throated Divers were still low-flyers, even though this decreased significantly with increasing wind speed (Table 1, Fig. 2). No low flying Red-throated Divers were recorded in tail winds of over 15.4 m s^{-1}. Thus, the proportion of birds flying at medium height became greater with increasing wind speed. High-flying Red-throated Divers – rarely observed in headwinds – made up as much as 90% of the individuals in tail winds. Their proportion increased in general with wind speed.

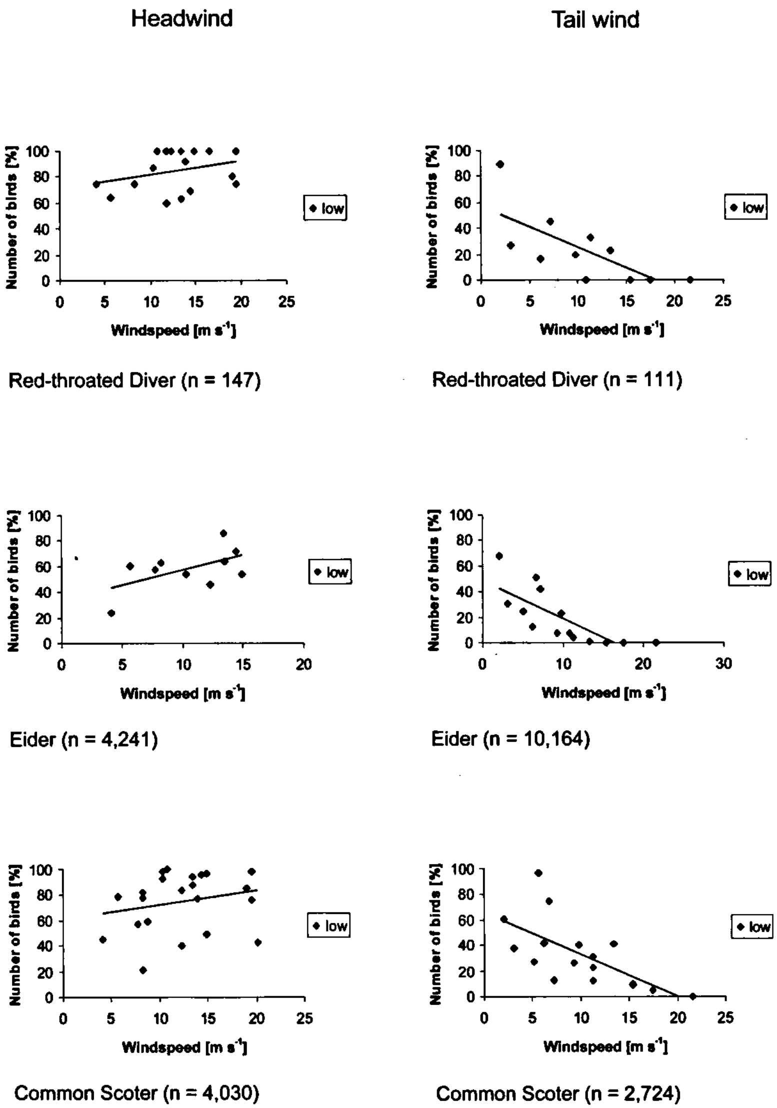


Figure 2. Flight altitude of westward migrating coastal birds in headwinds (NW-SW) and in tail winds (NE-SE). Lines = linear regression per flight level; correlation coefficient r: see Table 1.

Figuur 2. Vlieghoogte van westwaarts vliegende kustvogels bij tegenwind (NW-ZW) en bij meewind (NO-ZO). Lineaire regressielijn per vlieghoogte; zie tabel 1 voor waarden van correlatiecoëfficiënt r.

Common Eider *Somateria mollissima* The low flight path was the most frequently chosen by this species (46-72%; Fig. 2), increasingly so with stronger headwinds. The medium level was used most frequently at wind speeds of 4.1 m s^{-1} (42%), this proportion decreasing with stronger winds. The percentage of high-flying Common Eider dropped from 34% at 4.1 m s^{-1} to 0% at 13.4 m s^{-1} and more.

In light tail winds Common Eiders mainly flew low over the surface of the water (2 m s^{-1}: 68%; Fig. 2). The low level was used less with increasing wind speed, and was not used at all in winds in excess of 13.3 m s^{-1}. Instead, the proportion of high-flying Common Eider increased, reaching 86% at wind speeds of 13.3 m s^{-1}. The proportion of Common Eiders flying at medium height tended to remain constant with increasing wind speeds.

Common Scoter *Melanitta nigra* The percentage of Common Scoters flying low into the wind increased with increasing wind speed, reaching values of over 90% at speeds of 10.3 m s^{-1} and above (Fig. 2). Correspondingly, the stronger the wind, the smaller the number of Common Scoters migrating at medium level. Only 1-9% of the Common Scoters observed flew high into the wind. In tail winds of increasing strength, Common Scoters became increasingly reluctant to fly low over the surface of the water (Fig. 2). Instead, the percentage of birds migrating at medium height rose and eventually predominated. 5-39% of the Common Scoters passed at the high level but increasing wind speeds did not result in a clear trend.

Flight altitudes in relation to wind direction Considered without reference to prevailing wind speeds, westward moving Red-throated Divers used most frequently the low level in winds from the NW-SW sector (headwind; 83%; Fig. 3). They rarely flew higher (medium: 15%, high: 2%). In winds from the NE-SE sector (tail winds), the two (or three) higher flight levels were used more often: low = 34%, medium = 27%, high = 38%, very high = 1%. The pattern of flight altitude allocation in headwind conditions differed significantly from that in tail winds (Table 2).

When flying against the wind, approximately 75% of Shelduck passed low over the water and 23% selected the next higher level (Fig. 3). In tail winds, a preference for the high and very high levels was detected (51% and 3% respectively); the percentage of low-flying birds was 15%. In headwinds, the majority (58%) of Common Eider migrated low over the water, but large numbers also chose the medium level (34%; Fig. 3). In tail winds, the greatest number of Common Eiders flew past at medium height (38%), but almost as many (31%) – certainly much more than in Red-throated Divers and Common Scoters – migrated at high level. Westward migrating Common Scoters mostly

*Table 2. The numbers of coastal migrants passing Wangerooge in autumn 1999, grouped according to wind direction and flight altitude. χ^2 = significance of the 2*3 contingency tables for differences between headwinds and tail winds. $p < 0.001$.*

Tabel 2. Aantal trekvogels dat Wangeroog najaar 1999 passeerde, gegroepeerd naar windrichting en vlieghoogte. $p < 0.001$.

	Headwind			Tailwind			
	low	medium	high	low	medium	high	χ^2
Red-throated Diver	113	21	2	38	30	43	74.4
Shelduck	218	70	17	107	221	380	349.9
Common Eider	2442	1428	371	2998	3850	3316	1305.9
Common Scoter	3286	711	33	1022	1389	308	1429.8
Sandwich Tern	179	560	40	0	63	117	392.1
Comm/Arctic Tern	5	117	26	0	33	90	85.8

flew low over the water during headwinds, whereas the medium level was used most often during tail winds (51%; Fig. 3).

Most Sandwich Terns *Sterna sandvicensis* flying into the wind clearly preferred the medium level (72%) and a further 23% selected the low level (Fig. 3). In tail winds the high level was most frequently used (65%); 35% flew at medium height, and there were no records of low-flying migrating Sandwich Terns. 79% of Common/Arctic Terns *S. hirundo/paradisaea* migrated in headwinds at medium levels and another 18% flew high (Fig. 3). Headwinds saw the bulk (73%) of the birds in the high flight path, whereas only 23% were to be found at medium height.

Even within a single observation day it became evident that flight altitude was influenced by the direction of the wind. During the autumn migration period, Common Eiders off Wangerooge regularly moved in both easterly and westerly directions (see also Camphuysen & van Dijk 1983, Platteeuw *et al.* 1994). On days during which migration took place in both directions, one of the routes – eastward or westward – had headwinds. On nine headwind days (only days with more than 1,000 individuals were considered), Common Eiders migrated for the most part low in a westerly direction. Conversely, birds moving east on those days mostly had a medium or high flight altitude (Fig. 4). In same-day comparisons, they always moved one or two levels higher up. On nine tail wind days, however, the mass of the birds migrated medium or high levels in a westerly direction. The birds moving east for the most part flew low over the water (Fig. 4).

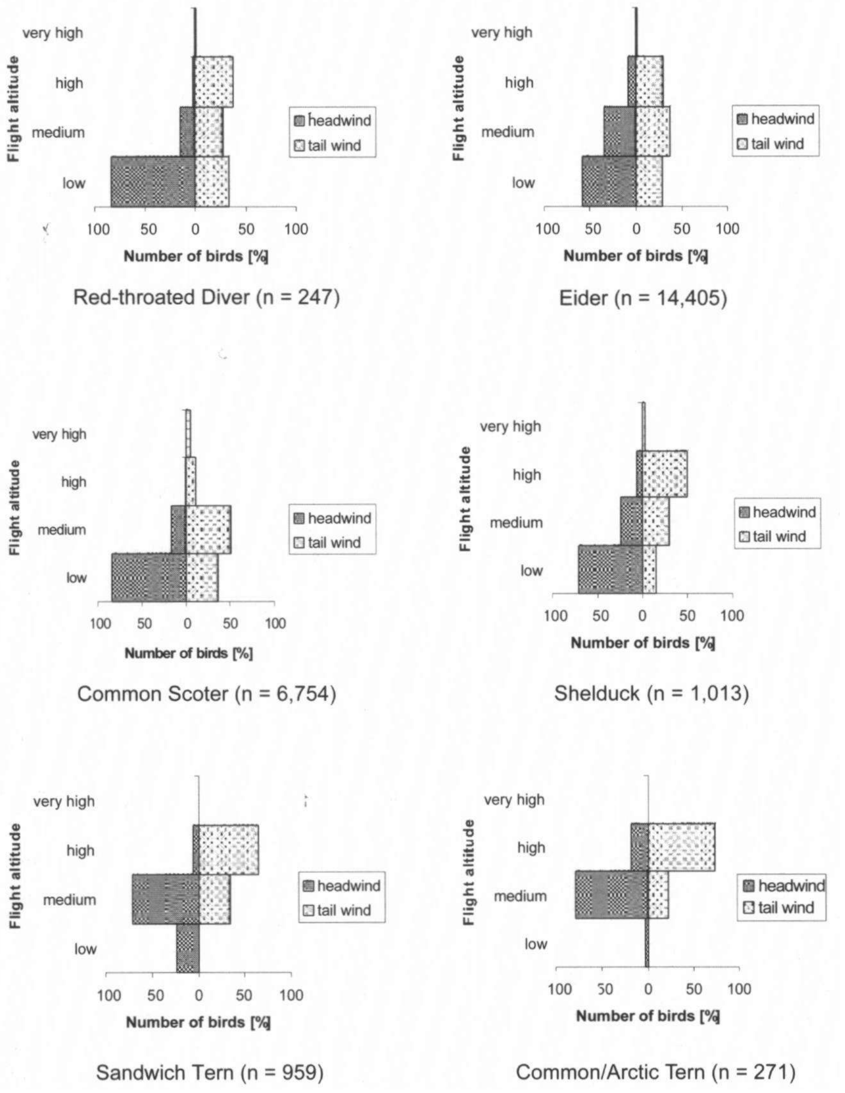
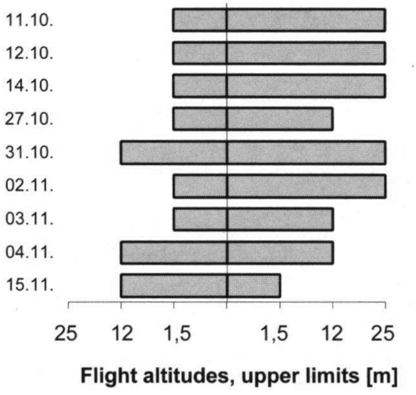


Figure 3. Relative frequency of westward moving coastal birds, grouped according to flight altitude and wind direction.

Figuur 3. Relatieve verdeling van westwaarts vliegende kustvogels, gegroepeerd naar vlieghoogte en windrichting.



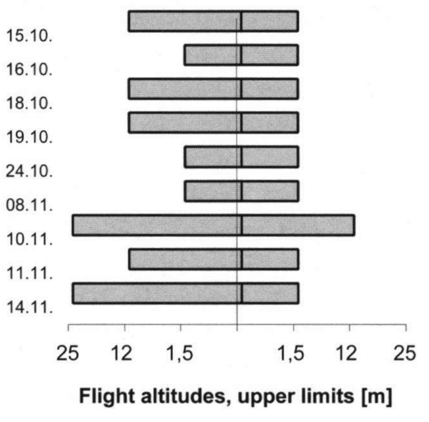
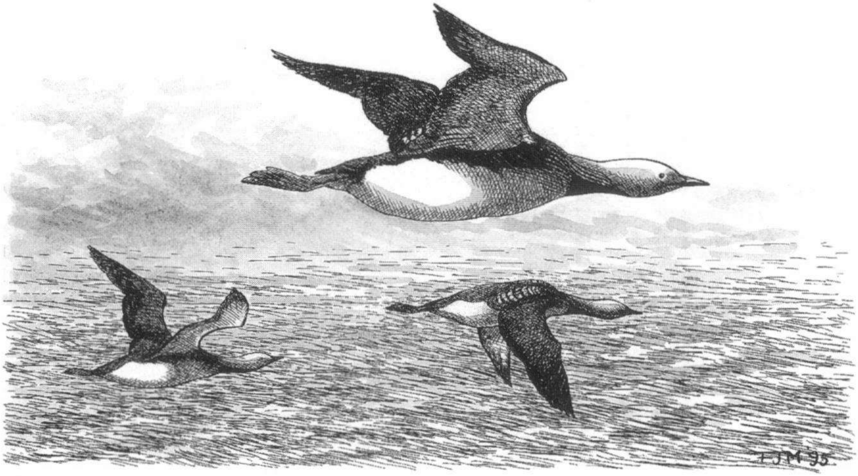


Figure 4 . Common Eider flight altitudes on days with NW-SW winds off Wangerooge (upper) and Common Eider flight altitudes on days with NE-SE winds off Wangerooge (lower), autumn 1999. The bars show in each case the most frequent level; westerly migrants to the left, easterly to the right of the central axis.

Figuur 4. Vlieghoogtes van Eiders op dagen met NW-ZW-winden langs Wangerooge (boven) en vlieghoogtes op dagen met NO-ZO-winden (onder), najaar 1999. De staven geven voor iedere dag de meest frequente vlieghoogte weer; westwaarts vliegende vogels links, oostwaarts vliegende vogels rechts van de y-as.



Black-throated Divers Parelduikers *(Frits-Jan Maas)*

DISCUSSION

According to Bruderer (1971), migration altitude is influenced – always within the limits set by the aerodynamic and physiological characteristics of the species – by secondary (external) factors, principally meteorological factors such as wind, fog, cloud conditions and precipitation, and changes in overall weather conditions. Among these, wind is of greatest importance (Alerstam 1979a). The horizontal speed of wind over the sea increases with height; directly above the water surface there is a zone of lower wind speed caused by the breaking effect of the water. Jameson (1960) describes a case where the wind speed just 15 m above sea level was at force 8 Bft, twice that immediately above the water surface. Wind reaches its full force only above 500 m (Alerstam 1979b; Nachtigall 1987; Stein & Schultz 1995).

Assuming that the radar ornithological results apply, the observations of the present study confirm those of numerous investigations showing that the height of migration in tail wind conditions is greater than that in headwinds, and that where wind direction is opposed to the migration direction, in general lower flight altitudes with attendant lower wind speeds are selected (Bruderer 1971; Karlsson 1976; Kumari 1983; Bruderer 1997; Bruderer & Liechti 1998).

The reason for the migratory behaviour observed off Wangerooge is probably that birds need to save time and energy when on migration (cf. Berthold 2000). In general, active flying costs birds much energy per unit of time. In order to minimise these costs, some bird species have developed flight techniques that enable them to cover long distances with less energy expenditure (e.g. gliding and soaring, formation flying; see reviews by Rüppel 1980; Norberg 1996). Still other species employ alternating flight techniques, such as the shearwaters, which flap-glide, alternately beating their wings and sheering through the wave-troughs. These means of saving energy are not available to all species. Some species have unfavourable wing area to body mass ratios (wing loading) and find it impossible to glide or soar long distances over water; such species are obliged to propel themselves forward by continuous wing-beating (swans, geese, ducks, auks etc., Rüppel 1980; Pennycuick 1987 a, b). The species under investigation in this paper belong mostly to the latter group. The most efficient way for these birds to minimise energy costs of migrating up-wind in terms of optimal migration (Alerstam & Lindström 1990) is to fly low – the stronger the headwind, the lower the flight level. In tail winds, they migrate more efficiently at greater heights (see also Gatter 2001). The present study suggests, that this pattern is also valid for migration across the North Sea at low(er) altitudes.

Behaviour like this makes it possible for birds in some cases almost to double their flight speed and to halve their energy costs (Liechti & Bruderer 1998; Liechti & Schaller 1999; Liechti *et al.* 2000). These relationships have already been found by Bellrose (1967) who summarised the findings of his radar studies: "[...] demonstrate that birds have a phenomenal understanding of winds. They select [...] altitudes having favourable directional winds and favourable wind speeds." The data on flight altitudes presented in this paper are predominantly based on migration flights (Krüger 2001). It is, however, not possible to quantify the extent to which they have been influenced by compensating movements or have been caused by disturbances. Those shorter flights could be performed in a different manner (e.g. lower flight altitudes) and under different energy saving strategies as real migration flights.

An interesting result of this study is that the visible, diurnal movements of the species investigated take place mainly at low heights above the water surface (up to 25 m, occasionally up to 50 m, rarely higher). This accords with other observations of bird migration in coastal areas. Thus 75% of migrating Red-throated Divers in the Fehmarn Belt (Baltic Sea) in the winter of 1956/57 were observed between 6 and 15 m (mean flight altitude: 10.5 m, maximum: 45 m). In other years also, flight altitudes of 60-100 m were registered during tail wind conditions (Drenckhahn *et al.* 1974). Temme (1974) found that the majority of Common Eiders off Norderney (southern North Sea) migrated between 1 and 3 m over the water surface, in rare occasions up to 20-25 (45) m. Common Scoters off Rügen (Baltic Sea) were recorded migrating usually at altitudes of 1-2 m; in strong tail winds they reached 10-100 m (Nehls & Zöllick 1990).

The findings of this study are not only interesting in terms of coastal bird ecology but also with respect to current environmental issues in the southern North Sea. Extensive plans to construct windmill farms in offshore areas of the German Bight and other areas may create a substantial risk for migrating birds at sea. In order to study the potential risk with regard to collision (which causes mortality) and flight route disturbance, comprehensive environmental impact assessments need to be carried out (e.g. Garthe 2000). Such studies should consider flight altitudes of birds also in relation to the prevailing meteorological situations.

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VLIEGHOOGTES VAN KUSTVOGELS IN RELATIE TOT WINDRICHTING EN WINDSNELHEID

Tijdens systematische zeetrektellingen tussen 1 september en 15 november 1999 op het Oost-Friese eiland Wangerooge, werden waarnemingen verzameld over de vlieghoogte van kustvogels in relatie tot windrichting en -snelheid. Bij Roodkeelduiker *Gavia stellata*, Eider *Somateria mollis*ima en Zwarte Zee-eend *Melanitta nigra* nam het aandeel laag (0-1.5 m)tegen de wind in vliegende vogels toe met toenemende windsnelheid. Het aandeel laag vliegende vogels nam met meewind omgekeerd evenredig af met de windsnelheid, terwijl het aandeel hoger vliegende vogels (1.5-25 m) toenam. Het aandeel individuen dat tegen de wind invloog was, ongeacht de windsnelheid, het hoogst bij Roodkeelduiker, Bergeend *Tadorna tadorna*, Eider en Zwarte Zee-eend. Grote Stern *Sterna sandvicensis* en Noordse Dief *S.hirundo/paradisaea* vertonen een zelfde beeld, zij het op grotere hoogte. Met meewind vloog het merendeel van deze soorten in de bovenste hoogteklassen. Vergelijking van de vlieghoogtes laat zoen dat alle soorten met meewind aanmerkelijk hoger vliegen. Dit gedrag kan verklaard worden uit energetisch oogpunt. Deze studie laat tevens zien dat dagtrek van de waargenomen soorten met name op lage hoogtes (tot 25 m, soms tot 50 m, zelden hoger) boven zee plaatsvindt. De gegevens wijzen op potentiële, schadelijke effecten op vogels van de bouw van voorgestelde offshore windmolenparken. Om van enig nut te zijn bij risico-analyse van potentiële verstorende effecten van windmolenparken op door de Noordzee trekkende vogels moeten waarnemingen van vlieghoogtes tegen de achtergrond van de gehele metereologische situatie beschouwd worden.

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