From: BrownScott, Jennifer
To: Sissi Bruch; Elizabeth Tobin; Hansi Hals
Cc: Kilbride, kilb; Loverti, Vanessa
Subject: Draft Avian Monitoring Plan
Date: Monday, May 17, 2021 10:10:47 AM
Attachments: Mori 2001.pdf
Owens1977.pdf
Smit and Visser 1993.pdf
Smit and Visser 1993_reduced.pdf

Thank you for the opportunity to provide comments/recommendations related to monitoring impacts from commercial aquaculture operations proposed on the DNR Use Easement tidelands within the boundary of Dungeness National Wildlife Refuge. To reduce duplication, we have consolidated WA Maritime NWRC, Region 1 Inventory and Monitoring Program and R1 Migratory Bird Program comments/recommendations related to the JST draft avian monitoring plan below:

Given the uncertainty of disturbance outcomes, importance of the area for migrating and wintering shorebirds and waterfowl, and the high interest in understanding potential impacts, a robust sampling scheme providing data for statistical analysis would be the most appropriate monitoring/study design. During meetings with your team we discussed how the lack of baseline data and difficulty in identifying adequate replicate/control plots renders many monitoring approaches ineffectual. We continue to recommend a BACI design assessing effects (disturbance) to migratory birds at the level of the lease area itself (rather than within small sampling units) as the appropriate monitoring method to generate statistically defensible conclusions. It is our understanding from group discussion that Jamestown S'Klallam Tribe's intent to initiate oyster farming operations this summer, and other management constraints, have resulted in selection of a non-BACI designed monitoring plan. Although not recommended due to data analysis and interpretation limitations, we would provide the following comments/suggestions if a non-BACI design is chosen:

The monitoring approach detailed in the draft avian monitoring plan is not likely to provide data appropriate for statistical analysis or allow scientifically defensible conclusions related to shorebird and waterfowl disturbance from commercial aquaculture activities in this location. The statistical approach identified in the draft plan (ANOVA) requires independence of treatment plots, and homogeneous and normally distributed variance for control and treatment data. Given all treatment plots need to be located within a distance of farming activities where disturbance effects may occur, we are concerned there may not be the ability to create the independence required for ANOVA. Control plots would not be comparable to treatment plots given the unique, transitional nature of the lease area. Additionally, many zero data points are likely to be collected (no birds seen) due to the small size of the sampling units (approximately 150 ft in width), which would not provide a normal distribution. Given these site and study design limitations, it is unlikely that ANOVA could be used to analyze collected data.

Assessment of disturbance effects to all migratory birds in and around the lease (e.g., within flushing distance of the lease) would provide an anecdotal representation of potential effects on and adjacent to the lease are compared with focusing on focal species within small sampling units. These effects should include changes to foraging behavior (e.g., pause in feeding, gear avoidance) in addition to those listed in the monitoring plan. Consider conducting area counting of birds (shorebirds and waterfowl), where these counts would be partitioned by strata (eelgrass, mudflats, and 5-acre farmed plot) in the 50-acre lease area with a buffer based upon flight disturbance distance.

We do not recommend monitoring only target species due to the difficulty in identifying birds to species, especially at night. Targeting a limited number of species could create a zero data point, even if disturbance to birds was occurring at the site. If an approach is approved that allows only monitoring of target species, then western sandpiper and dunlin are more appropriate species than least sandpiper.

Observation should be performed by an experienced neutral third party at frequencies adequately representing the possible impact of aquaculture activities that likely vary by season, throughout individual months, and over time. More frequent data collection is needed to better capture this variability and cumulative impacts of human disturbance. Information collection should also capture disturbance from predators (e.g., eagles) or other sources (e.g., refuge visitors). Feasibility and accuracy of performing observations at night using different approaches should be examined to determine the monitoring limitations. This is particularly important because farm operations during the most sensitive time periods will likely take place at night, due to the association with low tide cycles.

The monitoring plan should describe key assumptions associated with the sampling design, the level of accuracy and precision of the data collected, and sources of error (sampling and non-sampling) associated with the methodology for data collection. One or more sampling objectives describing the bias and precision for the survey would provide transparency regarding limitations of data interpretation and use. results mean and how they can be interpreted and used.

The attached references (Mori et al., 2001; Owens 1977; and Smit & Visser 1993) appear to provide greater maximum flushing/disturbance distances than those listed in the draft plan.

If we can provide any further assistance or clarification of our comments, please do not hesitate to reach out.

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The effect of human disturbance and flock composition on the flight distances of waterfowl species

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ARTICLE

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The effect of human disturbance and flock composition on the flight distances of waterfowl species

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Abstract Flocking bird species tolerate an approaching human up to a certain distance. We measured this distance, i.e., flight distance, to an approaching small boat for 11 waterfowl species. The flight distances correlated positively with flock size and species diversity (Shannon index H') in species that showed relatively short flight distances when they were in a single-species flock. However, we did not observe such a correlation for single-species flocks that showed relatively long flight distances. Only pochards (*Aythya ferina*), a species with large individual variation in flight distances, showed a positive correlation between flight distance and flock size in both single- and multispecies flocks. Flight distance seemed to be affected by usage of the water area: flight distances tended to be longer for waterfowl species that use a water area for foraging than for those that use it primarily for resting. Thus, the behavior of actively foraging species may be more affected by human disturbances than that of resting species.

Key words Flight distance · Flock composition · Human disturbance · Usage of water area · Waterfowl species

Introduction

Flocking bird species tolerate an approaching human up to a certain distance within which they attempt to escape. This distance (flight distance) can be used to determine the effect of human disturbance on wild birds, and there are numerous studies that report how human activities affect terrestrial birds (Stalmaster and Newman 1978; Dhindsa and Boag 1989; Kenney and Knight 1992; Greig-Smith 1981; Cooke 1980; Roberts and Evans 1993).

Some authors have studied the effects of human activities on waterfowl (Batten 1977; Boyle and Samson 1985; Korschgen et al. 1985; Banford et al. 1990; Klein 1993; Rodgers and Smith 1997). The waterfowl species in these studies include Pelecaniformes (e.g., pelicans and cormorants), Ciconiiformes (e.g., egrets and herons), and Charadriiformes (e.g., plovers), but the information on Anseriformes (e.g., ducks), which is one of the most common waterfowl in winter in Japan, is rather limited. Moreover, there are few studies on waterfowl species in which flight distances are measured and discussed in relation to flock composition (but see Rodgers and Smith 1997).

Many migrant wintering waterfowl species in Japan, especially ducks, assemble to forage and rest at water areas that are used for human activities such as fishing and boating. Therefore, it is of interest from not only an ethological but also a conservation perspective how these waterfowl respond to human disturbance and what factors influence their behavior, because fishing and boating, which are popular recreations, may disturb habitats and decrease waterfowl numbers.

We report here on flight distances of waterfowl flocks disturbed by an approaching boat and discuss factors that influence the flight distances of waterfowl. We determined whether (1) flight distances varied among species and between single- and multispecies flocks and (2) flight distances were affected by flock characteristics (size and diversity), usage of water area (resting versus foraging), body mass, and muscle mass per body mass.

Methods

The study was conducted between January 18 and 22, 2000, on the north and south parts of Lake Biwa, Lake Nishinoko, and Takayama Dam Lake (Fig. 1). Total survey times were 6, 4.5, 3, and 4 h for north and south parts of Lake Biwa,

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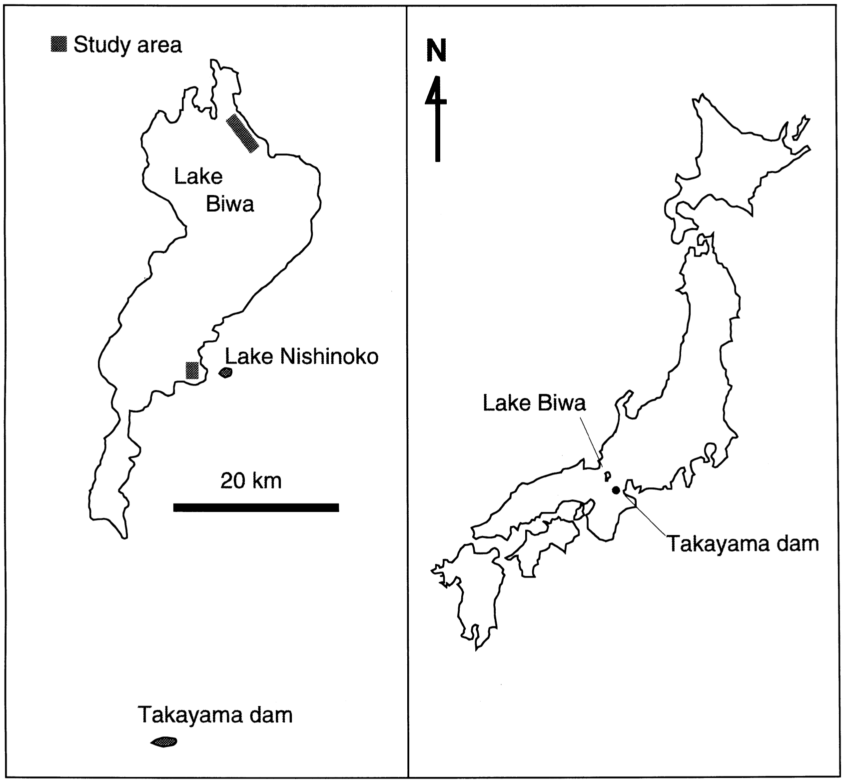
Fig. 1. Map of the study areas



Lake Nishinoko, and Takayama Dam Lake, respectively. Flight distances were measured using a Laser Range Finder (model 200400; Bushnell, USA). The procedure for measuring flight distance was (1) locate a target flock, (2) record characteristics of the flock (the number of birds and species), (3) approach the flock by a small boat (with a 9.9-hp outboard motor; Yamaha, Japan) at a speed of 10 km/h, and (4) record the distance at which the birds (or each species) of the flock flew off. Time interval between the approaches was within 5 min. During the interval, we could move in the opposite direction of the flying birds about 200 m to find a new flock unlikely to have been disturbed by the previous approach. We did not identify individual birds during the study; therefore, a few individuals may have been approached more than once. However, as the study areas were large and there were many waterfowl in the area, the chances of repeated observations of an individual were minimal. Because of uneven sampling effort we had to pool data from different lakes. In most cases, all members of the approached flock flew off almost simultaneously, but we measured the flight distance for the bird of each species that flew off first.

In data analysis, we defined a flock composed of single species as a single-species flock and those with more than one species a multispecies flock. We measured 201 flight distances of single-species flocks and 152 flight distances for 63 multispecies flocks in total. We also grouped the waterfowl species into two groups: "resting species" and "foraging species" according to diet and foraging patterns, based on Haneda (1952, 1954, 1962). Resting species use a water area mostly for resting and mainly forage on a land-based diet such as nutritious nutlets and seeds (more than 50% of total diet), whereas foraging species have a mainly aquatic diet such as aquatic plants, insects, and mollusks (more than 50% of total diet). However, for wigeons, Haneda (1962) reported that more than 50% of the diet was aquatic, but Takeshi Watanabe (unpublished data) observed that wigeons in Kinki district, where the present study was conducted, forage mainly on land-based diets. Therefore, we considered this species a resting species. Resting species observed in the survey were green-winged teals (*Anas crecca*), wigeons (*A. penelope*), mallards (*A. platyrhynchos*), spot-bill ducks (*A. poecilorhynchoa*), gadwalls (*A. strepera*), and mandarin ducks (*Aix galericulata*). Foraging species observed were shovellers (*Anas clypeata*), falcated ducks (*A. falcata*), pochards (*Aythya ferina*), tufted ducks (*A. fuligula*), and Bewick's swans (*Cygnus bewickii*). A statistical test revealed that it did not affect this grouping whether the waterfowl species was *Anas* or the other genus (Fisher's exact test; $P = 0.24$). Thus, phylogenetic bias affecting the grouping of water area usage is negligible. The values for body mass and muscle mass per body mass for each waterfowl species used were obtained from Haneda (1961).

Results

Waterfowl species and flight distance

Mean flight distance of waterfowl species varied between 64.5 m (gadwalls) and 160.0 m (Bewick's swans) and between 82.7 m (wigeons) and 141.5 m (Bewick's swans) in a single-species flock and a multispecies flock, respectively (Table 1). Significant interspecies difference was found for single-species flocks (Kruskal–Wallis test, $H = 58.94$, 10 df; $P < 0.01$), but not for multispecies flocks ($H = 14.01$, $P > 0.05$). Variation of mean flock size among species were not responsible for the interspecies difference of flight distance in single-species flock (Kendall's rank correlation; $n = 11$, $\tau = 0.02$, $P > 0.05$). Gadwalls, wigeons, spot-bill ducks, and green-winged teals, which showed relatively short flight distances in single-species flocks, had longer flight distances in multi- than in single-species flocks, but the rest of the species did not show this trend (see Table 1). Larger flock size in multispecies flocks of those four species did not seem to be responsible for this trend, because not only those four species but also other species, except for mandarin ducks and Bewick's swans, showed larger flock size in multispecies flocks (Table 1).

The mean flight distance in single-species flocks for resting species (mean ± SD, 78.9 ± 15.1 m; $n = 6$) was significantly shorter than that for foraging species (122.9 ± 30.1 m, $n = 5$; U test, $U = 2$, $P < 0.05$). In multispecies flocks, there was no significant difference in mean flight distance between "resting" and "foraging" species (99.0 ± 13.5 m, $n = 6$ and 116.0 ± 17.3 m, $n = 5$ for resting and foraging species, respectively; $U = 7$, $P > 0.05$). Flight distance of a multispecies flock composed of only resting species was significantly shorter than that with foraging species (85.5 ± 29.1 m, $n = 29$ and 110.5 ± 54.8 m, $n = 37$; U test, $U = 372$, $P < 0.05$). Flock size of multispecies flocks did not show this tendency (17.6 ± 18.5 and 35.1 ± 49.3 for flock without and with foraging species, respectively; $U = 510$, $P > 0.05$).

Neither body mass nor muscle mass/body mass correlated with mean flight distance of waterfowl species in single-species flocks ($n = 10$; body mass, $\tau = 0.345$, $P > 0.05$; muscle mass/body mass, $\tau = 0.07$, $P > 0.05$), suggesting that physical characteristics did not affect the flight distance.

Time of day (morning or afternoon) did not influence the flight distance for each species except for mallards in multispecies flock [mean ± SD of mallards, 123.6 ± 57.4 m ($n = 12$) and 78.0 ± 20.1 m ($n = 7$) for morning and afternoon, respectively; U test, $U = 18.5$, $P = 0.047$], but flock size of mallards in multispecies flock did not differ between time of day (34.7 ± 33.7 and 20.6 ± 20.8 for morning and afternoon, respectively; U test, $U = 28.5$, $P = 0.25$).

Flock characteristics and flight distance

Positive correlation between flock size and flight distance was found in 5 of 11 species (gadwalls, wigeons, spot-bill ducks, pochards, and mallards) in pooled data (Table 2). However, only pochards showed consistent correlation between flock size and flight distance in both single- and multispecies flocks. The diversity index (Shannon index, H') of flocks was positively correlated to flight distance in gadwalls, wigeons, spot-bill ducks, and green-winged teals (Table 2). Because these species did not show correlation between flock size in multispecies flocks and flight distance, the diversity of flocks certainly affected the flight distance of these species. All these species showed relatively short flight distance in single-species flocks (see Table 1). Species that showed relatively long flight distances in single-species flock did not show a significant correlation between diversity of flocks and flight distance (Tables 1, 2). Flight distances in a single-species flock of the foregoing six species that showed correlation between flight distance and flock characteristics (77.4 ± 42.6 m, $n = 131$) were shorter than those of the other species (119.8 ± 54.9 m, $n = 70$; $U = 2265.5$, $P < 0.01$). Therefore, flock characteristics affected flight distance for species that showed relatively short flight distance in single-species flocks.

Usage of water area seemed to affect the relationship between flock characteristics and flight distance: five species of the six species that showed significant correlation between size or diversity of flock and flight distance were "resting species," and four species of the five species that showed no significant correlation between flock characteristics and flight distance were "foraging species." However, this tendency approached but did not achieve significance (Fisher's exact test; $P = 0.067$).

Table 1. Summary of the survey

Species	Type	Flock size [mean ± SD (n)]			Flight distance (m) [mean ± SD]		
		ssf	msf	difference	ssf	msf	difference
Gadwalls	R	3.1 ± 1.8 (19)	27.2 ± 32.9 (25)	$P < 0.01$	64.5 ± 16.6	107.2 ± 52.9	$P < 0.01$
Wigeons	R	6.6 ± 10.7 (38)	29.6 ± 45.3 (27)	$P < 0.01$	67.7 ± 35.2	82.4 ± 19.6	$P < 0.01$
Spot-bill ducks	R	4.6 ± 5.6 (17)	23.9 ± 30.8 (14)	$P < 0.01$	69.3 ± 37.5	91.1 ± 35.6	$P < 0.05$
Green-winged teals	R	5.5 ± 5.4 (15)	25.5 ± 44.0 (12)	$P < 0.05$	76.3 ± 57.6	93.2 ± 36.8	$P < 0.05$
Pochards	F	11.6 ± 19.8 (15)	47.4 ± 55.5 (21)	$P < 0.01$	88.6 ± 34.8	104.9 ± 51.5	n.s.
Mandarin ducks	R	16.5 ± 16.6 (21)	38.0 ± 7.1 (2)	n.s.	96.0 ± 39.3	117.5 ± 9.2	n.s.
Mallards	R	5.6 ± 9.9 (28)	29.5 ± 29.8 (19)	$P < 0.01$	99.3 ± 53.1	106.8 ± 51.5	n.s.
Falcated ducks	F	2.9 ± 2.5 (12)	11.6 ± 10.6 (9)	$P < 0.01$	103.7 ± 51.6	100.4 ± 41.1	n.s.
Shovellers	F	1.3 ± 0.6 (12)	50.1 ± 60.7 (7)	$P < 0.01$	114.2 ± 64.4	107.0 ± 38.0	n.s.
Tufted ducks	F	5.1 ± 4.0 (15)	54.6 ± 60.8 (14)	$P < 0.01$	148.0 ± 61.9	139.0 ± 73.3	n.s.
Bewick's swans	F	11.1 ± 6.9 (9)	44.5 ± 27.6 (2)	n.s.	160.0 ± 26.9	141.5 ± 82.7	n.s.

Type, type of water area usage; R, resting; F, foraging (see text); ssf, single-species flock; msf, multispecies flock; difference, difference between single- and multispecies flocks tested by U test; n.s., not significant

Table 2. Correlation between flight distance (FD) and flock characteristics (size and diversity)

Species	Type	FD vs. flock size			FD vs. H'
		ssf	msf	pool	
Gadwalls	R	n.s.	n.s.	0.28	0.39
Wigeons	R	0.25	n.s.	0.30	0.27
Spot-bill ducks	R	0.36	n.s.	0.44	0.36
Green-winged teals	R	n.s.	n.s.	n.s.	0.39
Pochards	F	0.41	0.27	0.32	n.s.
Mandarin ducks	R	n.s.	n.s.	–	–
Mallards	R	n.s.	n.s.	0.22	n.s.
Falcated ducks	F	n.s.	n.s.	n.s.	n.s.
Shovellers	F	n.s.	n.s.	n.s.	n.s.
Tufted ducks	F	n.s.	n.s.	n.s.	n.s.
Bewick's swans	F	n.s.	n.s.	–	–

Diversity, Shannon index (H'); Type, type of water area usage; R, resting; F, foraging (see text); ssf, single-species flock; msf, multispecies flock; pool, pooled data

Values are Kendall's τ ($P < 0.05$); ns, not significant; –, cannot be tested because of small sample sizes

Discussion

Previous studies on flight distance of terrestrial birds reported that the flight distance varies depending on species, age of flock members, and size of the flocks (Dhindsa and Boag 1989; Burger and Gochfeld 1991). Our results revealed that there were interspecies differences in flight distances and consistency of the relationship between flight distance and that flock characteristics (e.g., single- versus multispecies flock) also depended on species. There were two types of waterfowl showing different response in flight distances to human disturbance: (1) species showing relatively short flight distances that are also affected by flock size and diversity (gadwalls, wigeons, spot-bill ducks, green-winged teals, and pochards, mallards; type 1), and (2) species showing relatively long flight distances in single-species flocks that are not affected by flock characteristics (mandarin ducks, falcated ducks, shovellers, tufted ducks, and Bewick's swans; type 2).

Numerous authors have discussed the effect of vigilant individuals on flight in birds (Batten 1977; Cooke 1980; Greig-Smith 1981). Matsuoka (1994) tested and partially supported this effect with the brown-eared bulbul, *Hypsipetes amaurotis*. These authors have concluded that because a flock may react in accordance with its most vigilant member and that there is a greater chance of having at least one alert member in larger flocks, flock size positively affects the flight distance. This concept may explain the tendency that flight distances of multispecies flock of type 1 species were longer than those of single-species flock because a multispecies flock, at least for some species (type 1), may translate to the higher likelihood of more vigilant species (type 2) in the flock. The finding that multispecies flocks with foraging species showing a relatively longer flight distance exhibited greater flight distances than those without them also supports the explanation.

It is interesting that, in the present study, consistent correlation between flock size and flight distance was found only in pochards, especially in a single-species flock. Pochards showed a large variation in flight distance; the coefficient of variation was 0.61 when the flock was composed of only one bird ($n = 6$), which is the largest value among the waterfowl studied (0.22–0.61). This large individual difference in flight distance is a possible reason why flight distance in pochards correlates to size rather than diversity of the flock.

What factors affect the vigilance of waterfowl species? For example, flight distance may be influenced by the flight ability of species such as easiness of takeoff (Cooke 1980; Burger and Gochfeld 1991). Thus, species with heavy body mass or small muscle mass/body mass should show long flight distances, but this is not the case for waterfowl species in the present study. Rodgers and Smith (1997) also reported no correlation between body size and flight distance in waterfowl in Florida.

The flight distances of resting species tended to be affected by flock characteristics (size or diversity), but those of foraging species were not affected. Flight distances of foraging species in single-species flocks were significantly longer than those of resting species. These observations suggest that usage of water area has a role in determining the flight distance of waterfowl species. For foraging species, long flight distance is likely influenced because of the trade-off of vigilance with foraging. Barbosa (1995, 1997) reported that different vigilance rates result in different flocking behavior in waders; tactile hunters tend to make larger flocks than visual hunters to avoid predators. Thus, the behaviors of species that have to trade off between vigilance and foraging may be strongly affected by predation risk. As for the foraging species in the present study, they correspond to tactile hunters among wading birds because foraging species have to dive for foraging. This finding suggests that the foraging species are under greater predation risk and are more sensitive to approaching strangers than are resting species. Another possible and compatible explanation for the longer flight distance of foraging species is that these species use rather open water area for foraging. Thus, the birds can become aware of strangers approaching.

If the foregoing interpretation is correct, we predict that flight distances of fish-eating waterfowl such as goosanders (*Mergus merganser*) or common cormorants (*Phalacrocorax carbo*) and little grebes (*Tachybaptus ruficollis*) should be relatively long and should not be affected by flock characteristics. This prediction is testable but further studies are required.

The present results indicate that effects of human disturbance on waterfowl depend on species and flock characteristics. Thus, effects of intensive boating activity should be considered for the management of waterfowl species. For example, bass fishing using a small motorboat is very popular in these days, but intensive boat-fishing activity at shallow water areas that are rich in aquatic plant and benthos and are favorable for sensitive foraging species of waterfowl should be restricted, even if the area is good for fishing.

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Responses of wintering Brent Geese to human disturbance

N. W. OWENS

This paper describes the effects of human disturbance on Dark-bellied Brent Geese *Branta bernicla bernicla* wintering in Essex in 1973–1974 and 1974–1975 in terms of: (a) the restriction of feeding area; (b) the effects on feeding behaviour and flighting. The study was one of four interrelated studies of Brent Geese, initiated by the proposal to reclaim the Maplin Sands (an important Brent Goose feeding area) to build the third London airport.

Methods

The study area included all the coastline between the River Colne and Leigh Marsh in Essex (Figure 1). Seasonal changes in the numbers and precise distribution of geese were recorded on 1:25,000 outline maps, and also the nature and intensity of disturbance and local movements of geese. The amount of feeding time lost, and the extra time in flight, through disturbance were determined. An area was selected and observation begun 10 minutes after arrival, to allow the geese to settle, from at least 200 m away. Once a minute the number of geese present, the proportion of geese feeding, in eighths, and the number of geese in flight, were recorded. The time and estimated distance from the geese of every disturbance were also recorded within each minute.

A count or good estimate of the number of flying birds was made once every minute, and an estimate, in eighths, of the proportion of the flock that held their necks below horizontal. (Birds occasionally held their heads low for other reasons than feeding.) The accuracy of these estimates was checked in flocks of known size by counting accurately the number of birds with their heads down, immediately following an estimate in eighths. The latter method was found to give a reasonable estimate of the proportion of birds with heads down ($r = 0{\cdot}96$; $p < 0{\cdot}001$; Figure 2).

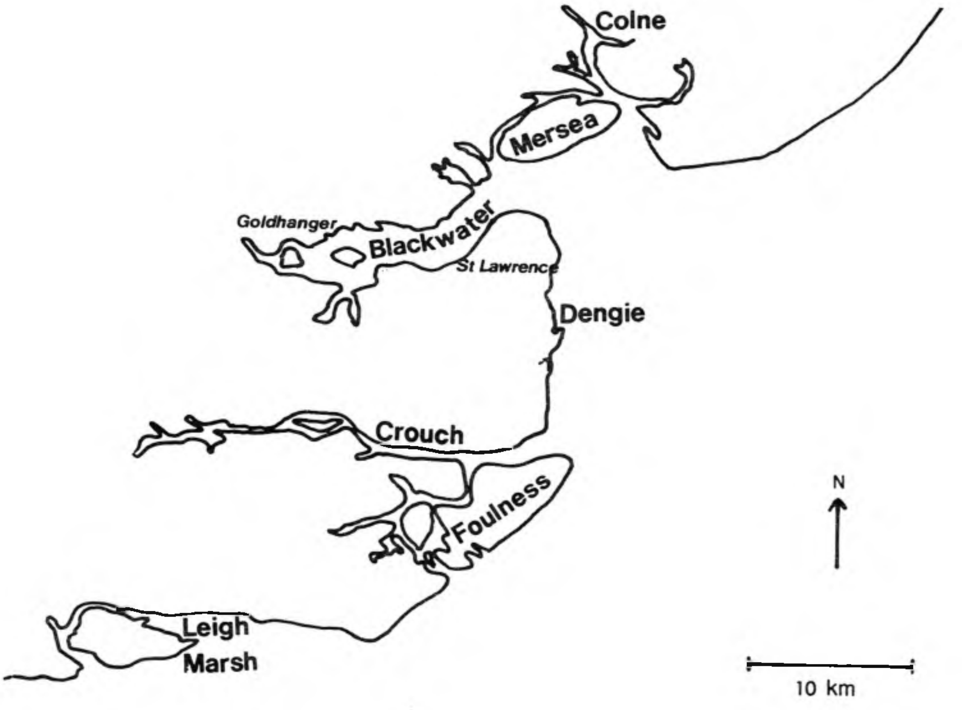

Figure 1. The study area.

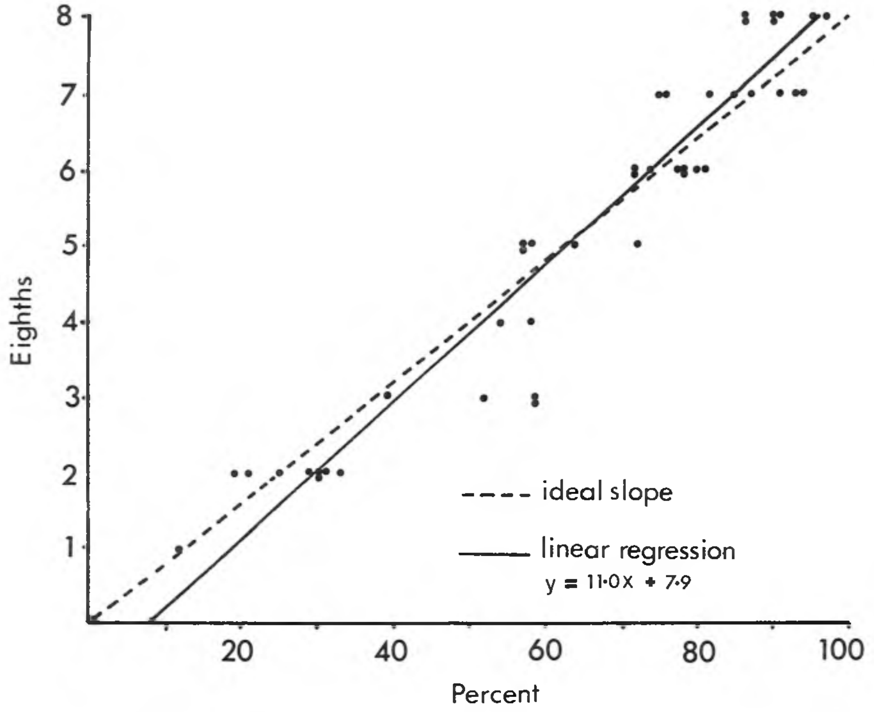

Figure 2. The relationship between estimates by eighths and percentage estimates by actual head counts of the proportion of geese with their heads down (feeding).

Sampling methods

Six sites, namely the Colne, Goldhanger and St Lawrence Bay (Blackwater), the Dengie Peninsula, Leigh Marsh, and Foulness, were chosen for quantitative study. This selection ranged from little disturbed to very disturbed sites and at times supported about two-thirds of the British and one-third of the world population of Brent in 1973–1974. In each area it was possible to spread watches evenly over the tidal cycle and fairly evenly between dawn and dusk, though there was a tendency to watch slightly more frequently between 09.00–11.00 hrs and between 14.00–16.00 hrs. Most data were collected between November and February. At Leigh and Goldhanger, comparative data were collected in early and late winter.

Estimation of feeding time lost as a result of disturbance

The effects of disturbance rarely lasted longer than 20 minutes after a disturbance ceased. Thus the percent of time spent feeding was estimated firstly when there had been no disturbance for at least 20 minutes, and secondly throughout disturbed and undisturbed periods. The difference between the two estimates gives a measure of the proportion of their time that geese were prevented from feeding by disturbance. This measure, unlike most measures, is unaffected by the extent to which birds compensated for disturbance by feeding more during undisturbed times. Such a measure was necessary because the extent of compensation could not be determined. The lost feeding time comprised disturbance flights, walking or swimming away from a feeding area, and simply head-raising.

Experimental disturbances

Goose flocks feeding on saltmarsh in North Norfolk were disturbed experimentally in February and March. Standard approaches were made on foot, wearing a bright red jacket. The distance between the observer and the nearest bird when the flock flew up was measured by pacing.

Results

Responses to disturbance

When mildly alarmed, Brent Geese put their heads up briefly, but quickly resumed feeding. When somewhat more alarmed, they stopped feeding for longer, sometimes walking away and calling. When severely disturbed they took flight, often resettling in the same place after disturbances by aeroplanes or loud noises, but usually leaving when disturbed by people on the ground. Geese re-alighted in dense flocks, gradually spreading out to feed, sometimes by further flighting away from the main group of birds. The disturbance behaviour of a flock may be determined by the behaviour of its most nervous members, since a few geese taking flight tended to cause the whole flock to follow. Adults with families spend more time with their heads raised. These 'sentinels', probably males, often first gave warning of potential danger, though they were not necessarily the first to fly.

Brent Geese were particularly susceptible to disturbance by aircraft, and any 'plane below about 500 m and up to 1·5 km away could put them to flight. Slow, noisy aircraft were especially harmful, and helicopters caused widespread panic. The geese were very slow to become habituated to aircraft, though at Leigh Marsh in January–February they did cease responding to the transport planes that took off regularly from Southend Airport. Other low-flying aircraft continued to cause disturbance throughout the winter (Table 1).

Large birds with a slow wingbeat such as Great Black-backed Gulls *Larus marinus*, Herons *Ardea cinerea* and Hen Harriers *Circus cyaneus* were also liable to put the geese to flight. Even Carrion Crows *Corvus corone* landing near a goose flock caused birds to raise their heads briefly. The intensity of response to aircraft and their slowness to habituate to them may have been partly a result of the visual resemblance of aircraft to large birds. Kestrels *Falco tinnunculus*, Merlins *F. columbarius* and Sparrowhawks *Accipiter nisus* did not always cause disturbance, though geese sometimes flew up when these raptors caused waders to give alarm calls.

At low tide, disturbance was caused by bait-diggers, bird-watchers, and people walking out to moored boats or shellfish beds. At high tide disturbance was often caused by people on the shore. There was a decrease during the winter in the distance at which people at Leigh and Goldhanger put Brent Geese to flight (Figure 3). Before New Year, about one-third of people approaching to within 100 m put birds to flight, whereas after New Year only 12% of people did so at this distance ($p < 0{\cdot}001$). In early winter it was not possible to approach the geese more closely than 50 m. In January–March however, twelve observations were made of

Table 1. The frequency of disturbing incidents that put some or all of the Brent Geese being watched to flight.

Place	Time of year	Total time watched (mins)	Mean time between disturbances (mins)	Number of disturbances by:— People on the ground (a)	(b)	(c)	Aircraft (d)	(e)	(f)	(g)	Loud noises (h)	(i)	(j)	Total
C	Jan–Mar	1179	147	1	1		1					4	1	8
G	Nov–Dec	1439	60	10	1	1	7			2			3	24
G	Feb–Mar	1428	179	2	1	1	4							8
G	Jan–Feb (weekends)	452	75	5									1	6
S	Feb–Mar, Nov	611	76	4			1	1	1		1			8
D	Nov–Mar	1958	218	2		3	4							9
F	Oct	581	290									2		2
L	Nov—Dec	862	32	14			4	6			3			27
L	Jan–Mar	947	118	1		2	4				1			8
L	Oct–Nov (weekends)	600	25	7		3	10	4						24
Totals:		167 h 37 m		46	3	10	35	11	1	2	5	6	5	124

C = Colne, G = Goldhanger, S = St Lawrence Bay, D = Dengie, F = Foulness, L = Leigh.
(a) on shore or seawall; (b) wildfowlers; (c) bait-diggers; (d) small propellor-driven aircraft; (e) transport aircraft; (f) jet aircraft; (g) helicopters; (h) boats with outboard engines; (i) army explosives; (j) gun shots.

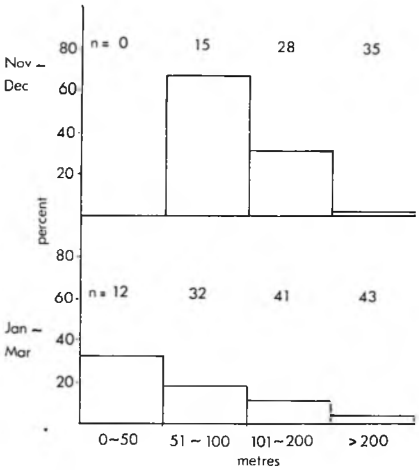

Figure 3. The distances at which people on the ground put Brent Geese to flight in early and late winter. Vertical scale shows percentage of disturbances that occurred at each distance.

people coming within this distance, and on only four occasions were the geese put to flight. At Leigh, geese sometimes stayed on the ground when people came as near as 20 m to them.

Experimental approaches to flocks of between 6 and 400 geese on the Norfolk saltmarshes showed that there was a tendency for larger flocks to take flight at greater distances ($r = 0{\cdot}67$; $n = 22$; $p < 0{\cdot}001$; Figure 4).

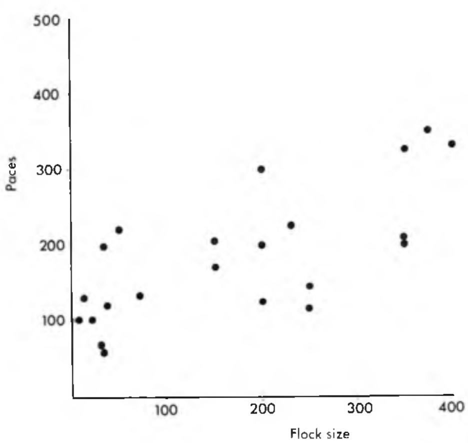

Figure 4. The distances at which flocks of different size were put to flight by experimental disturbances in north Norfolk in February–March 1974 and 1975.

Brent Geese learned the dangers associated with particular places. For example at the Colne salting, much used by wildfowlers, geese in February could not be approached within 500 m, whereas the same geese could be approached to within 150 m on the Colne mudflats. Similarly, they were more easily disturbed when on novel feeding areas, such as fields behind the sea wall. For example, during an undisturbed 90 minute watch of birds feeding on winter wheat at Dengie on 8th January 1974 (soon after they started feeding over the sea wall), 34% of the time was spent feeding, compared with a mean of 59% on intertidal areas at Dengie. Large boats rarely caused disturbance, being generally in deep water. Even when they did come close, in the Colne estuary, the birds ignored them. Yachts, too, rarely disturbed Brent Geese, but small boats with noisy outboard engines caused them to take flight.

Brent Geese quickly become habituated to most sounds. Unexpected ones, such as nearby gun shots from wildfowlers, usually put the geese to flight. Similarly, the first shots of the day at the Colne Army ranges caused geese to leave the saltings for the mudflats. They quickly returned however, and ignored all subsequent firing that day. At Foulness, the extremely loud but regular bangs made during weapon testing caused little reaction after the first weeks. Brent Geese fed undisturbed 50 m from passing trains at Leigh Marsh.

When disturbances occurred very frequently, birds appeared to become more easily disturbed on subsequent occasions. For example, three people walking on the *Zostera* beds at Leigh in November approached Brent Geese three times in the space of one hour. At the first approach, the birds flew up when the people were about 200 m away, at the second approach 600 m, and on the third at 800 m.

Effects of disturbance on distribution and movements

Brent Geese were not totally excluded by disturbance from any large areas with suitable food. Geese avoided heavily disturbed feeding sites in early winter but used all such areas later, as food stocks became depleted elsewhere. At Leigh Marsh, for example, the geese at first avoided the area around the north-east corner of Two Tree Island, close to the town of Leigh, a cockle processing depot, a car park, and the railway. In the second half of November, however, only the disturbed parts of the *Zostera* bed remained green and the birds started to feed there (Figure 5). A similar pattern occurred in the north Blackwater (Figure 6), and in all the other major feeding areas where there was disturbance from the shore. The geese only penetrated narrow creeks without all-round visibility when other areas had been depleted of food (Figure 7).

Frequency and intensity of disturbances putting geese to flight

In 168 hours of observation of geese at the selected sites, human disturbance that caused some birds to fly occurred on average once every 81 minutes. Forty-eight percent of disturbances were by people (mostly on the shore), 39% by aircraft (mostly small propellor-driven planes), 9% by loud noises and 4% by small boats. Figures for the separate study sites are given in Table 1. Leigh Marsh, early in the winter, was the

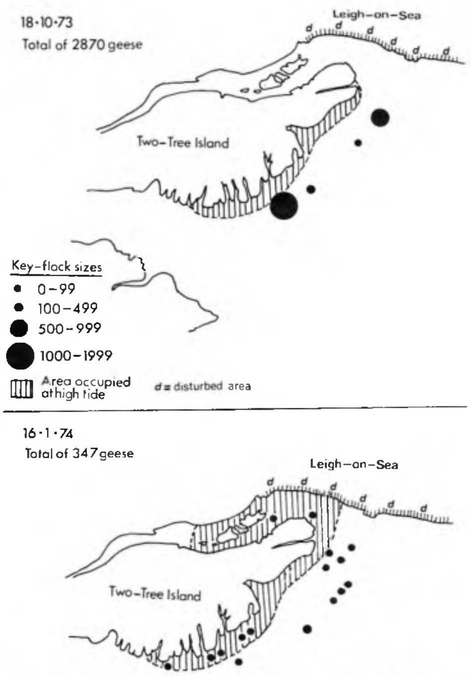

Figure 5. The distribution of Brent Geese at Leigh Marsh before and after habituation to disturbance by people on the shore at Leigh-on-Sea.

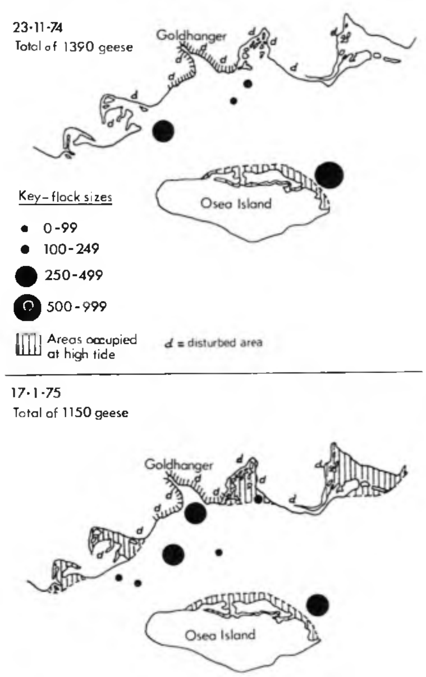

Figure 6. The distribution of Brent Geese in the north Blackwater before and after habituation to disturbance by people on the northern shore.

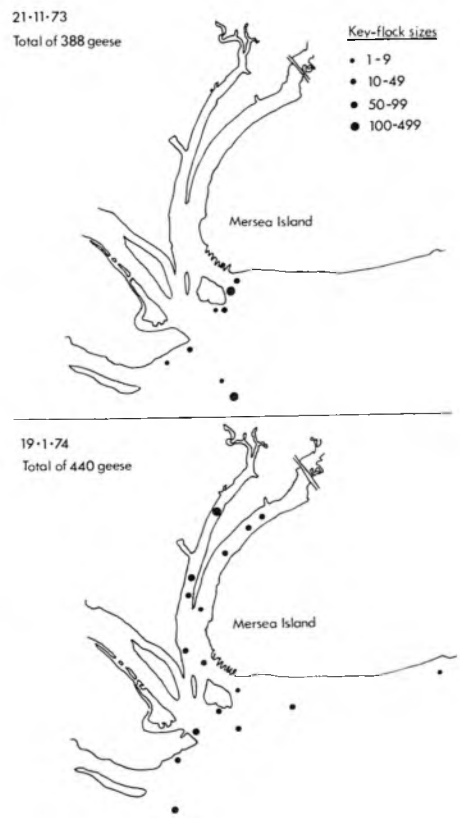

Figure 7. The distribution of Brent Geese near Mersea Island, illustrating the penetration of narrow creeks in late winter.

most disturbed study area, disturbances occurring about once every 30 minutes. This was about twice the frequency of the Blackwater estuary. Dengie, the Colne and Foulness were relatively undisturbed. Aircraft and people on the shore caused flighting in all areas except Foulness, where Army restrictions largely prevented these sources of disturbance. Bait-diggers caused some flighting at Goldhanger, Dengie and Leigh, and boats at Leigh and St Lawrence. Flighting was caused by gun shots on the Colne and Blackwater and by Army explosions on the Colne and Foulness.

Disturbances by aircraft on average caused about twice as many geese to take flight as disturbances by people ($d = 5{\cdot}3$; $p < 0{\cdot}001$; Table 2), largely because the area affected by an aircraft tended to be larger than that affected by a person on the ground. Taking into account their lesser frequency, aircraft caused about 1·6 times as much disturbance as people.

Table 2. The relative effectiveness of people and aircraft at putting geese to flight.

	Mean percentage of geese taking flight	No. of observations
People	$38 \pm 4{\cdot}7$	51
Aircraft	$77 \pm 3{\cdot}6$	30

Feeding time lost

Geese lost time from feeding by disturbance in all areas throughout the winter except at Leigh in late winter (Table 3). Over all areas, disturbance prevented geese from feeding for an average of 3·5% of their time. The greatest losses of feeding time were at weekends at Leigh and Goldhanger.

When the tide was out, there was a large area in which displaced Brent Geese could resettle, and so feeding could be resumed very quickly. Around high tide however, the available feeding space was relatively crowded and more likely to be disturbed. Disturbed geese then tended to fly out and sit on the water, only returning to feed when the disturbance had passed. A significantly greater amount of feeding time was lost per disturbing incident in the six hours around high tide than in the six hours around low tide ($p < 0{\cdot}001$, Mann-Whitney U-test). Thus walkers on the shore at high tide caused a greater loss of feeding time than bait diggers at low tide.

The proportion of time spent in food-seeking activity in daylight in 1973–1974 was probably close to the maximum possible. Undisturbed birds with their heads up, although counted as not feeding, were usually foraging (walking to the next patch of food). Very few birds were seen resting, except when the tide completely covered the feeding grounds. The proportion of time spent feeding in *Enteromorpha* areas was smaller than on *Zostera* areas in 1973–1974 ($p < 0{\cdot}05$, Mann-Whitney U-test). This was largely because birds on *Enteromorpha* spent a greater proportion of their time foraging, not because they rested more. Geese on *Zostera* in early winter spent a much greater proportion of time feeding in 1973–1974 than in 1974–1975 (Table 3). The difference was due to birds in the latter

Table 3. The feeding time lost as a result of disturbance.

Place	Months	Year	% Time feeding, no disturbance (A)	% Time feeding, overall (B)	% Time disturbance, prevented feeding (A–B)	Time watched mins
Colne, mudflats	Feb–Mar	1973	41·8	41·1	0·7	235
Colne, saltings	Feb–Mar	1973	91·1	90·3	0·8	209
Goldhanger	Nov–Dec	1973	64·3	61·2	3·1	519
Goldhanger	Feb–Mar	1974	50·0	48·0	2·0	581
Goldhanger	Jan–Feb (weekends)	1974	51·9	44·8	7·1	295
St Lawrence Bay	Feb–Mar, Nov	1973	67·8	63·3	4·5	501
Dengie	Mar, Nov, Dec Jan–Feb	1973 1974	59·3	57·3	2·0	435
Foulness	Oct	1973	82·4	80·5	1·9	581
Leigh	Nov–Dec	1973	79·3	74·4	4·9	862
Leigh	Jan–Mar	1974	62·7	62·9	+0·2	697
Leigh	Oct–Nov (weekends)	1974	53·3	41·6	11·7	600

season resting at low tide, and may have been related to the small number of young birds. Later however, birds fed throughout the tidal cycle.

Brent Geese fed at night throughout the winter, sometimes in cloudy weather, and on quite sparse *Enteromorpha*, for example in the Blackwater in January and February. However, geese appeared not to feed so intensely at night as during the day, mostly feeding at mid-tide as the water lifted the food off the mud.

Extra time spent in flight

A flight was considered to be due to disturbance when there was a clear causal connection between a disturbing incident and a flight of geese, and also when birds flew back to their feeding grounds after disturbance had passed. In the absence of disturbance, Brent Geese spent an average of 1·1% of their time in flight (Figure 8). The total time spent flying was highly correlated with the amount of flying caused by disturbance ($r = 0{\cdot}93$; $n = 11$; $p < 0{\cdot}001$). In the Blackwater and at Leigh Marsh, disturbance caused the amount of flying to more than double, and at Leigh at weekends in early winter, Brent Geese spent an extra 5·5% of their time in flight. Over all areas and times of year, disturbance caused an extra 1·7% of time to

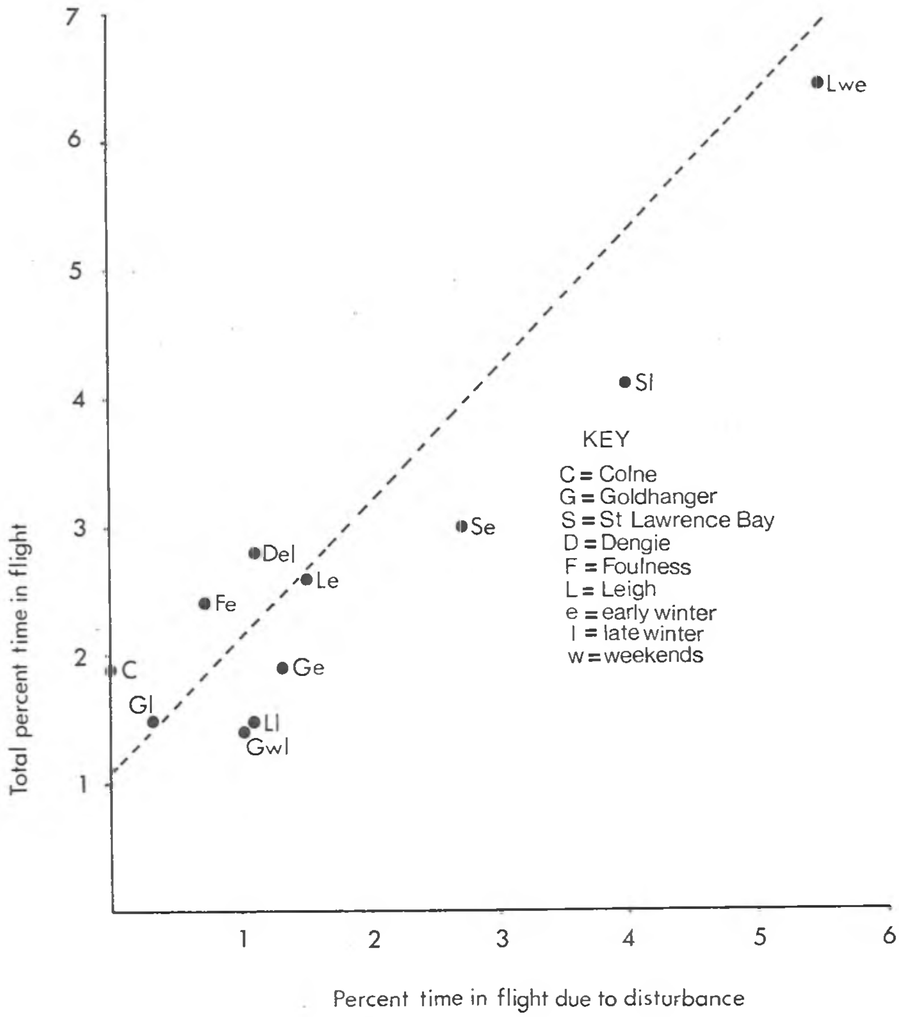

Figure 8. The relationship between the amount of flying due to disturbance and the total amount of flying.

be spent in flight.

On some occasions, disturbance caused birds to make 'normal' flights to other feeding areas earlier than they would otherwise have done. This partly compensated for the effects of disturbance. Thus, the amount of flying not due to disturbance tended to decrease as the amount of disturbance flying increased ($r = 0{\cdot}71$; $n = 10$; $p < 0{\cdot}01$; Figure 9).

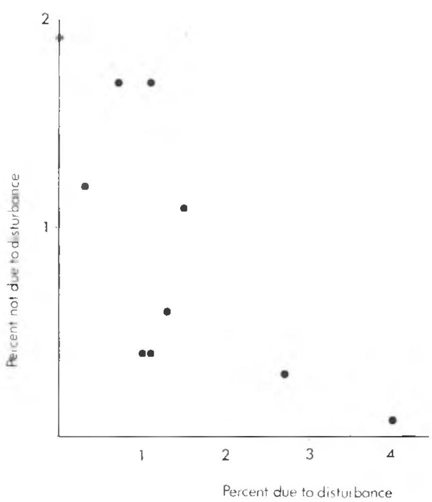

Figure 9. The relationship between the amount of flying due and not due to disturbance.

Discussion and conclusions

Restriction of feeding area

At high bird densities, feeding rates in some wader species may be depressed (Goss-Custard 1970). It is probable that similar effects occur in Brent Geese, and these could be made worse through the restriction of feeding area by disturbance. However, since this restriction occurred in early winter when there was still plenty of food, the effects were probably slight.

Feeding areas with restricted visibility were at first avoided but were used when other areas had been eaten out (for example around Mersea Island). Narrow estuaries in Suffolk and Essex, such as the Orwell, Stour and Crouch, supported proportionally fewer geese than other feeding areas, and were the only Essex feeding areas that were under capacity in 1973–1974 (K. Charman, pers. com.). This was probably a result both of restricted visibility and of the greater 'edge effects' in small feeding areas. An additional cause could be the reduced tolerance of larger flocks to disturbance. Apparently the maximum as well as the mean distance at which geese were disturbed increased with increasing flock size. Thus small flocks may have tolerated conditions in narrow estuaries better, and reducing disturbance therein would therefore not necessarily greatly improve their holding capacity for Brent Geese.

Effects on feeding behaviour and flighting

Disturbance would be harmful if it consistently resulted in birds losing more energy (through extra flying and lost feeding time) than they were able to make up by food intake. Disturbance was most intense at Leigh Marsh and the Blackwater. For example, at Leigh on weekends in 1974–1975, geese were prevented from feeding for 11·7% of their time and an extra 5·5% of time was spent in flight. On weekdays the figures were 4·9% and 1·5% respectively. Ringing results have shown that some individual Brent Geese may stay in one area, and so experience intense disturbance, for 3–4 months at a stretch (A. St Joseph & T. Bennett, pers. com.). The low digestive efficiency of geese (Owen 1972) and the restriction of feeding by the tide suggests that Brent Geese are likely to spend most of their available time feeding. Except in early winter 1974–1975, Brent Geese appeared to feed in daylight hours as intensively as tide and food availability allowed. Similarly, Rudge (1970) described Brent Geese on Foulness as spending an increasing proportion of their time feeding as the *Zostera* becomes depleted, spending all of the, shorter, days on the *Zostera* beds by mid-November. From about mid-November onwards it therefore seems unlikely that Brent Geese could have compensated for intense disturbance except by feeding more at night. Pink-footed *Anser brachyrhynchus*, Greylag *A. anser* and White-fronted *A. a. albifrons* Geese are known to increase their nocturnal feeding when intensive daytime shooting occurs (Newton & Campbell 1973; Owen 1972).

The extensive movement of Brent Geese on to farmland in recent winters (Bennett & St Joseph 1974) suggests that intertidal food resources became depleted. This was probably a consequence of the very large population (41,000 in Britain in 1973–1974; Ogilvie 1974) and the prior removal of many of the Dutch feeding grounds through reclamation (Ogilvie & Matthews 1969). Past occurrences of inland feeding by Brent

Geese and Black Brant *B. b. nigricans* have all been associated with food shortage; during the *Zostera* disease of the 1930s (Moffitt 1942; Morzer Bruijns & Timmerman 1968), poor food growth in 1951–1952 (Leopold & Smith 1953) and in the cold winter of 1962–1963 (Rudge 1970). Weights of Brent Geese in the Foulness/Blackwater area decreased from a mean of 1,248 g (n = 101) in January–February 1974 (about 9%; $p < 0{\cdot}01$) (A. St Joseph & T. Bennett, pers. com.). In 1933–1935, during the *Zostera* disease, some Brent Geese in the Netherlands weighed as little as 500 g (Morzer Bruijns & Timmerman 1968). Similarly, White-fronted Geese that had died of starvation in January 1963 were 42% lighter than the average for normal winters (Beer & Boyd 1964). Thus, weight loss of Brent Geese in winter may be indicative of food shortage, but a mean weight loss of only 9% is unlikely to result in any deaths. Nevertheless, poor winter food supplies may also result in reduced breeding performance in geese, for example in Black Brant (Cottam, Lynch & Nelson 1944) and Barnacle Geese *B. leucopsis* (Cabot & West 1973).

If Brent Geese were losing weight through food shortage, any disturbance could not be compensated for. Food shortage probably occurred in January–March, by which time the geese had become used to the proximity of people, though not to 'planes, which caused more than half of all flighting. Moreover geese feeding on farmland were more wary and more easily put up than when on mudflats.

Although the overall impact of disturbance is probably not very serious at present, it is worrying that the two most disturbed areas, Leigh Marsh and the Blackwater, are also the two most important feeding areas in Britain in terms of goose numbers, apart from Foulness (K. Charman, pers. com.). It is especially important that increases in disturbance should not occur in these two areas. Zonation in the use of coastal areas in Essex may soon be required. For example, people could be discouraged from walking close to the shore at high tide in certain areas, whilst yacht marinas, bait-digging, oyster beds, etc., could be concentrated in areas less important for wildfowl. The restriction of low-flying aircraft is even more important, since Brent Geese are so slow to become habituated to them. Ideally, aircraft should not fly below 500 m over estuaries.

Acknowledgements

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Summary

An assessment is given of the effects of human disturbance on the distribution and behaviour of Dark-bellied Brent Geese *Branta bernicla bernicla* wintering in Essex.

Disturbed areas and places with poor visibility were avoided in early winter, but were used later when other areas became depleted of food. Geese became partially habituated to the proximity of people and to some loud noises, but not to small low-flying aircraft.

The areas which contained the most geese apart from Foulness, namely Leigh Marsh and the Blackwater estuary, were also the most disturbed. Here, disturbance at weekends prevented geese from feeding for up to 11·7% of their time, and caused the time spent in flight to increase as much as sevenfold. Overall levels of disturbance were much lower than this, and would probably have been unimportant so long as adequate food was available on which geese could feed in undisturbed times, and at night. However, a shortage of food probably prevented complete compensation for the effects of disturbance.

Disturbance could be greatly reduced by restricting access to the sea wall in certain areas around high tide, and by controlling the numbers of low-flying aircraft.

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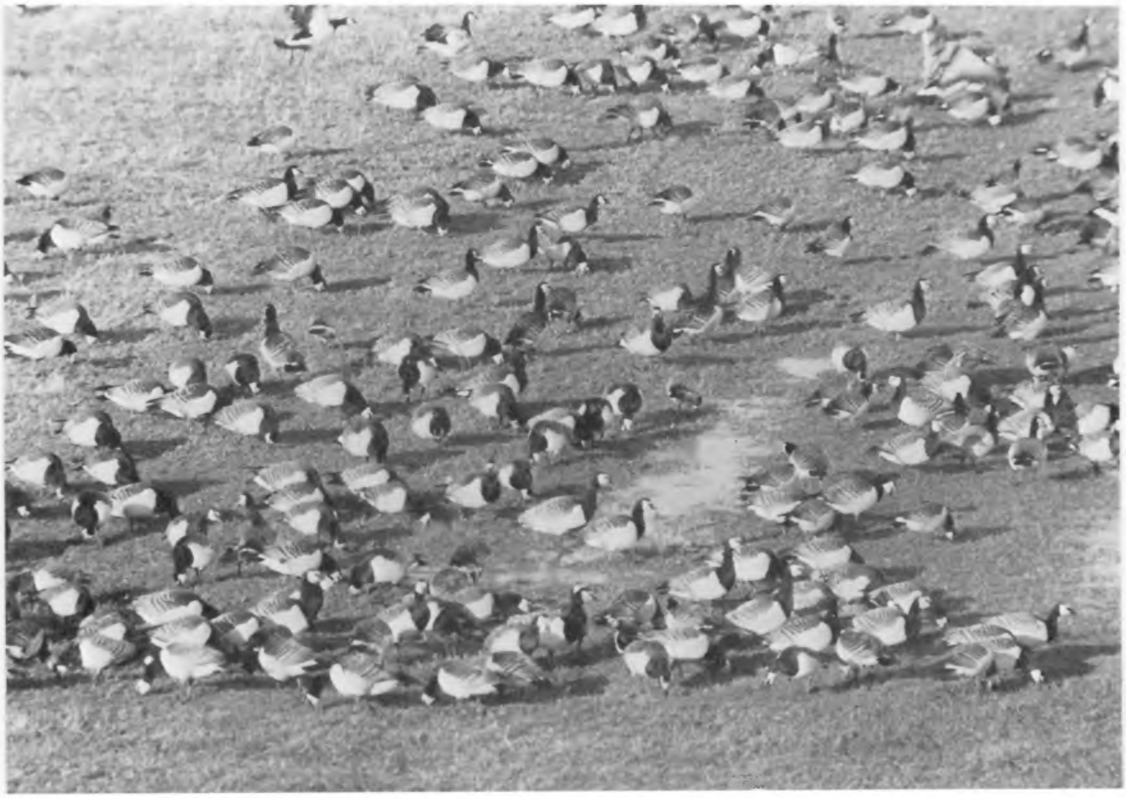
A feeding flock of Barnacle Geese *Branta leucopsis*. The birds with their heads up may be on the look out for danger, or obtaining information on food availability, see pp. 15–20. (*Philippa Scott*).



Effects of disturbance on shorebirds: a summary of existing knowledge from the Dutch Wadden Sea and Delta area

Cor J. Smit & George J.M. Visser

Smit, C.J. & Visser, G.J.M. 1993. Effects of disturbance on shorebirds: a summary of existing knowledge from the Dutch Wadden Sea and Delta area. *Wader Study Group Bull.* 68: 6-19.

The extent to which shorebirds are disturbed by various activities is discussed, with reference to studies carried out on the Wadden Sea and Delta area. The effects of leisure activities on foraging and roosting birds are discussed. The effects of small airplanes, jets and helicopters are also considered, as are the effects of disturbance on food intake and behaviour of territorial birds. Frequent disturbance may force waders to abandon traditional high-tide roosts. The implications of disturbance on energy are not yet clear but indicate that the effects can be larger than would appear from the studies described.

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INTRODUCTION

The Wadden Sea and Delta area are both wetlands of outstanding importance for many bird species ecologically dependent on intertidal habitats (Wolff & Smit 1984; Leeuwis *et al.* 1984). At the same time these areas are intensively used for a great variety of human activities. In some cases this leads or may lead to conflicts between the interests of birds and man (Figure 1). Over the past 20 years the scale of most of these (potential) conflicts has been studied in the Dutch part of the Wadden Sea and the Delta area and, more recently, also in the Danish and German Wadden Sea. The more recent investigations have focussed on whether limits should be set to human presence in an area or whether certain activities should be banned from (parts of) an area.

Interactions birds / man

Resting birds	Foraging birds
Tourism - walking	Bait digging
- surfing, sailing	Walking over mudflats
Farming	Civil aircrafts
Hunting, egg collecting	Military activities
Military activities	Fisheries
	Leisure boats

Figure 1. Human activities actually or potentially conflicting with the interests of resting and foraging shorebirds in the Dutch Wadden Sea and Delta area

Disturbance can be defined as ‘any situation in which a bird behaves differently from its preferred behaviour’ (Boere 1975) or ‘any situation in which human activities cause a bird to behave differently from the behaviour it would exhibit without the presence of that activity’ (Oranjewoud 1982). In this contribution we will restrict ourselves to disturbance caused by human activities: disturbance from natural causes (weather, predators) has not been studied in detail and will only briefly be addressed. We will not discuss the effects on breeding birds and mainly cover Dutch studies from coastal sites (with some information from the German part of the Wadden Sea). Outside The Netherlands very little is known of this work. This is very comprehensible: with the exception of some preliminary data on part of the problem (Smit & Visser 1985) and some rather brief summaries (Wolff *et al.* 1982, Smit *et al.* 1987), the results have been presented in not easily available reports from institutes, government agencies and universities. Access to these reports is also hampered by language barriers: nearly all information is published in Dutch. This paper is an attempt to summarize briefly the results of these studies.

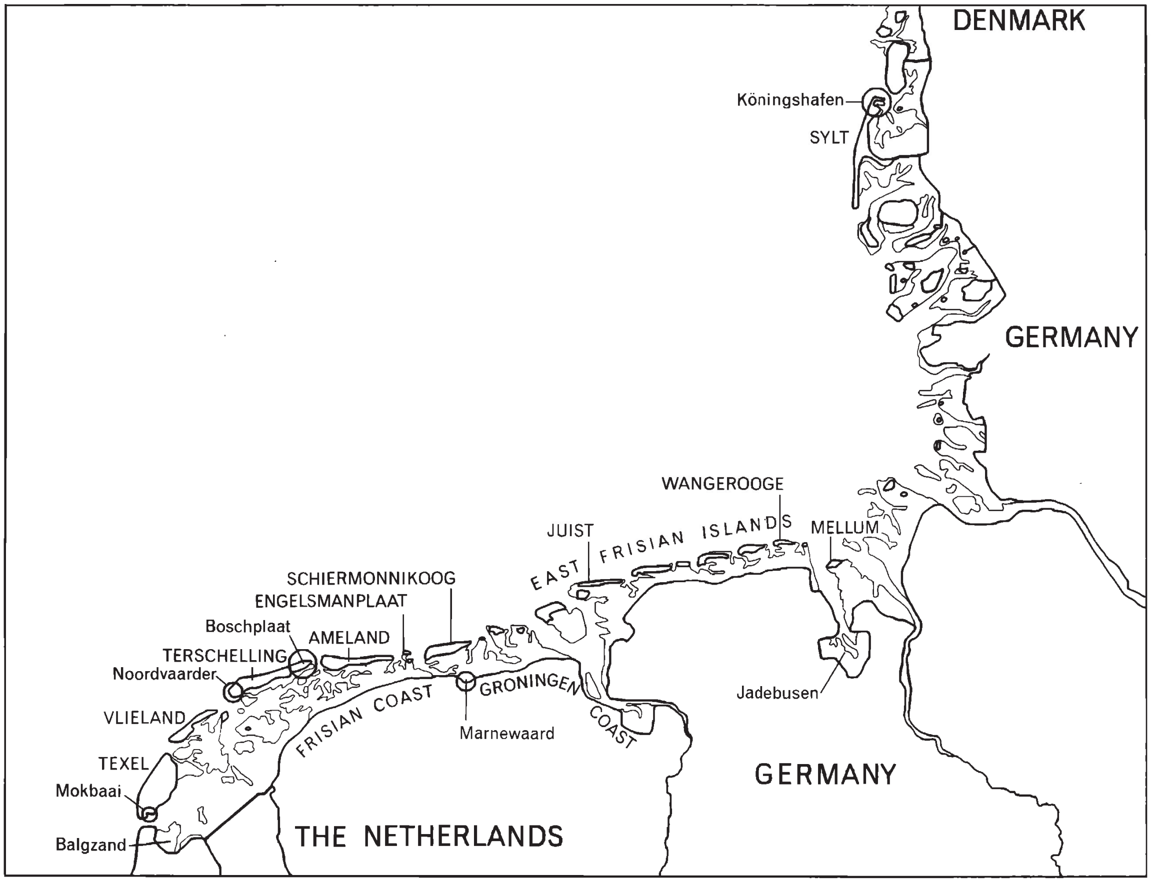

Figure 2. Map of the Dutch part of the Wadden Sea with location of sites referred to in the text.

EFFECTS OF LEISURE ACTIVITIES ON BIRDS RESTING AT HIGH-TIDE ROOSTS

High-tide roosts may be encountered in many places along the borders of the Wadden Sea and the Delta estuaries. On the mainland coast of the Wadden Sea (Figure 2) shorebirds roost on man-made saltmarshes. In most of the Wadden Sea these areas are not intensively used for agricultural purposes, and have a rather low degree of human disturbance. On the shores of the Wadden Sea barrier islands and in the Delta area the disturbance frequency is generally much higher, but from most places quantitative data on the scale of the problem are lacking.

Flocks of shorebirds may be disturbed by a variety of human activities, though natural causes (such as predators) may also take an important share. Table 1 presents the reasons for disturbance, as registered on Terschelling. In particular small aircraft and tourists walking are important sources of disturbance; cattle or people with a highly predictable behaviour (like farmers) are less so. Table 2 shows that small aircraft and people walking around also cause birds to take flight at large distances. Cars, agricultural activities and dogs caused less disturbance (Blankestijn *et al.* 1986). There are also differences between species as illustrated by the flight distances when birds are approached by walking people (Figure 3). Golden Plovers *Pluvialis apricaria* are fairly tolerant, but Curlew *Numenius arquata* and Redshank *Tringa totanus* tend to take flight at more than twice as great a distance. Detailed summer observations at

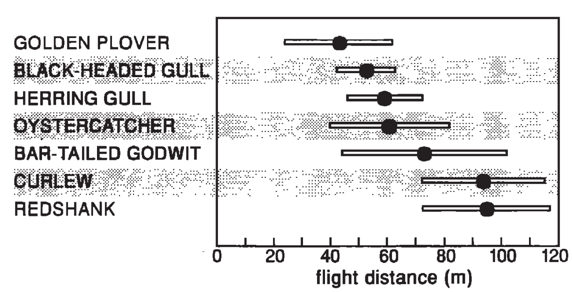

Figure 3. Distances (mean values in m and 95% confidence limits) at which flocks of roosting waders and gulls were recorded to take flight when approached by walking people. Data from Terschelling, July - September 1981 (data: Tensen & van Zoest 1983).

Table 1. Disturbance frequency, expressed as a percentage of the total amount of visible disturbance in one study situation at high-tide roosts in a cultivated grassland area at Terschelling. The study was carried out in July-September 1981, when relatively many tourists on bicycles were present on the island. Most of these have a very predictable behaviour through their preference for metalled cycle paths (data: Tensen & van Zoest 1983).

Source of disturbance	Curlew	Bar-tailed Godwit	Oystercatcher	Gulls
Small aircraft	39	23	18	27
Walking person(s)	31	32	65	17
Agricultural activities	10	8	4	7
Cows	1	2	13	1
Cyclist(s)	–	1	–	–
Natural	11	16	–	24
Unknown reason	8	18	–	24

Terschelling show that walking people within 250 m of roosting Oystercatchers *Haematopus ostralegus* caused flocks to fly in 57% of the cases. As a mean, these birds were 38 seconds per hour on the wing (mean of 320 observation hours). Curlews flew up in 76% of the cases. On average these birds flew 57 sec/h (mean over 50 hours) (Visser 1986). Figure 4 shows that before flying up, the behaviour of roosting birds may already have been considerably affected: looking up and walking away become more dominant as distances get smaller.

Weather conditions partly determine flight distances. Kersten (1975) reports that Curlews can be more easily disturbed during rainy weather. At the same time the roosts are less compact, smaller and distributed over larger areas. Several studies show that large flocks are more easily disturbed (Zwarts 1972; Kooy *et al.* 1975). Flight distances are very much time and location dependent. These differences are sometimes rather difficult to explain. At the comparatively undisturbed Banc d'Arguin, Mauritania (where flight distances for most species are smaller than in the Wadden Sea) flocks of wintering Oystercatchers fly up at 400-500 m (Smit unpubl.) whereas in the Wadden Sea they are a rather tolerant species (Figure 3, Table 2). Birds roosting in cultivated grasslands with a certain amount of human activity can often be approached to closer distances than those roosting in remote salt marshes (within the same area and time of the year). Curlews roosting in cultivated grassland areas at Terschelling could be approached to approximately 100 m, whereas on the salt marshes on same island the flight distance was 200 m (Tensen & van Zoest 1983).

Hunting may increase flight distances for non-target species as well as target species. By the end of September, Brent Geese *Branta bernicla* in Denmark take flight at 210 m; by the end of October (after the start of the hunting season) the mean flight distance has increased to 370 m (Rudfeld 1990). Comparable

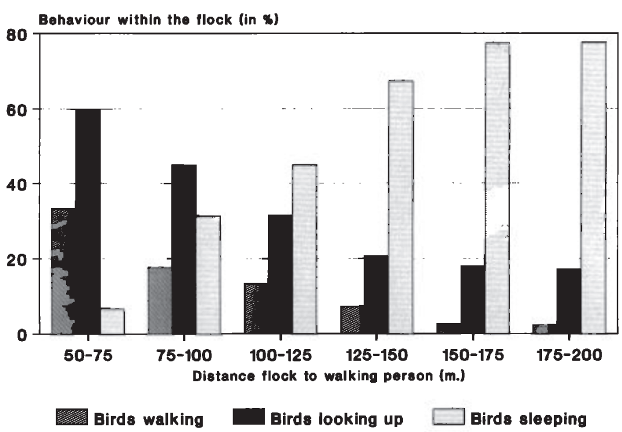

Figure 4. Behaviour of flocks of Curlews when approached by walking people, in relation to the distance to the flocks. Data were collected in standardized experimental situations, using flocks of Curlews roosting in cultivated grasslands (data: Blankestijn *et al.* 1986).

Table 2. Mean distances (m) at which flocks of Oystercatchers and Curlews flew up when approached by various sources of disturbance. Data from flocks roosting in cultivated grasslands on the island of Terschelling (data: Blankestijn *et al.* 1986).

Source of disturbance	Oystercatcher	Curlew
Small aircraft	500	–
Walking person (s)	82	213
Helicopter	–	200
Car	106	188
Egg collector	46	140
Farmer/Agricultural activities	60	129
Dog(s)	–	90
Cattle	10	–

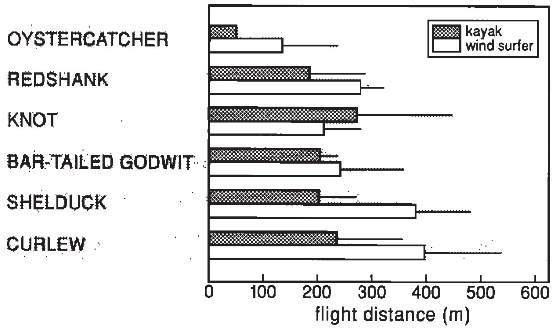

Figure 5. Distances (mean values in m and standard deviations) at which flocks of roosting waders were recorded to take flight when approached by a kayak or wind surfer. Data from the Jadebusen (German mainland coast) (from: Koepff & Dietrich 1986).

observations have been made on inland feeding geese (cf. Gerdes & Reepmeyer 1983).

Koepff & Dietrich (1986) studied the effects of kayaks and wind surfers on roosting waders and Shelduck *Tadorna tadorna* in the Jadebusen (German Wadden Sea). Although there are some differences in species composition between this and the previously mentioned study, more or less the same order of disturbance susceptibility was found (Figure 5). Kayaks and sailing boats disturbed more often than motor boats and wind surfers. Kayaks have a small draught which enables them to come very close to the high-tide roosts. In the Königshafen, Sylt, wind surfers had strong disturbing effects on dabbling ducks. A few zigzag movements of a single surfer were sufficient for a complete departure of all ducks present. In the same situation Brent Geese left the area when approached at 300 m or less (Küsters & von Raden 1986).

Waders may leave their usual high-tide roosts as a result of disturbance but the available data are somewhat difficult to interpret. Boer *et al.* (1970) found on the Balgzand that Bar-tailed Godwits *Limosa lapponica* used two high-tide roosts. One was used especially in summer and was situated in a relatively quiet area. The second was used mainly in winter at a location where in summer many tourists were present. A comparable feature was found in Denmark where Bar-tailed Godwits also changed roosting sites, probably as a result of disturbance from hunting (Rudfeld 1990). The eastern part of the island of Ameland consists of a large sandflat. Normally 10,000 Curlews roost here in summer nights, whereas during the day only some hundreds are present. These birds use alternative day-time roosts on the sandflats of Engelsmanplaat and on the Frisian coast. In winter, when considerably fewer people visit that area, Curlews do roost on Ameland (Kersten 1975). Zwarts (1972) noted that a traditional Curlew roost on the salt marshes was gradually abandoned after an increase in disturbance by tourism. Ringing activities on Vlieland on two successive nights lead to severe disturbance of Redshank roosts. It took five days before the normally occurring numbers were present again. Cannon-netting at a Curlew high-tide roost on the same island on two nights with a nine days interval also led to a temporary departure. In this case it took 2-3 weeks before the numbers were back to normal again (Zegers 1973).

EFFECTS OF LEISURE ACTIVITIES ON FORAGING BIRDS

Although data on flight distances are available for some tidal flats, it is impossible to give standard figures on this matter. Distances vary between sites and are dependent on earlier experiences (learning) in that particular location. In Denmark, for instance, Curlews show an extreme wariness and have a flight distance of 500 m, probably because they are a hunted species in that country (Meltofte 1986). In the Mokbaai, Texel, a small bay surrounded by sea walls and dunes, with a large variety of human activities (recreation, bait digging, angling, helicopter traffic, navy inflatables speeding through the channel, etc.) some Dunlins can be approached to within 10-20 m or less without any visible disturbance. At the same time of the year Dunlin flocks feeding on the open mudflats east of the island may take flight at a distance of 100 or 200 m. Such differences were also found at Terschelling, where birds close to the sea wall (with rather frequent human activities) tolerated people walking on the tidal flats at shorter distances than

Table 3 Mean flight distances (in m) of wader species, when approached by people walking over the tidal flats near Terschelling (Dutch Wadden Sea) at various distances from the sea wall (data: Glimmerveen & Went 1984).

Species	200-300 m from sea wall	500-1,000 m from sea wall	mussel bed at 1,000 m from sea wall
Oystercatcher	79	113	77
Bar-tailed Godwit	101	138	–
Curlew	140	196	102

Table 4. Mean distances and ranges (m) at which birds take flight when approached by people walking over the tidal flats (from: van der Meer 1985 (Delta area), Wolff *et al.* 1982 and Smit unpubl. (Wadden Sea)).

Species	Delta		Wadden Sea	
	Flight dist.	Range	Flight dist.	Range
Curlew	211	124-299	339	225-550
Shelduck	148	99-197	250	200-300
Grey Plover	124	106-142	–	50-150
Ringed Plover	121	80-162	–	–
Bat-tailed Godwit	107	88-127	219	150-225
Brent Goose	105	58-152	–	–
Oystercatcher	85	81-89	136	25-300
Dunlin	71	57-86	163	100-300
Turnstone	47	31-53	–	150-250

birds foraging farther away from the sea-wall (Table 3). The flight distance is also influenced by the behaviour of a person or group of people. One individual person generally disturbs less than a group; dogs running around are very disturbing. Bait diggers, working at the same spot for longer periods, are tolerated at shorter distances than a walking person.

Birds taking flight are the most obvious result of disturbance. As in resting birds (Figure 4), they often change their behaviour long before they take flight. Van der Meer (1985) has shown that some birds do so at distances which are on average 30% greater than those at which they take flight. In Brent Geese it was as much as 95% (205 m and 105 m respectively). Using the distances at which birds take flight we can simply compute the area where no birds are present. The size of such an area will be πr^2. The results of these calculations are depicted in Figure 6. In general, the situation will be more complex because people will move over the tidal flats. If this happens birds will leave from an area in front and on both sides of a person or group (Figure 7). Using the information on the distance at which birds take flight and additional information on the time needed for recovery we can calculate the size of the area where birds are temporarily forced out. When a person or group crosses the tidal flats of the Wadden Sea from the mainland to one of the islands (a popular sport in The Netherlands in which tens of thousands participate each summer) this information also allows us to calculate the loss of feeding area from which the birds are forced out. Van der Meer (1985) calculated the size of this area at:

$$\text{surface} = \pi r_2^2 + 2r_1.h_1.s + 2(r_2-r_1).h_2.s$$

in which:

surface = area abandoned by foraging birds (in m^2)
s = walking speed in m/s
r_1 = flight distance in metres (zone 1)
r_2 = distance at which birds stopped feeding in metres (zone 2)

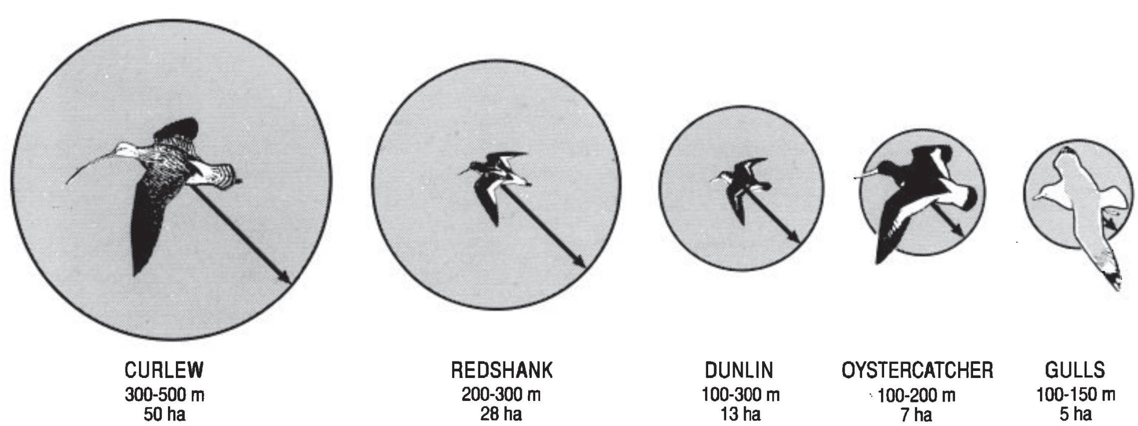

Figure 6. Theoretical size of areas without any birds for five shorebird species, using the information from the Wadden Sea from Table 4.

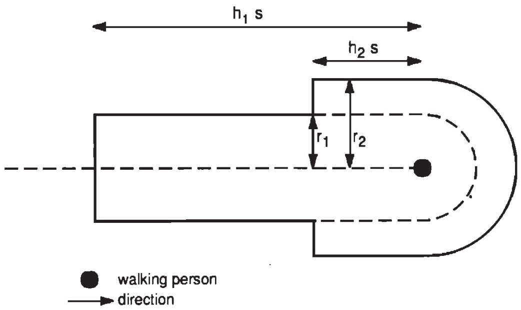

Figure 7. Theoretical size of the area without birds, after disturbance from a single person or a group walking over the tidal flats. See text for additional information (from: Van der Meer 1985)

h_1 = recovery speed from zone 1 in seconds
h_2 = recovery speed from zone 2 in seconds

For Oystercatchers in the Delta area for a person walking with a speed of 1 m/s (which equals 3.6 km/h) the following figures were measured:

r_1 = 85 m
r_2 = 120 m
h_1 = 900 seconds
h_2 = 300 seconds

For Oystercatchers this calculation leads to a disturbed area of 20 ha. For bait diggers the disturbed area will be somewhere in between r_1 and r_2. Once again the disturbed area will be πr_2, which means that a bait digger is surrounded by an area of 3.3 ha without any Oystercatchers.

Similar data on the effects of other sources of disturbance on feeding birds are much more scanty. A small motor boat near Terschelling, sailing at approximately 10 km/h, caused Oystercatchers to walk away at 95 m; at 50 m most birds stopped feeding or flew off. Curlews were less tolerant and responded at 190 m. At 95 m most Curlews walked away or stopped feeding. As in other studies Bar-tailed Godwits reacted at distances in between those of Oystercatchers and Curlews (Glimmerveen & Went 1984).

EFFECTS OF SMALL AIRPLANES, JETS AND HELICOPTERS

Visser (1986) extensively studied the behaviour of birds roosting at the Noordvaarder, Terschelling. This area faces military activities (including a jet shooting range, helicopter activities, transport vehicles, etc.) and a variety of activities linked with tourists and local inhabitants (including people walking with or without dogs, angling, cross-country motorcycles, etc.). The frequent presence of jets and helicopters allows for a comparison of the effects of the two aircraft types. Figure 8 shows that helicopters disturb more frequently and over longer distances than jets, even though activities from jets are accompanied by shooting and high sound levels. The relatively mild effects from military jets are also known from other places (Boer *et al.* 1970; de Roos 1972) and are shown in Table 5. From these data it appears that small civil aircraft cause much more disturbance. Again, there were clear differences between species. Oystercatchers were rather tolerant of aircraft disturbance; Curlews were less so. Other species (like Bar-tailed Godwits) were in

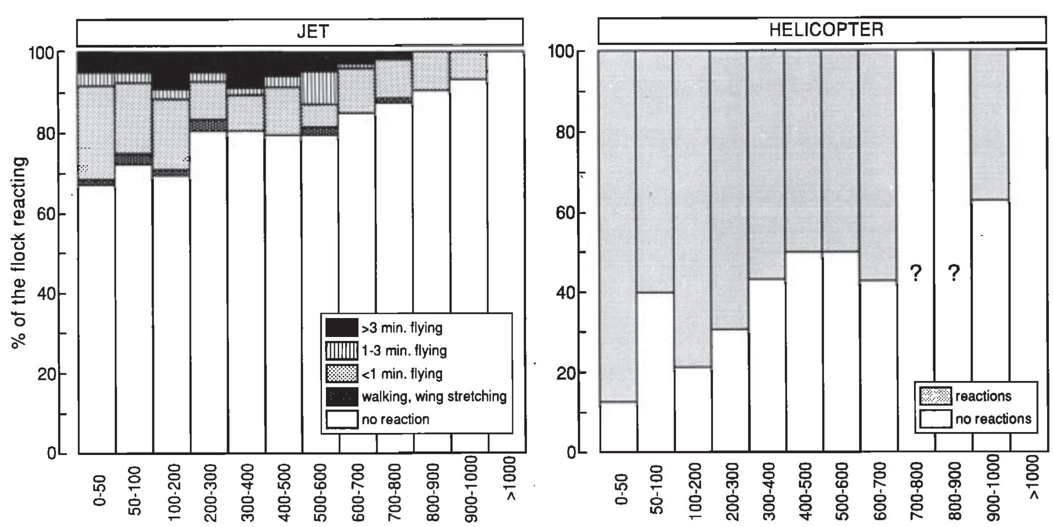

Figure 8. Distances (in m) at which military jets and helicopters caused disturbance among roosting Bar-tailed Godwits at the Noordvaarder, Terschelling. Data were collected from 1980-84 and represent 925 (jets) and 100 (helicopters) potential cases of disturbance (data from Visser 1986).

Table 5. Disturbance of waders (total number of hours of observation time, number of flocks observed, the frequency at which flocks flew up and the % of flocks reacting) at the Noordvaarder (Terschelling) in summer (1980-84). Flock sizes were >100 (Oystercatcher and Bar-tailed Godwit) and >20 (Curlew). Disturbance was considered to occur when more than 50% of the flock flew up. Altitudes of all aircraft were below 300 m. (data from: Visser 1986).

Disturbance from jet at <1200 m	Hours obs.	n	Flight frequency	%	Average duration (s)
	July 15-September 15				
Oystercatcher	320	2120	110	5	36
Bar-tailed godwit	150	925	168	18	56
Curlew	50	299	48	16	50
	July 16-December 1 and March 1-May 1				
Oystercatcher	320	2120	110	5	36
Bar-tailed godwit	150	925	168	18	56
Curlew	50	299	48	16	50

Disturbance from helicopter at <250 m	Hours obs.	n	Flight frequency	%	Average duration (s)
	July 15-September 15				
Oystercatcher	320	108	29	27	38
Bar-tailed godwit	150	58	43	74	73
Curlew	50	23	12	52	65
	July 16-December 1 and March 1-May 1				
Oystercatcher	300	84	27	32	22
Bar-tailed godwit	200	62	44	71	41
Curlew	30	12	8	68	38

Disturbance from helicopter at <1500 m	Hours obs.	n	Flight frequency	%	Average duration (s)
	July 15-September 15				
Oystercatcher	320	15	11	73	50
Bar-tailed godwit	150	13	11	85	114
Curlew	50	7	6	86	83
	July 16-December 1 and March 1-May 1				
Oystercatcher	300	3	2	–	48
Bar-tailed godwit	200	2	2	–	168
Curlew	30	–	–	–	–

between. Heinen (1986) found that a small aircraft flying over roosts of shorebirds on the East Friesian islands Juist, Wangerooge and Mellum (German Wadden Sea) led to 'disturbed behaviour' (varying from looking up and more frequent calling to taking flight and not returning to the initial roosting place and 4 categories in between) in 44-53% of the cases, depending on species, altitude, location and aircraft type. In her study, in which she unfortunately did not specify the distances between roosting flocks and planes, jets disturbed more often (in 84% of all potentially disturbing situations) than small civil aircraft (56%) and motor gliders (50%), whereas helicopters were very disturbing indeed (100%). Brent Geese were among the most strongly reacting species (64-92%), together with Curlew (42-86%) and Redshank (70%). Shelduck (42%) and Bar-tailed Godwit (38%) reacted less often. Civil aircraft flying at an altitude of >300 m disturbed in 8%, those flying at 150-300 m in 66% and those flying <150 m in 70% of the cases. These figures are comparable with those found by de Vlas (1986) in the Dutch Wadden Sea.

Observations on the tidal flats east of the island of Texel, with jets from the Vlieland shooting range frequently passing directly over at altitudes of less than 100 m, showed that foraging birds generally did not respond. Occasionally short reactions were noted, varying from looking up, stopping foraging for a few seconds, to short flights of 10-30 seconds. Occasionally somewhat stronger reactions were noted, possibly from birds which had recently arrived in the area (like Brent Geese, shortly after their arrival from the Siberian breeding grounds) (Smit & Visser 1985).

Experiments on tidal flats south of the island of Terschelling show that 10 minutes after a single disturbance by a small plane at 360 m altitude bird numbers were back at the same level as prior to the disturbance. A plane passing twice (at 450 and 360 m

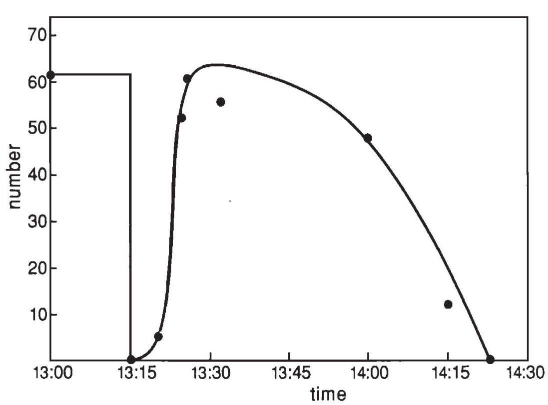

Figure 9. The number of foraging Curlews in the Zandkreek (Delta area) before and after disturbance of a small civil aircraft on 9 March. Effects on Oystercatchers were much longer lasting (from: Van der Meer 1985).

respectively) caused more dramatic effects. After 45 minutes only 67% and 87% of the originally present Oystercatcher and Curlew numbers had returned to the study plot (Glimmerveen & Went 1984). Small and slow flying aircraft are considered to be among the most disturbing phenomena in the Wadden Sea. The behaviour of the plane and its altitude both govern the reaction of the birds: flying high in a straight line leads to smaller effects than flying low or with unpredictable curves (Boer *et al.* 1970). There is some discussion between authors on the altitude at which planes cause no disturbance. According to the Werkgroep Waddenzee (1975) there is still disturbance when an aircraft passes at 1,000 m. Baptist & Meininger (1984) always registered disturbance at 150 m and found that at 300 m there was still disturbance within a radius of 1,000 m. Glimmerveen & Went (1984) found that individual Curlews only partly reacted by taking flight. On one occasion they observed a Curlew which pressed itself stiff to the ground when a plane came over at 450 m, in another case a Curlew only looked up rather frequently (altitude 360 m). The result of a passing small airplane (altitude 150 m) is also shown in Figure 9. All Curlews flew up but had recommenced feeding after 7 minutes. In contrast to many other studies the recovery time for Oystercatchers was much longer: 30 minutes. Using the model described above, an aircraft passing over at 150 m, creates a disturbed area of more than 15,000 ha! (Van der Meer 1985).

Ultra Light aircraft are a new development in aviation technology. Very little research on the effects of Ultra Lights has been carried out so far, but our first impression is that they are very disturbing, probably because of the low altitude at which these planes operate and the noise they produce. Numbers of roosting and foraging Bewick's Swans *Cygnus bewickii* close to an Ultra Light airstrip at Schouwen Duiveland (Delta area) dropped from 1,400-4,300 in 1986-88 to only a few birds in 1989, after the strip had been used for one year (Brilman in Smit & Visser 1989).

EFFECTS OF MILITARY SHOOTING ACTIVITIES

Early studies showed strong effects of the Vlieland and Terschelling shooting ranges on waders. Flocks of roosting Knot disappeared almost completely from the island of Vlieland (Van der Baan *et al.* 1958). In another study in the same area, Tanis (1962) found no response in roosting Shelduck, Mallard *Anas platyrhynchos*, Eider *Somateria mollissima* and gulls, but waders all took flight after the first shot. All *Tringa*s moved to more peaceful roosting sites and most Dunlin and Knot 'left'. Some of these birds returned later that day but continued shooting forced others to leave again. Oystercatchers, Bar-tailed Godwits and Curlews returned to the previously used roosting area. The total

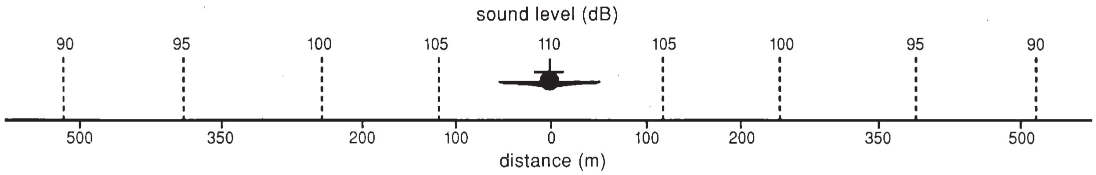

Figure 10. Sound levels of a completely loaded overflying jet at an altitude of 50 m, in relation to the distance at which the plane is flying (from Hoffmann, in Küsters & von Raden 1986).

numbers of ducks, waders and gulls in the heavily disturbed area amounted to 69,000 prior to shooting sessions (Monday-Friday) and to 38,000 during the shooting sessions.

At present, tank shooting at Vlieland is combined with bombing and rocket shooting from jets for most of the year. These activities yield sound levels of 84-100 dB(A) at 5 km from the firing range. Nowadays, the shooting activities still have disturbing effects, the extent depending on the time the shooting starts. When the roosts have already been established, the first shot may cause considerable numbers of birds to take flight. Some return to the original roosting site, whereas others select a site farther away from the shooting range. If shooting starts when the birds are still arriving from the feeding areas, such a resettlement more or less takes place automatically (Smit unpubl.). Theoretically it is possible that some birds stay away from disturbed areas altogether, to roost elsewhere on nearby islands. However, there is no information to confirm such behaviour. A comparison of the past and present situation at Vlieland shows that roosting birds still respond to shooting activities, despite the fact that shooting has been going on there for about 40 years. This may be due to the very high sound levels, or to the use of different types of ammunition, leading to strong differences in sound levels. Küsters & von Raden (1986) suggest that continuous reactions of birds to jet shooting and bombing at Sylt may be due to sound levels exceeding the pain threshold at 120 dB(A) (van Son 1987). He registered short lasting sound levels of 105 dB(A) at 100 m from overflying jets (Figure 10). Very high sound levels were absent in another study from the Dutch Wadden Sea. In contrast to experiences of the previous studies, Wintermans (1991) could not find effects of military shooting on waders roosting along the Groningen coast. In his study area sound levels did not exceed 55 dB(A).

Shooting activities at Vlieland have little visible effects on feeding waders. Prey choice, behaviour and intake rates of Oystercatcher and Curlews were not different on days with and without shooting (Smit 1986). He found indications that the diversity of feeding shorebirds south of Vlieland was higher on days without shooting, suggesting that some species are less tolerant of high sound levels and move away from that area.

Wintermans (1991), studying the effects from a shooting range in the Marnewaard found no indications for a lower diversity on the tidal flats. This could be due to the lower sound levels in that area, which were between 43-87 dB(A). Apparently, shooting alone has limited visible effects on feeding waders. However, very strong sound levels, as in the Vlieland and Sylt examples, incidental heavy shooting (Visser 1986) or sonic booms (Burger 1981a,b) may lead to strong reactions. Earlier observations on Vlieland (van Koersveld in Platteeuw 1986) suggest that reactions are stronger if sound is combined with visual disturbance.

EFFECTS OF DISTURBANCE ON FOOD INTAKE AND BEHAVIOUR OF TERRITORIAL BIRDS

Disturbance of non-territorial birds often forces all birds to leave the most heavily disturbed areas. Consequently, they have to feed in higher densities elsewhere. This may affect their food intake. Zwarts (1980) and Goss-Custard (1980) showed that food intake of waders decreased when bird densities increased, probably due to a higher level of interactions between birds. More or less territorial waders react differently. Zegers (1973) showed that a single person or group of people may cause the departure of most or all Redshanks, Oystercatchers and Curlews from their preferred feeding site, a mussel bed south of Schiermonnikoog (Figure 11). After such a disturbance only 9% of the originally present number of birds could still be found in the study area. The speed at which birds return to the preferred feeding areas varies between species. When forced out from preferred feeding areas such birds often simply wait until the source of disturbance has disappeared again. Beliën & Van Brummen (1985) studied food intake and behaviour of an individual Oystercatcher from a hide, in a situation in which it was possible to manipulate the length of the disturbed period in a standardized way. By carefully forcing out a single bird from its preferred feeding site they were able to show that the intake-rate may drop to almost zero, despite the fact that birds continue to feed in the area to which the bird has gone. These results are confirmed by comparable experiments described by Hooijmeijer (1991). Figure 12 shows that during disturbance resting and walking become more dominant in the behaviour. After disturbance feeding became

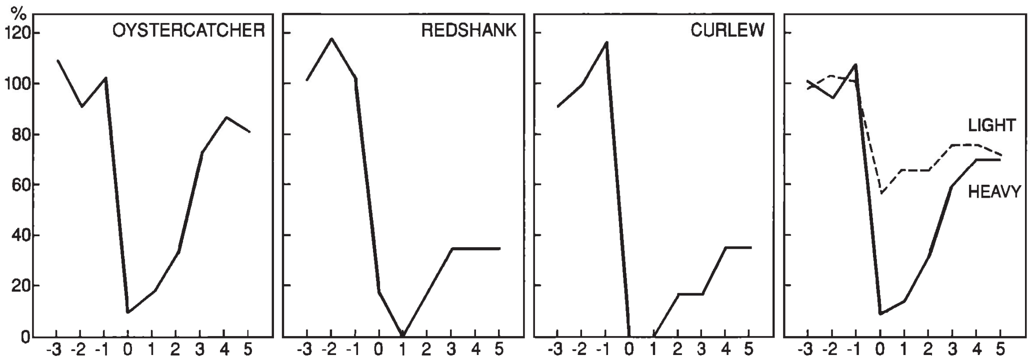

Figure 11. Effects of heavy disturbance on the number of Oystercatchers, Redshanks and Curlews in study plots on mussel beds close to Schiermonnikoog. Light disturbance: dotted line, heavy disturbance: straight line. The mean number of birds prior to disturbance is set at 100%, the figures at the abscissa indicate 15 minute intervals before and after disturbance (from: Zegers 1973).

much more dominant again. Figure 13 shows that the intake rate during a recovery period was much higher. In an undisturbed low-tide period the food intake of the same bird is rather similar over the whole period.

HABITUATION

Reijnen & Thissen (1987), studying the presence of breeding songbirds along motorways, found reduced densities for some species, despite the predictability and constancy of sound levels and traffic activity on the motorways. Apparently, some birds do not 'get used' to disturbance. This agrees with the shooting range effects on roosting waders at Vlieland. The absence of a visible response by foraging waders shows that in other situations habituation may take place. This process ("learning") is probably facilitated by a more or less constant supply of identical stimuli. This may be the reason for the presence of Lapwings *Vanellus vanellus*, gulls and Starlings *Sturnus vulgaris* at airfields where starting and landing patterns of planes are very predictable, both in terms of sound levels and in movements (c.f. Burger 1981a,b).

In some areas in the Wadden Sea helicopters or small civil aircraft may cause panic reaction among thousands of roosting or foraging birds (e.g. Van der Kamp & Koopman 1989). In areas where planes are common at least some habituation can be noted. As shown in earlier in this paper, there are large differences in the effects of jets and small civil aircraft between the studies from Heinen (1986) and Visser (1986). In the Mokbaai, Texel, a high degree of habituation has occurred to standard helicopter movements. Helicopters transporting crew to offshore drilling platforms pass over at a frequency of 2-3 per hour at 100-300 m altitude. These activities do not appear to have strong effects on feeding and roosting waders and ducks. The same area is also used for activities from

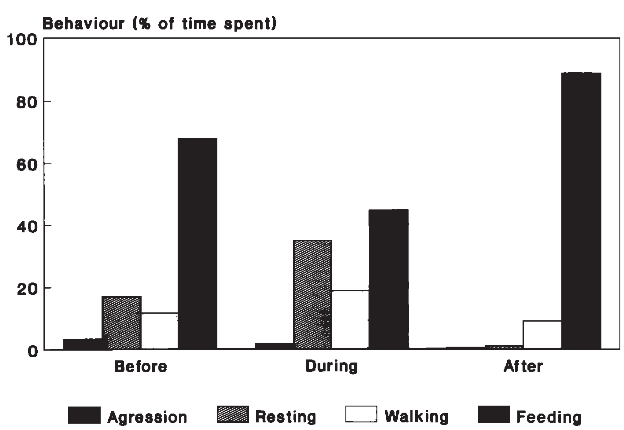

Figure 12. Behaviour (in % of time spent) of an individually marked Oystercatcher (LYCB) when forced out from its 'territory' on a mussel bed in the Mokbaai, Texel. The behaviour was registered for a whole low tide period, the disturbance was initiated artificially (from: Hooijmeijer 1991).

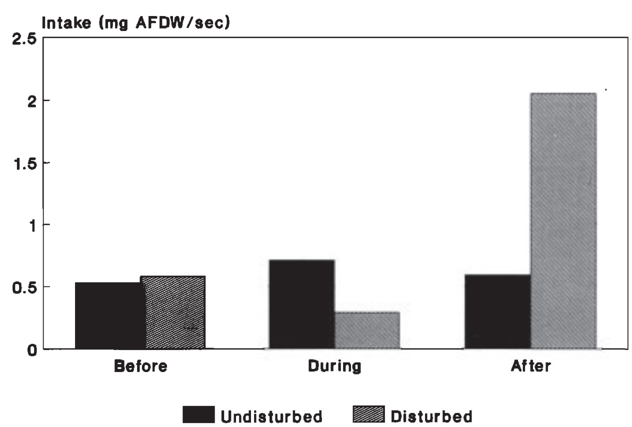

Figure 13. Intake rates (mg Ash Free Dry Weight/s) of an individually marked Oystercatcher (LYCB) in an undisturbed low tide period (artificially cut into three parts) and during a low-tide period in which the bird was forced out from its 'territory' on a mussel bed in the Mokbaai, Texel (from: Hooijmeijer 1991).

military helicopters, often at low altitudes. Despite a large degree of habituation to standard helicopter movements, these activities may force birds to less disturbed parts of the bay, and some species (like Cormorants *Phalacrocorax carbo* or Eiders) often temporarily leave the area. Small aircraft passing over at altitudes of over 300 m have effects comparable to those of civil helicopters. 'Unusual' types of planes, however, which show up at low frequencies still have strong effects (Smit unpubl.). This has also been found to happen on Vlieland. Under normal conditions roosting birds do not react severely when jets at the Vliehors shooting range pass by at high speed. Relatively slowly flying A10 jets are much less common in that area and can force thousands of birds to take flight for several minutes. This aircraft type is able to fly at a very low speed, can make very short curves and carries very strong machine guns. Consequently, its behaviour and sound production is very different from 'ordinary' jets, which are much more common there (Smit & Visser 1985). Also in the Mokbaai the birds could be more easily disturbed after the appearance of an unusual aircraft type. After such an event, an overflying Grey Heron *Ardea cinerea* or Great Black-backed Gull *Larus marinus* may even cause panic

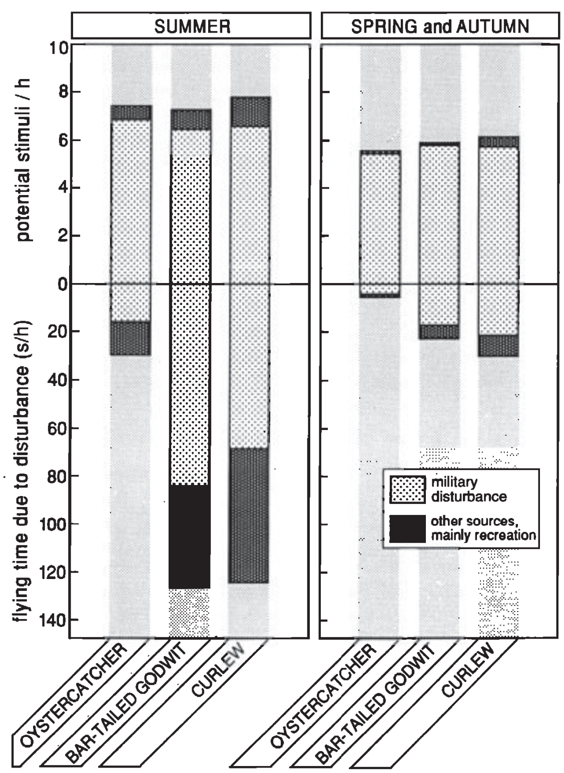

Figure 14. Number of potential disturbance cases per hour and the time these cases actually resulted in disturbance (seconds per hour) in summer and spring/autumn at the Noordvaarder, Terschelling for Oystercatcher, Bar-tailed Godwit and Curlew (data: Visser 1986).

reactions whereas under normal conditions they would have much smaller effects (Smit unpubl.).

These data suggest that birds are able to distinguish between types of planes. This is not really surprising. At the Banc d'Arguin, Mauritania, waders also appeared to distinguish between predators. Fish-eating Ospreys *Pandion haliaetus* were observed to land in between flocks of waders without any disturbance, whereas potentially dangerous Marsh Harriers *Circus aeruginosus* forced thousands of waders to take flight (Piersma 1982 and Smit unpubl.). Apparently, birds can learn through experience that some potentially dangerous objects are not dangerous after all. An unknown or infrequently occurring object, however, will be regarded with caution.

FACILITATION

The data presented so far suggest that high levels of disturbance lead to higher tolerance levels. This may be true in some cases but cannot be considered a rule. The opposite (referred to as facilitation) may also occur. Figure 14 depicts the number of potentially disturbing activities at the Noordvaarder, Terschelling, from 15 July - 15 September (summer) and 1 March - 1 May and 15 September - 1 December (spring/autumn) and the actual amount of disturbance resulting from these. In summer the number of potentially disturbing stimuli from military activities is only slightly larger than in spring and autumn. Their effect, however, is much larger. This is due to a cumulation of effects of disturbance from different sources. Leisure activities alone already may have a large disturbing effect. Combined with military activities they lead to disturbance levels far exceeding the effects each activity alone would have had. Comparable results were found on Sylt, Germany, where overflying jets appeared to have larger effects when prior to these activities wind surfers had been present in the area (Küsters & von Raden 1986). These reactions are comparable to the Heron and Black-backed Gull example from the Mokbaai, described previously.

A summary of all factors determining the behaviour of a single bird after disturbance is given in Figure 15. Birds respond as a function of earlier experiences, reactions of other birds nearby and several factors determining either their willingness to remain at the same place or act as a motivation to leave for another place. Activity rhythms and the availability of food and rest are important factors influencing the decision to remain at the same site. Birds feeling hungry will sooner leave high-tide roosts than well-fed birds that have just arrived from the feeding areas (Visser 1986). Protection through nature protection measures or the presence of a flock of conspecifics may also play a role. Additionally,

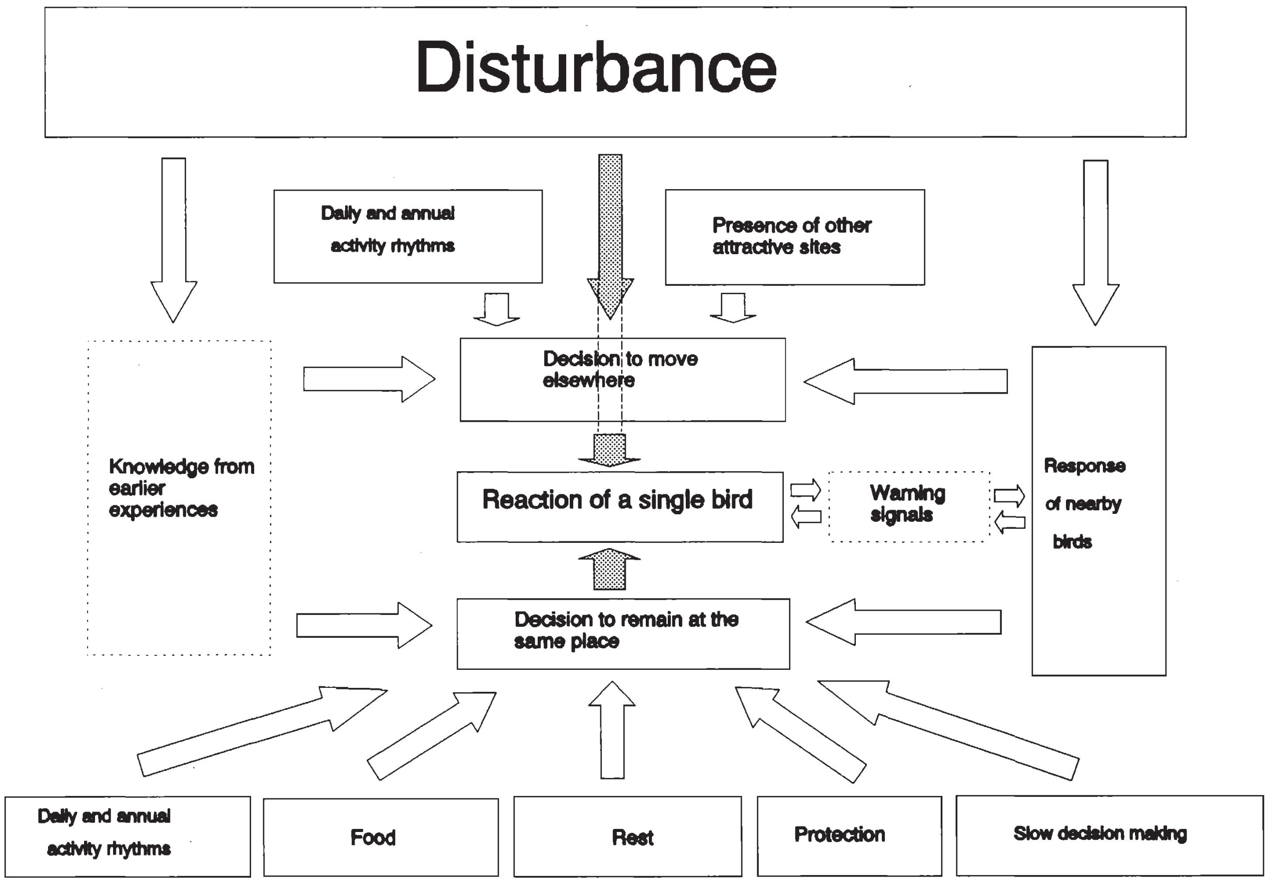

Figure 15. Reactions of a single bird on disturbance and the factors potentially affecting its behaviour (modified after Küsters & von Raden 1986)

a bird may postpone an immediate reaction in order to minimize its energy expenditure (referred to as 'slow decision making'). Activity rhythms and the presence of suitable alternative feeding or roosting sites may induce a decision to move elsewhere. Birds may respond directly to disturbance, for instance from a shot in a previously undisturbed area. In many cases, however, birds will not respond immediately but use earlier experiences and the behaviour of other birds in the same area as a filter mechanism. Warning signals (without any further disturbance) may also lead to behavioural responses.

THE USE OF PRESENTLY AVAILABLE DATA AND FUTURE NEEDS

This contribution shows that in the past 20 years there has been much study of the effects of disturbance. We could ask ourselves, however, whether these data are the tools we actually need to understand the effects on a bird. In the case of disturbance to non-territorial birds, we also need to know the consequences of feeding in higher densities. Another question is whether non-territorial birds are really non-territorial. From several studies we know that at least some species of non-territorial birds nevertheless do show a high site-fidelity within a winter and between years, at least at the roosting places (Furness & Galbraith 1980, Symonds *et al.* 1984). This could mean that these birds do not distribute themselves over the tidal flats as freely as we may think. Consequently, regular disturbance in part of their preferred feeding area could affect their food intake more than when they would freely distribute over large areas. To what extent will be extremely difficult to measure. Birds may also be able to compensate by feeding longer or by more frequent or longer feeding at night. Cage experiments during which the length of the low-tide period was artificially manipulated have shown that (territorial) Oystercatchers are able to compensate for lost feeding time by increasing their efficiency (Swennen *et al.* 1989). Of course we do not know to what extent this is possible in the field and at what price. Oystercatchers could run a higher risk of bill damage, other species could be more vulnerable to predators because of reduced vigilance.

Frequent disturbance may force waders to abandon traditional high-tide roosts. This is demonstrated in the Dee estuary (Mitchell *et al.* 1988) where Bar-tailed Godwits declined 99%, Knots 79% and Dunlins 81%. In this case the birds continued to use the traditional feeding areas. This behavioural change involved higher energy costs, because the birds had to fly an extra 40 km each tidal cycle. Heavy disturbance can also lead to a total departure from feeding sites. This is probably happening in Denmark where suitable wetlands do not harbour any Curlews, probably due to large flight distances and wariness as a result of hunting (Meltofte 1986). The consequences of such banishment are largely unknown and are part of a major applied ecological question: 'how many birds can an estuary support' (c.f. Sutherland & Goss-Custard 1991, Lambeck 1991, Meire 1991).

In this contribution we have restricted ourselves very much to visible reactions. What is really happening to birds is a much more complicated problem. Heart-rates of Eiders and Oystercatchers appear to increase considerably when incubating birds are approached by man or a helicopter, despite the fact that the birds showed no visible reaction (Gabrielsen 1987, Hüppop & Hagen 1990). The implications on energy of disturbance are not yet clear but indicate that the effects can be much larger than would appear from the studies described in this paper.

The previous examples of what we still do not know may give too pessimistic a picture of our knowledge of disturbance. Clearly, there are many limitations on what we can do with the existing data. Nevertheless, they can be useful tools for modelling bird reactions. They can also be well applied by policy makers or for local protection measures (such as keeping visitors to coastal nature reserves at a sufficient distance from the high-tide roosts). However, the available data are not yet suitable for answers to key questions like 'what are the effects of disturbance on energy budgets of a bird' or 'what are the repercussions of being in a bad condition on survival or reproduction rate'. Such questions will involve more studies on energy loss, the costs (or lower intake) of feeding at alternative feeding sites and the consequences of higher costs or lower intake rates on body-condition.

ACKNOWLEDGEMENTS

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Effects of disturbance on shorebirds: a summary of existing knowledge from the Dutch Wadden Sea and Delta area

Cor J. Smit & George J.M. Visser

Smit, C.J. & Visser, G.J.M. 1993. Effects of disturbance on shorebirds: a summary of existing knowledge from the Dutch Wadden Sea and Delta area. *Wader Study Group Bull.* 68: 6-19.

The extent to which shorebirds are disturbed by various activities is discussed, with reference to studies carried out on the Wadden Sea and Delta area. The effects of leisure activities on foraging and roosting birds are discussed. The effects of small airplanes, jets and helicopters are also considered, as are the effects of disturbance on food intake and behaviour of territorial birds. Frequent disturbance may force waders to abandon traditional high-tide roosts. The implications of disturbance on energy are not yet clear but indicate that the effects can be larger than would appear from the studies described.

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INTRODUCTION

The Wadden Sea and Delta area are both wetlands of outstanding importance for many bird species ecologically dependent on intertidal habitats (Wolff & Smit 1984; Leeuwis *et al.* 1984). At the same time these areas are intensively used for a great variety of human activities. In some cases this leads or may lead to conflicts between the interests of birds and man (Figure 1). Over the past 20 years the scale of most of these (potential) conflicts has been studied in the Dutch part of the Wadden Sea and the Delta area and, more recently, also in the Danish and German Wadden Sea. The more recent investigations have focussed on whether limits should be set to human presence in an area or whether certain activities should be banned from (parts of) an area.

Interactions birds / man

Resting birds	Foraging birds
Tourism - walking	Bait digging
- surfing, sailing	Walking over mudflats
Farming	Civil aircrafts
Hunting, egg collecting	Military activities
Military activities	Fisheries
	Leisure boats

Figure 1. Human activities actually or potentially conflicting with the interests of resting and foraging shorebirds in the Dutch Wadden Sea and Delta area

Disturbance can be defined as 'any situation in which a bird behaves differently from its preferred behaviour' (Boere 1975) or 'any situation in which human activities cause a bird to behave differently from the behaviour it would exhibit without the presence of that activity' (Oranjewoud 1982). In this contribution we will restrict ourselves to disturbance caused by human activities: disturbance from natural causes (weather, predators) has not been studied in detail and will only briefly be addressed. We will not discuss the effects on breeding birds and mainly cover Dutch studies from coastal sites (with some information from the German part of the Wadden Sea). Outside The Netherlands very little is known of this work. This is very comprehensible: with the exception of some preliminary data on part of the problem (Smit & Visser 1985) and some rather brief summaries (Wolff *et al.* 1982, Smit *et al.* 1987), the results have been presented in not easily available reports from institutes, government agencies and universities. Access to these reports is also hampered by language barriers: nearly all information is published in Dutch. This paper is an attempt to summarize briefly the results of these studies.

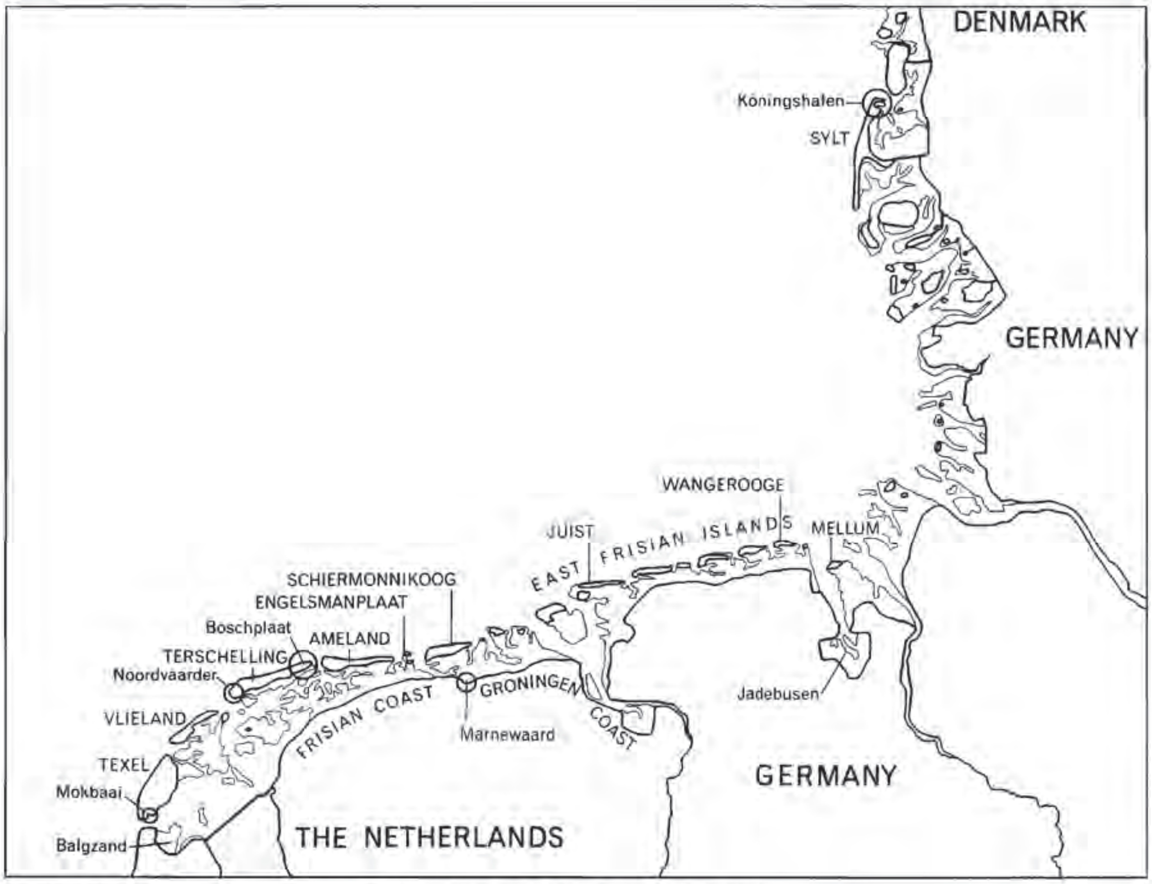

Figure 2. Map of the Dutch part of the Wadden Sea with location of sites referred to in the text.

EFFECTS OF LEISURE ACTIVITIES ON BIRDS RESTING AT HIGH-TIDE ROOSTS

High-tide roosts may be encountered in many places along the borders of the Wadden Sea and the Delta estuaries. On the mainland coast of the Wadden Sea (Figure 2) shorebirds roost on man-made saltmarshes. In most of the Wadden Sea these areas are not intensively used for agricultural purposes, and have a rather low degree of human disturbance. On the shores of the Wadden Sea barrier islands and in the Delta area the disturbance frequency is generally much higher, but from most places quantitative data on the scale of the problem are lacking.

Flocks of shorebirds may be disturbed by a variety of human activities, though natural causes (such as predators) may also take an important share. Table 1 presents the reasons for disturbance, as registered on Terschelling. In particular small aircraft and tourists walking are important sources of disturbance; cattle or people with a highly predictable behaviour (like farmers) are less so. Table 2 shows that small aircraft and people walking around also cause birds to take flight at large distances. Cars, agricultural activities and dogs caused less disturbance (Blankestijn *et al.* 1986). There are also differences between species as illustrated by the flight distances when birds are approached by walking people (Figure 3). Golden Plovers *Pluvialis apricaria* are fairly tolerant, but Curlew *Numenius arquata* and Redshank *Tringa totanus* tend to take flight at more than twice as great a distance. Detailed summer observations at

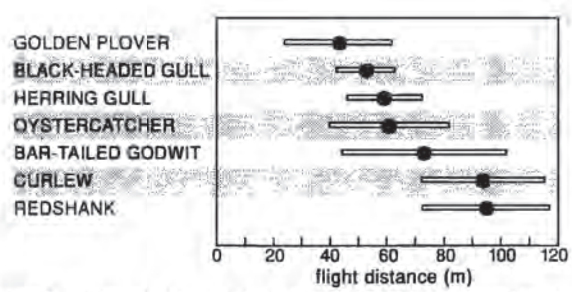

Figure 3. Distances (mean values in m and 95% confidence limits) at which flocks of roosting waders and gulls were recorded to take flight when approached by walking people. Data from Terschelling, July - September 1981 (data: Tensen & van Zoest 1983).

Table 1. Disturbance frequency, expressed as a percentage of the total amount of visible disturbance in one study situation at high-tide roosts in a cultivated grassland area at Terschelling. The study was carried out in July-September 1981, when relatively many tourists on bicycles were present on the island. Most of these have a very predictable behaviour through their preference for metalled cycle paths (data: Tensen & van Zoest 1983).

Source of disturbance	Curlew	Bar-tailed Godwit	Oystercatcher	Gulls
Small aircraft	39	23	18	27
Walking person(s)	31	32	65	17
Agricultural activities	10	8	4	7
Cows	1	2	13	1
Cyclist(s)	–	1	–	–
Natural	11	16	–	24
Unknown reason	8	18	–	24

Terschelling show that walking people within 250 m of roosting Oystercatchers *Haematopus ostralegus* caused flocks to fly in 57% of the cases. As a mean, these birds were 38 seconds per hour on the wing (mean of 320 observation hours). Curlews flew up in 76% of the cases. On average these birds flew 57 sec/h (mean over 50 hours) (Visser 1986). Figure 4 shows that before flying up, the behaviour of roosting birds may already have been considerably affected: looking up and walking away become more dominant as distances get smaller.

Weather conditions partly determine flight distances. Kersten (1975) reports that Curlews can be more easily disturbed during rainy weather. At the same time the roosts are less compact, smaller and distributed over larger areas. Several studies show that large flocks are more easily disturbed (Zwarts 1972; Kooy *et al.* 1975). Flight distances are very much time and location dependent. These differences are sometimes rather difficult to explain. At the comparatively undisturbed Banc d'Arguin, Mauritania (where flight distances for most species are smaller than in the Wadden Sea) flocks of wintering Oystercatchers fly up at 400-500 m (Smit unpubl.) whereas in the Wadden Sea they are a rather tolerant species (Figure 3, Table 2). Birds roosting in cultivated grasslands with a certain amount of human activity can often be approached to closer distances than those roosting in remote salt marshes (within the same area and time of the year). Curlews roosting in cultivated grassland areas at Terschelling could be approached to approximately 100 m, whereas on the salt marshes on same island the flight distance was 200 m (Tensen & van Zoest 1983).

Hunting may increase flight distances for non-target species as well as target species. By the end of September, Brent Geese *Branta bernicla* in Denmark take flight at 210 m; by the end of October (after the start of the hunting season) the mean flight distance has increased to 370 m (Rudfeld 1990). Comparable

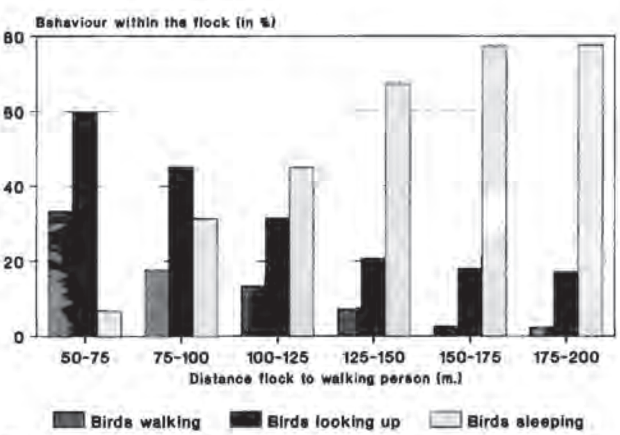

Figure 4. Behaviour of flocks of Curlews when approached by walking people, in relation to the distance to the flocks. Data were collected in standardized experimental situations, using flocks of Curlews roosting in cultivated grasslands (data: Blankestijn *et al.* 1986).

Table 2. Mean distances (m) at which flocks of Oystercatchers and Curlews flew up when approached by various sources of disturbance. Data from flocks roosting in cultivated grasslands on the island of Terschelling (data: Blankestijn *et al.* 1986).

Source of disturbance	Oystercatcher	Curlew
Small aircraft	500	–
Walking person (s)	82	213
Helicopter	–	200
Car	106	188
Egg collector	46	140
Farmer/Agricultural activities	60	129
Dog(s)	–	90
Cattle	10	–

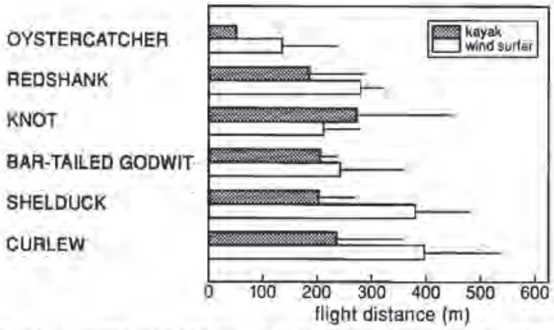

Figure 5. Distances (mean values in m and standard deviations) at which flocks of roosting waders were recorded to take flight when approached by a kayak or wind surfer. Data from the Jadebusen (German mainland coast) (from: Koepff & Dietrich 1986).

observations have been made on inland feeding geese (cf. Gerdes & Reepmeyer 1983).

Koepff & Dietrich (1986) studied the effects of kayaks and wind surfers on roosting waders and Shelduck *Tadorna tadorna* in the Jadebusen (German Wadden Sea). Although there are some differences in species composition between this and the previously mentioned study, more or less the same order of disturbance susceptibility was found (Figure 5). Kayaks and sailing boats disturbed more often than motor boats and wind surfers. Kayaks have a small draught which enables them to come very close to the high-tide roosts. In the Königshafen, Sylt, wind surfers had strong disturbing effects on dabbling ducks. A few zigzag movements of a single surfer were sufficient for a complete departure of all ducks present. In the same situation Brent Geese left the area when approached at 300 m or less (Küsters & von Raden 1986).

Waders may leave their usual high-tide roosts as a result of disturbance but the available data are somewhat difficult to interpret. Boer *et al.* (1970) found on the Balgzand that Bar-tailed Godwits *Limosa lapponica* used two high-tide roosts. One was used especially in summer and was situated in a relatively quiet area. The second was used mainly in winter at a location where in summer many tourists were present. A comparable feature was found in Denmark where Bar-tailed Godwits also changed roosting sites, probably as a result of disturbance from hunting (Rudfeld 1990). The eastern part of the island of Ameland consists of a large sandflat. Normally 10,000 Curlews roost here in summer nights, whereas during the day only some hundreds are present. These birds use alternative day-time roosts on the sandflats of Engelsmanplaat and on the Frisian coast. In winter, when considerably fewer people visit that area, Curlews do roost on Ameland (Kersten 1975). Zwarts (1972) noted that a traditional Curlew roost on the salt marshes was gradually abandoned after an increase in disturbance by tourism. Ringing activities on Vlieland on two successive nights lead to severe disturbance of Redshank roosts. It took five days before the normally occurring numbers were present again. Cannon-netting at a Curlew high-tide roost on the same island on two nights with a nine days interval also led to a temporary departure. In this case it took 2-3 weeks before the numbers were back to normal again (Zegers 1973).

EFFECTS OF LEISURE ACTIVITIES ON FORAGING BIRDS

Although data on flight distances are available for some tidal flats, it is impossible to give standard figures on this matter. Distances vary between sites and are dependent on earlier experiences (learning) in that particular location. In Denmark, for instance, Curlews show an extreme wariness and have a flight distance of 500 m, probably because they are a hunted species in that country (Meltofte 1986). In the Mokbaai, Texel, a small bay surrounded by sea walls and dunes, with a large variety of human activities (recreation, bait digging, angling, helicopter traffic, navy inflatables speeding through the channel, etc.) some Dunlins can be approached to within 10-20 m or less without any visible disturbance. At the same time of the year Dunlin flocks feeding on the open mudflats east of the island may take flight at a distance of 100 or 200 m. Such differences were also found at Terschelling, where birds close to the sea wall (with rather frequent human activities) tolerated people walking on the tidal flats at shorter distances than

Table 3 Mean flight distances (in m) of wader species, when approached by people walking over the tidal flats near Terschelling (Dutch Wadden Sea) at various distances from the sea wall (data: Glimmerveen & Went 1984).

Species	200-300 m from sea wall	500-1,000 m from sea wall	mussel bed at 1,000 m from sea wall
Oystercatcher	79	113	77
Bar-tailed Godwit	101	138	–
Curlew	140	196	102

Table 4. Mean distances and ranges (m) at which birds take flight when approached by people walking over the tidal flats (from: van der Meer 1985 (Delta area), Wolff *et al.* 1982 and Smit unpubl. (Wadden Sea)).

Species	Delta		Wadden Sea	
	Flight dist.	Range	Flight dist.	Range
Curlew	211	124-299	339	225-550
Shelduck	148	99-197	250	200-300
Grey Plover	124	106-142	–	50-150
Ringed Plover	121	80-162	–	–
Bat-tailed Godwit	107	88-127	219	150-225
Brent Goose	105	58-152	–	–
Oystercatcher	85	81-89	136	25-300
Dunlin	71	57-86	163	100-300
Turnstone	47	31-53	–	150-250

birds foraging farther away from the sea-wall (Table 3). The flight distance is also influenced by the behaviour of a person or group of people. One individual person generally disturbs less than a group; dogs running around are very disturbing. Bait diggers, working at the same spot for longer periods, are tolerated at shorter distances than a walking person.

Birds taking flight are the most obvious result of disturbance. As in resting birds (Figure 4), they often change their behaviour long before they take flight. Van der Meer (1985) has shown that some birds do so at distances which are on average 30% greater than those at which they take flight. In Brent Geese it was as much as 95% (205 m and 105 m respectively). Using the distances at which birds take flight we can simply compute the area where no birds are present. The size of such an area will be πr^2. The results of these calculations are depicted in Figure 6. In general, the situation will be more complex because people will move over the tidal flats. If this happens birds will leave from an area in front and on both sides of a person or group (Figure 7). Using the information on the distance at which birds take flight and additional information on the time needed for recovery we can calculate the size of the area where birds are temporarily forced out. When a person or group crosses the tidal flats of the Wadden Sea from the mainland to one of the islands (a popular sport in The Netherlands in which tens of thousands participate each summer) this information also allows us to calculate the loss of feeding area from which the birds are forced out. Van der Meer (1985) calculated the size of this area at:

$$\text{surface} = \pi r_2^2 + 2r_1.h_1.s + 2(r_2-r_1).h_2.s$$

in which:

surface = area abandoned by foraging birds (in m^2)
s = walking speed in m/s
r_1 = flight distance in metres (zone 1)
r_2 = distance at which birds stopped feeding in metres (zone 2)

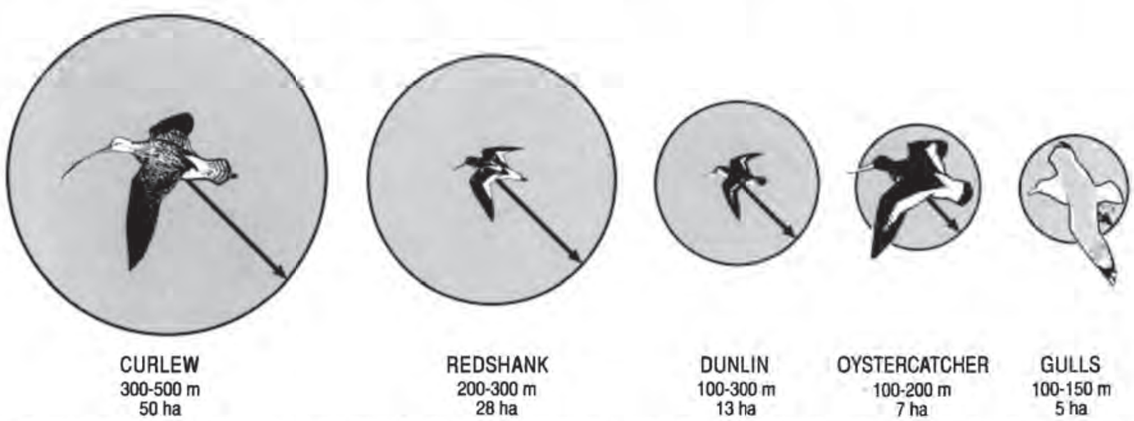

Figure 6. Theoretical size of areas without any birds for five shorebird species, using the information from the Wadden Sea from Table 4.

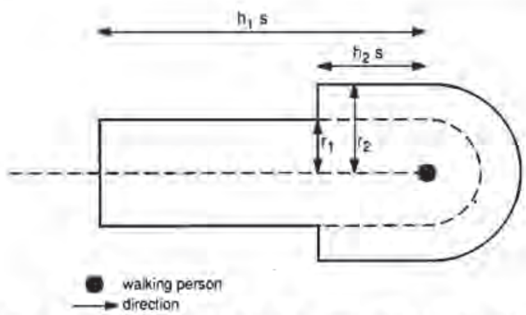

Figure 7. Theoretical size of the area without birds, after disturbance from a single person or a group walking over the tidal flats. See text for additional information (from: Van der Meer 1985)

h_1 = recovery speed from zone 1 in seconds
h_2 = recovery speed from zone 2 in seconds

For Oystercatchers in the Delta area for a person walking with a speed of 1 m/s (which equals 3.6 km/h) the following figures were measured:

r_1 = 85 m
r_2 = 120 m
h_1 = 900 seconds
h_2 = 300 seconds

For Oystercatchers this calculation leads to a disturbed area of 20 ha. For bait diggers the disturbed area will be somewhere in between r_1 and r_2. Once again the disturbed area will be πr_2, which means that a bait digger is surrounded by an area of 3.3 ha without any Oystercatchers.

Similar data on the effects of other sources of disturbance on feeding birds are much more scanty. A small motor boat near Terschelling, sailing at approximately 10 km/h, caused Oystercatchers to walk away at 95 m; at 50 m most birds stopped feeding or flew off. Curlews were less tolerant and responded at 190 m. At 95 m most Curlews walked away or stopped feeding. As in other studies Bar-tailed Godwits reacted at distances in between those of Oystercatchers and Curlews (Glimmerveen & Went 1984).

EFFECTS OF SMALL AIRPLANES, JETS AND HELICOPTERS

Visser (1986) extensively studied the behaviour of birds roosting at the Noordvaarder, Terschelling. This area faces military activities (including a jet shooting range, helicopter activities, transport vehicles, etc.) and a variety of activities linked with tourists and local inhabitants (including people walking with or without dogs, angling, cross-country motorcycles, etc.). The frequent presence of jets and helicopters allows for a comparison of the effects of the two aircraft types. Figure 8 shows that helicopters disturb more frequently and over longer distances than jets, even though activities from jets are accompanied by shooting and high sound levels. The relatively mild effects from military jets are also known from other places (Boer *et al.* 1970; de Roos 1972) and are shown in Table 5. From these data it appears that small civil aircraft cause much more disturbance. Again, there were clear differences between species. Oystercatchers were rather tolerant of aircraft disturbance; Curlews were less so. Other species (like Bar-tailed Godwits) were in

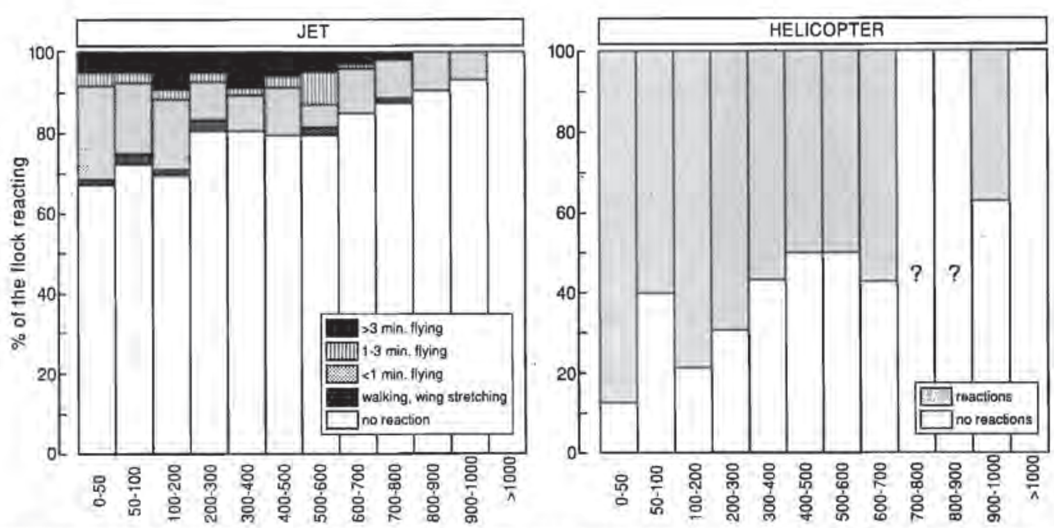

Figure 8. Distances (in m) at which military jets and helicopters caused disturbance among roosting Bar-tailed Godwits at the Noordvaarder, Terschelling. Data were collected from 1980-84 and represent 925 (jets) and 100 (helicopters) potential cases of disturbance (data from Visser 1986).

Table 5. Disturbance of waders (total number of hours of observation time, number of flocks observed, the frequency at which flocks flew up and the % of flocks reacting) at the Noordvaarder (Terschelling) in summer (1980-84). Flock sizes were >100 (Oystercatcher and Bar-tailed Godwit) and >20 (Curlew). Disturbance was considered to occur when more than 50% of the flock flew up. Altitudes of all aircraft were below 300 m. (data from: Visser 1986).

Disturbance from jet at <1200 m	Hours obs.	n	Flight frequency	%	Average duration (s)
	July 15-September 15				
Oystercatcher	320	2120	110	5	36
Bar-tailed godwit	150	925	168	18	56
Curlew	50	299	48	16	50
	July 16-December 1 and March 1-May 1				
Oystercatcher	320	2120	110	5	36
Bar-tailed godwit	150	925	168	18	56
Curlew	50	299	48	16	50

Disturbance from helicopter at <250 m	Hours obs.	n	Flight frequency	%	Average duration (s)
	July 15-September 15				
Oystercatcher	320	108	29	27	38
Bar-tailed godwit	150	58	43	74	73
Curlew	50	23	12	52	65
	July 16-December 1 and March 1-May 1				
Oystercatcher	300	84	27	32	22
Bar-tailed godwit	200	62	44	71	41
Curlew	30	12	8	68	38

Disturbance from helicopter at <1500 m	Hours obs.	n	Flight frequency	%	Average duration (s)
	July 15-September 15				
Oystercatcher	320	15	11	73	50
Bar-tailed godwit	150	13	11	85	114
Curlew	50	7	6	86	83
	July 16-December 1 and March 1-May 1				
Oystercatcher	300	3	2	–	48
Bar-tailed godwit	200	2	2	–	168
Curlew	30	–	–	–	–

between. Heinen (1986) found that a small aircraft flying over roosts of shorebirds on the East Friesian islands Juist, Wangerooge and Mellum (German Wadden Sea) led to 'disturbed behaviour' (varying from looking up and more frequent calling to taking flight and not returning to the initial roosting place and 4 categories in between) in 44-53% of the cases, depending on species, altitude, location and aircraft type. In her study, in which she unfortunately did not specify the distances between roosting flocks and planes, jets disturbed more often (in 84% of all potentially disturbing situations) than small civil aircraft (56%) and motor gliders (50%), whereas helicopters were very disturbing indeed (100%). Brent Geese were among the most strongly reacting species (64-92%), together with Curlew (42-86%) and Redshank (70%). Shelduck (42%) and Bar-tailed Godwit (38%) reacted less often. Civil aircraft flying at an altitude of >300 m disturbed in 8%, those flying at 150-300 m in 66% and those flying <150 m in 70% of the cases. These figures are comparable with those found by de Vlas (1986) in the Dutch Wadden Sea.

Observations on the tidal flats east of the island of Texel, with jets from the Vlieland shooting range frequently passing directly over at altitudes of less than 100 m, showed that foraging birds generally did not respond. Occasionally short reactions were noted, varying from looking up, stopping foraging for a few seconds, to short flights of 10-30 seconds. Occasionally somewhat stronger reactions were noted, possibly from birds which had recently arrived in the area (like Brent Geese, shortly after their arrival from the Siberian breeding grounds) (Smit & Visser 1985).

Experiments on tidal flats south of the island of Terschelling show that 10 minutes after a single disturbance by a small plane at 360 m altitude bird numbers were back at the same level as prior to the disturbance. A plane passing twice (at 450 and 360 m respectively) caused more dramatic effects. After 45 minutes only 67% and 87% of the originally present Oystercatcher and Curlew numbers had returned to the study plot (Glimmerveen & Went 1984). Small and slow flying aircraft are considered to be among the most disturbing phenomena in the Wadden Sea. The behaviour of the plane and its altitude both govern the reaction of the birds: flying high in a straight line leads to smaller effects than flying low or with unpredictable curves (Boer *et al.* 1970). There is some discussion between authors on the altitude at which planes cause no disturbance. According to the Werkgroep Waddenzee (1975) there is still disturbance when an aircraft passes at 1,000 m. Baptist & Meininger (1984) always registered disturbance at 150 m and found that at 300 m there was still disturbance within a radius of 1,000 m. Glimmerveen & Went (1984) found that individual Curlews only partly reacted by taking flight. On one occasion they observed a Curlew which pressed itself stiff to the ground when a plane came over at 450 m, in another case a Curlew only looked up rather frequently (altitude 360 m). The result of a passing small airplane (altitude 150 m) is also shown in Figure 9. All Curlews flew up but had recommenced feeding after 7 minutes. In contrast to many other studies the recovery time for Oystercatchers was much longer: 30 minutes. Using the model described above, an aircraft passing over at 150 m, creates a disturbed area of more than 15,000 ha! (Van der Meer 1985).

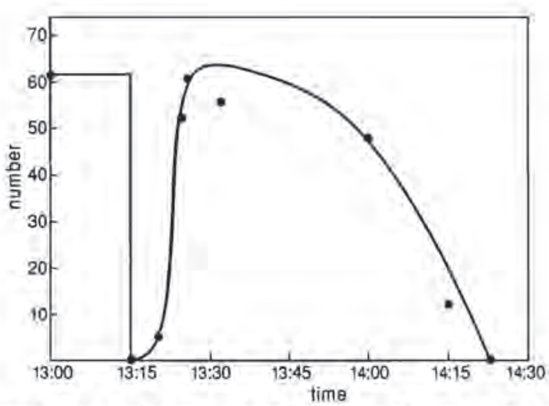

Figure 9. The number of foraging Curlews in the Zandkreek (Delta area) before and after disturbance of a small civil aircraft on 9 March. Effects on Oystercatchers were much longer lasting (from: Van der Meer 1985).

Ultra Light aircraft are a new development in aviation technology. Very little research on the effects of Ultra Lights has been carried out so far, but our first impression is that they are very disturbing, probably because of the low altitude at which these planes operate and the noise they produce. Numbers of roosting and foraging Bewick's Swans *Cygnus bewickii* close to an Ultra Light airstrip at Schouwen Duiveland (Delta area) dropped from 1,400-4,300 in 1986-88 to only a few birds in 1989, after the strip had been used for one year (Brilman in Smit & Visser 1989).

EFFECTS OF MILITARY SHOOTING ACTIVITIES

Early studies showed strong effects of the Vlieland and Terschelling shooting ranges on waders. Flocks of roosting Knot disappeared almost completely from the island of Vlieland (Van der Baan *et al.* 1958). In another study in the same area, Tanis (1962) found no response in roosting Shelduck, Mallard *Anas platyrhynchos*, Eider *Somateria mollissima* and gulls, but waders all took flight after the first shot. All *Tringas* moved to more peaceful roosting sites and most Dunlin and Knot 'left'. Some of these birds returned later that day but continued shooting forced others to leave again. Oystercatchers, Bar-tailed Godwits and Curlews returned to the previously used roosting area. The total

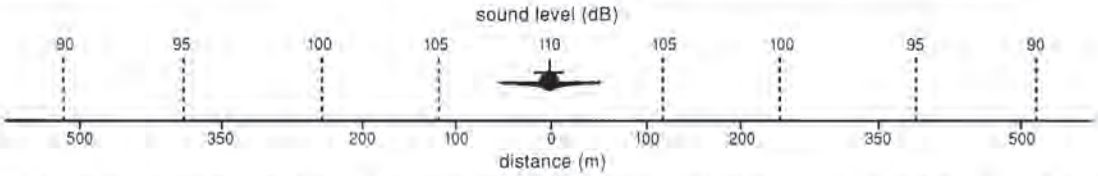

Figure 10. Sound levels of a completely loaded overflying jet at an altitude of 50 m, in relation to the distance at which the plane is flying (from Hoffmann, in Küsters & von Raden 1986).

numbers of ducks, waders and gulls in the heavily disturbed area amounted to 69,000 prior to shooting sessions (Monday-Friday) and to 38,000 during the shooting sessions.

At present, tank shooting at Vlieland is combined with bombing and rocket shooting from jets for most of the year. These activities yield sound levels of 84-100 dB(A) at 5 km from the firing range. Nowadays, the shooting activities still have disturbing effects, the extent depending on the time the shooting starts. When the roosts have already been established, the first shot may cause considerable numbers of birds to take flight. Some return to the original roosting site, whereas others select a site farther away from the shooting range. If shooting starts when the birds are still arriving from the feeding areas, such a resettlement more or less takes place automatically (Smit unpubl.). Theoretically it is possible that some birds stay away from disturbed areas altogether, to roost elsewhere on nearby islands. However, there is no information to confirm such behaviour. A comparison of the past and present situation at Vlieland shows that roosting birds still respond to shooting activities, despite the fact that shooting has been going on there for about 40 years. This may be due to the very high sound levels, or to the use of different types of ammunition, leading to strong differences in sound levels. Küsters & von Raden (1986) suggest that continuous reactions of birds to jet shooting and bombing at Sylt may be due to sound levels exceeding the pain threshold at 120 dB(A) (van Son 1987). He registered short lasting sound levels of 105 dB(A) at 100 m from overflying jets (Figure 10). Very high sound levels were absent in another study from the Dutch Wadden Sea. In contrast to experiences of the previous studies, Wintermans (1991) could not find effects of military shooting on waders roosting along the Groningen coast. In his study area sound levels did not exceed 55 dB(A).

Shooting activities at Vlieland have little visible effects on feeding waders. Prey choice, behaviour and intake rates of Oystercatcher and Curlews were not different on days with and without shooting (Smit 1986). He found indications that the diversity of feeding shorebirds south of Vlieland was higher on days without shooting, suggesting that some species are less tolerant of high sound levels and move away from that area.

Wintermans (1991), studying the effects from a shooting range in the Marneward found no indications for a lower diversity on the tidal flats. This could be due to the lower sound levels in that area, which were between 43-87 dB(A). Apparently, shooting alone has limited visible effects on feeding waders. However, very strong sound levels, as in the Vlieland and Sylt examples, incidental heavy shooting (Visser 1986) or sonic booms (Burger 1981a,b) may lead to strong reactions. Earlier observations on Vlieland (van Koersveld in Platteeuw 1986) suggest that reactions are stronger if sound is combined with visual disturbance.

EFFECTS OF DISTURBANCE ON FOOD INTAKE AND BEHAVIOUR OF TERRITORIAL BIRDS

Disturbance of non-territorial birds often forces all birds to leave the most heavily disturbed areas. Consequently, they have to feed in higher densities elsewhere. This may affect their food intake. Zwarts (1980) and Goss-Custard (1980) showed that food intake of waders decreased when bird densities increased, probably due to a higher level of interactions between birds. More or less territorial waders react differently. Zegers (1973) showed that a single person or group of people may cause the departure of most or all Redshanks, Oystercatchers and Curlews from their preferred feeding site, a mussel bed south of Schiermonnikoog (Figure 11). After such a disturbance only 9% of the originally present number of birds could still be found in the study area. The speed at which birds return to the preferred feeding areas varies between species. When forced out from preferred feeding areas such birds often simply wait until the source of disturbance has disappeared again. Beliën & Van Brummen (1985) studied food intake and behaviour of an individual Oystercatcher from a hide, in a situation in which it was possible to manipulate the length of the disturbed period in a standardized way. By carefully forcing out a single bird from its preferred feeding site they were able to show that the intake-rate may drop to almost zero, despite the fact that birds continue to feed in the area to which the bird has gone. These results are confirmed by comparable experiments described by Hooijmeijer (1991). Figure 12 shows that during disturbance resting and walking become more dominant in the behaviour. After disturbance feeding became

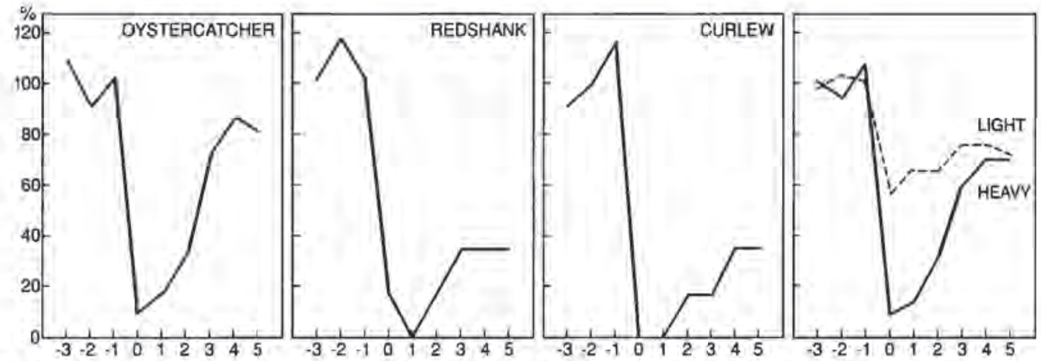

Figure 11. Effects of heavy disturbance on the number of Oystercatchers, Redshanks and Curlews in study plots on mussel beds close to Schiermonnikoog. Light disturbance: dotted line, heavy disturbance: straight line. The mean number of birds prior to disturbance is set at 100%, the figures at the abscissa indicate 15 minute intervals before and after disturbance (from: Zegers 1973).

much more dominant again. Figure 13 shows that the intake rate during a recovery period was much higher. In an undisturbed low-tide period the food intake of the same bird is rather similar over the whole period.

HABITUATION

Reijnen & Thissen (1987), studying the presence of breeding songbirds along motorways, found reduced densities for some species, despite the predictability and constancy of sound levels and traffic activity on the motorways. Apparently, some birds do not 'get used' to disturbance. This agrees with the shooting range effects on roosting waders at Vlieland. The absence of a visible response by foraging waders shows that in other situations habituation may take place. This process ("learning") is probably facilitated by a more or less constant supply of identical stimuli. This may be the reason for the presence of Lapwings *Vanellus vanellus*, gulls and Starlings *Sturnus vulgaris* at airfields where starting and landing patterns of planes are very predictable, both in terms of sound levels and in movements (c.f. Burger 1981a,b).

In some areas in the Wadden Sea helicopters or small civil aircraft may cause panic reaction among thousands of roosting or foraging birds (e.g. Van der Kamp & Koopman 1989). In areas where planes are common at least some habituation can be noted. As shown in earlier in this paper, there are large differences in the effects of jets and small civil aircraft between the studies from Heinen (1986) and Visser (1986). In the Mokbaai, Texel, a high degree of habituation has occurred to standard helicopter movements. Helicopters transporting crew to offshore drilling platforms pass over at a frequency of 2-3 per hour at 100-300 m altitude. These activities do not appear to have strong effects on feeding and roosting waders and ducks. The same area is also used for activities from

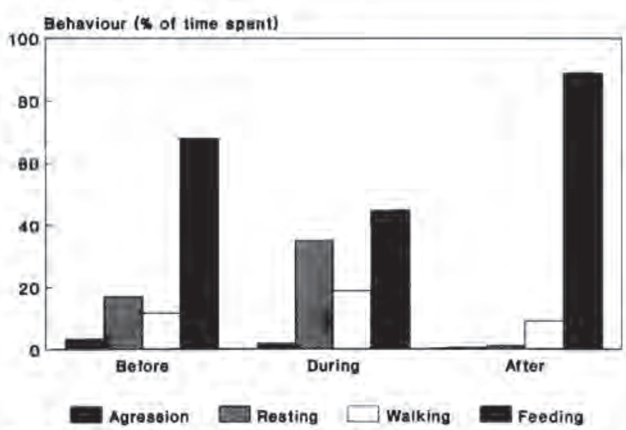

Figure 12. Behaviour (in % of time spent) of an individually marked Oystercatcher (LYCB) when forced out from its 'territory' on a mussel bed in the Mokbaai, Texel. The behaviour was registered for a whole low tide period, the disturbance was initiated artificially (from: Hooijmeijer 1991).

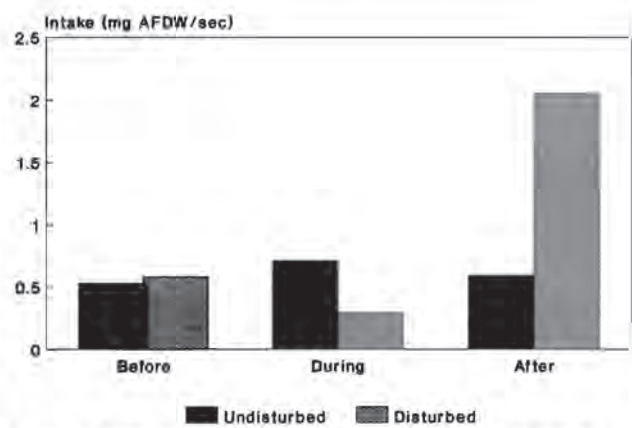

Figure 13. Intake rates (mg Ash Free Dry Weight/s) of an individually marked Oystercatcher (LYCB) in an undisturbed low tide period (artificially cut into three parts) and during a low-tide period in which the bird was forced out from its 'territory' on a mussel bed in the Mokbaai, Texel (from: Hooijmeijer 1991).

military helicopters, often at low altitudes. Despite a large degree of habituation to standard helicopter movements, these activities may force birds to less disturbed parts of the bay, and some species (like Cormorants *Phalacrocorax carbo* or Eiders) often temporarily leave the area. Small aircraft passing over at altitudes of over 300 m have effects comparable to those of civil helicopters. 'Unusual' types of planes, however, which show up at low frequencies still have strong effects (Smit unpubl.). This has also been found to happen on Vlieland. Under normal conditions roosting birds do not react severely when jets at the Vliehors shooting range pass by at high speed. Relatively slowly flying A10 jets are much less common in that area and can force thousands of birds to take flight for several minutes. This aircraft type is able to fly at a very low speed, can make very short curves and carries very strong machine guns. Consequently, its behaviour and sound production is very different from 'ordinary' jets, which are much more common there (Smit & Visser 1985). Also in the Mokbaai the birds could be more easily disturbed after the appearance of an unusual aircraft type. After such an event, an overflying Grey Heron *Ardea cinerea* or Great Black-backed Gull *Larus marinus* may even cause panic reactions whereas under normal conditions they would have much smaller effects (Smit unpubl.).

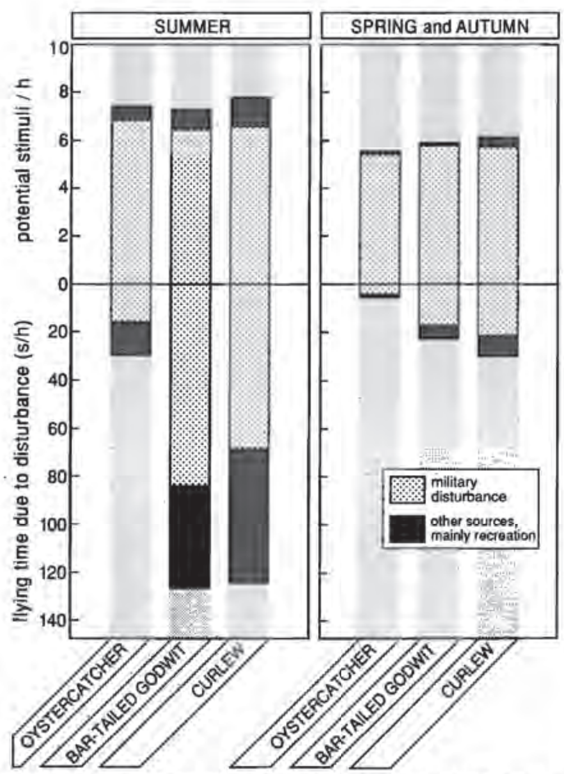

Figure 14. Number of potential disturbance cases per hour and the time these cases actually resulted in disturbance (seconds per hour) in summer and spring/autumn at the Noordvaarder, Terschelling for Oystercatcher, Bar-tailed Godwit and Curlew (data: Visser 1986).

These data suggest that birds are able to distinguish between types of planes. This is not really surprising. At the Banc d'Arguin, Mauritania, waders also appeared to distinguish between predators. Fish-eating Ospreys *Pandion haliaetus* were observed to land in between flocks of waders without any disturbance, whereas potentially dangerous Marsh Harriers *Circus aeruginosus* forced thousands of waders to take flight (Piersma 1982 and Smit unpubl.). Apparently, birds can learn through experience that some potentially dangerous objects are not dangerous after all. An unknown or infrequently occurring object, however, will be regarded with caution.

FACILITATION

The data presented so far suggest that high levels of disturbance lead to higher tolerance levels. This may be true in some cases but cannot be considered a rule. The opposite (referred to as facilitation) may also occur. Figure 14 depicts the number of potentially disturbing activities at the Noordvaarder, Terschelling, from 15 July - 15 September (summer) and 1 March - 1 May and 15 September - 1 December (spring/autumn) and the actual amount of disturbance resulting from these. In summer the number of potentially disturbing stimuli from military activities is only slightly larger than in spring and autumn. Their effect, however, is much larger. This is due to a cumulation of effects of disturbance from different sources. Leisure activities alone already may have a large disturbing effect. Combined with military activities they lead to disturbance levels far exceeding the effects each activity alone would have had. Comparable results were found on Sylt, Germany, where overflying jets appeared to have larger effects when prior to these activities wind surfers had been present in the area (Küsters & von Raden 1986). These reactions are comparable to the Heron and Black-backed Gull example from the Mokbaai, described previously.

A summary of all factors determining the behaviour of a single bird after disturbance is given in Figure 15. Birds respond as a function of earlier experiences, reactions of other birds nearby and several factors determining either their willingness to remain at the same place or act as a motivation to leave for another place. Activity rhythms and the availability of food and rest are important factors influencing the decision to remain at the same site. Birds feeling hungry will sooner leave high-tide roosts than well-fed birds that have just arrived from the feeding areas (Visser 1986). Protection through nature protection measures or the presence of a flock of conspecifics may also play a role. Additionally,

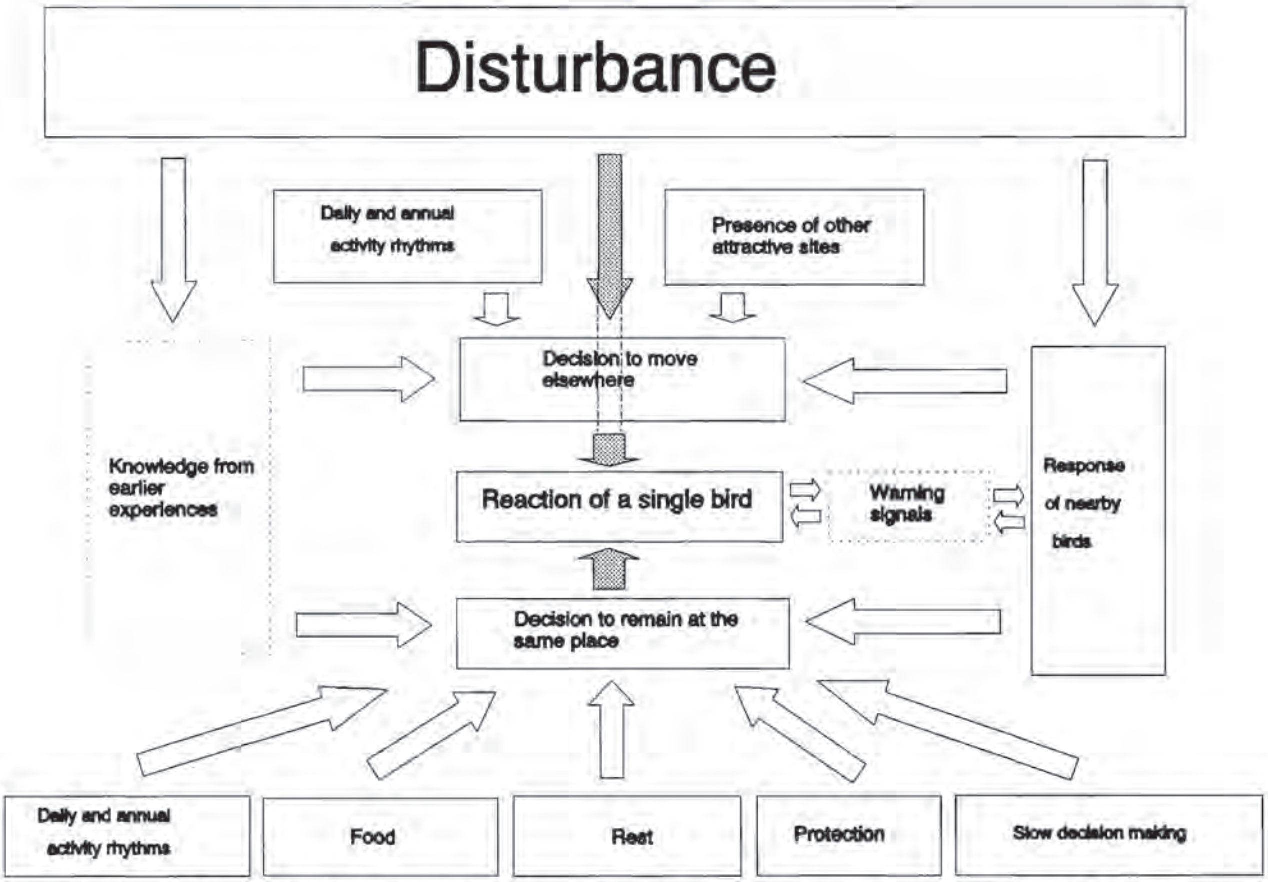

Figure 15. Reactions of a single bird on disturbance and the factors potentially affecting its behaviour (modified after Küsters & von Raden 1986)

a bird may postpone an immediate reaction in order to minimize its energy expenditure (referred to as 'slow decision making'). Activity rhythms and the presence of suitable alternative feeding or roosting sites may induce a decision to move elsewhere. Birds may respond directly to disturbance, for instance from a shot in a previously undisturbed area. In many cases, however, birds will not respond immediately but use earlier experiences and the behaviour of other birds in the same area as a filter mechanism. Warning signals (without any further disturbance) may also lead to behavioural responses.

THE USE OF PRESENTLY AVAILABLE DATA AND FUTURE NEEDS

This contribution shows that in the past 20 years there has been much study of the effects of disturbance. We could ask ourselves, however, whether these data are the tools we actually need to understand the effects on a bird. In the case of disturbance to non-territorial birds, we also need to know the consequences of feeding in higher densities. Another question is whether non-territorial birds are really non-territorial. From several studies we know that at least some species of non-territorial birds nevertheless do show a high site-fidelity within a winter and between years, at least at the roosting places (Furness & Galbraith 1980, Symonds *et al.* 1984). This could mean that these birds do not distribute themselves over the tidal flats as freely as we may think. Consequently, regular disturbance in part of their preferred feeding area could affect their food intake more than when they would freely distribute over large areas. To what extent will be extremely difficult to measure. Birds may also be able to compensate by feeding longer or by more frequent or longer feeding at night. Cage experiments during which the length of the low-tide period was artificially manipulated have shown that (territorial) Oystercatchers are able to compensate for lost feeding time by increasing their efficiency (Swennen *et al.* 1989). Of course we do not know to what extent this is possible in the field and at what price. Oystercatchers could run a higher risk of bill damage, other species could be more vulnerable to predators because of reduced vigilance.

Frequent disturbance may force waders to abandon traditional high-tide roosts. This is demonstrated in the Dee estuary (Mitchell *et al.* 1988) where Bar-tailed Godwits declined 99%, Knots 79% and Dunlins 81%. In this case the birds continued to use the traditional feeding areas. This behavioural change involved higher energy costs, because the birds had to fly an extra 40 km each tidal cycle. Heavy disturbance can also lead to a total departure from feeding sites. This is probably happening in Denmark where suitable wetlands do not harbour any Curlews, probably due to large flight distances and wariness as a result of hunting (Meltofte 1986). The consequences of such banishment are largely unknown and are part of a major applied ecological question: 'how many birds can an estuary support' (c.f. Sutherland & Goss-Custard 1991, Lambeck 1991, Meire 1991).

In this contribution we have restricted ourselves very much to visible reactions. What is really happening to birds is a much more complicated problem. Heart-rates of Eiders and Oystercatchers appear to increase considerably when incubating birds are approached by man or a helicopter, despite the fact that the birds showed no visible reaction (Gabrielsen 1987, Hüppop & Hagen 1990). The implications on energy of disturbance are not yet clear but indicate that the effects can be much larger than would appear from the studies described in this paper.

The previous examples of what we still do not know may give too pessimistic a picture of our knowledge of disturbance. Clearly, there are many limitations on what we can do with the existing data. Nevertheless, they can be useful tools for modelling bird reactions. They can also be well applied by policy makers or for local protection measures (such as keeping visitors to coastal nature reserves at a sufficient distance from the high-tide roosts). However, the available data are not yet suitable for answers to key questions like 'what are the effects of disturbance on energy budgets of a bird' or 'what are the repercussions of being in a bad condition on survival or reproduction rate'. Such questions will involve more studies on energy loss, the costs (or lower intake) of feeding at alternative feeding sites and the consequences of higher costs or lower intake rates on body-condition.

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