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

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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.

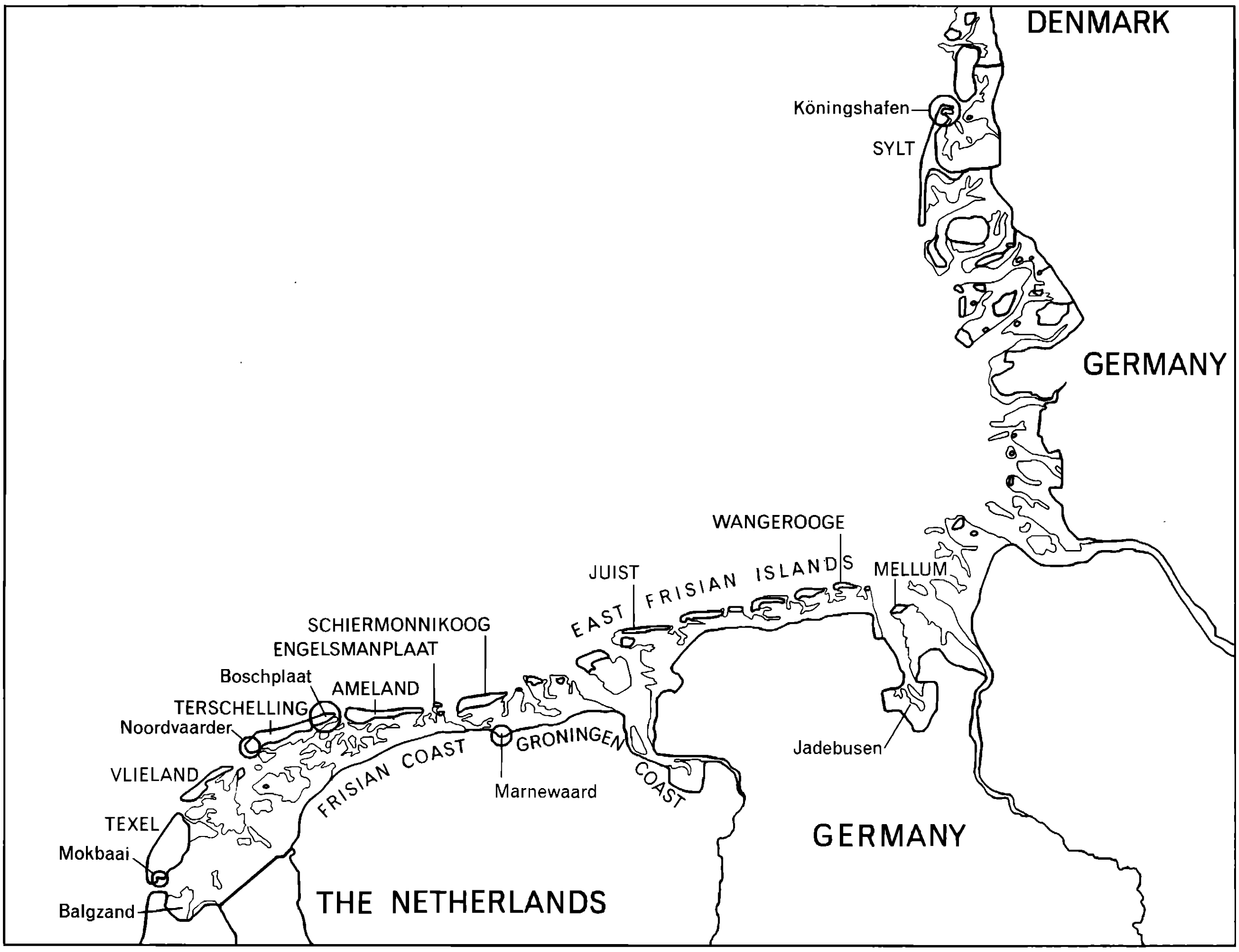

Figure 2. Map of the Dutch part of the Wadden Sea with location of sites referred to in the text.

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

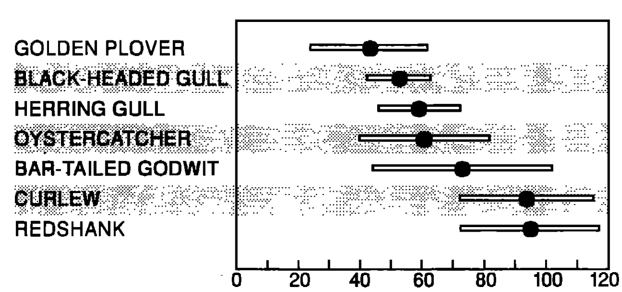

Figure 3. Distances (mean values in m and 95% confidence limits) at which flocks of roosting waders and gulls were recorded to take flight when approached by walking people. Data from Terschelling, July - September 1981 (data: Tensen & van Zoest 1983).

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

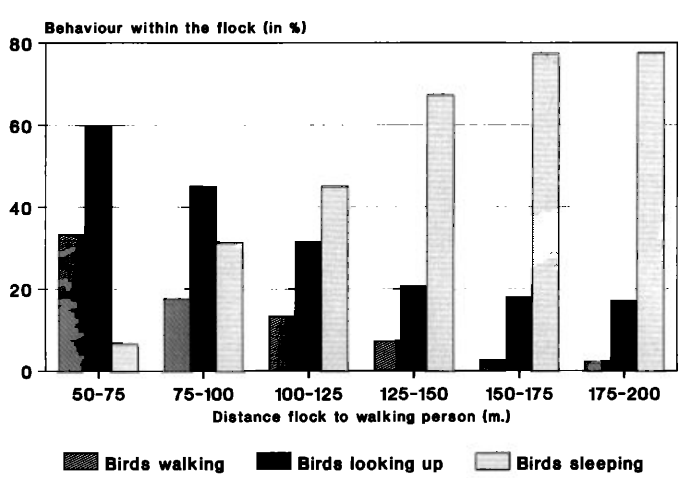

Figure 4. Behaviour of flocks of Curlews when approached by walking people, in relation to the distance to the flocks. Data were collected in standardized experimental situations, using flocks of Curlews roosting in cultivated grasslands (data: Blankestijn *et al.* 1986).

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	–

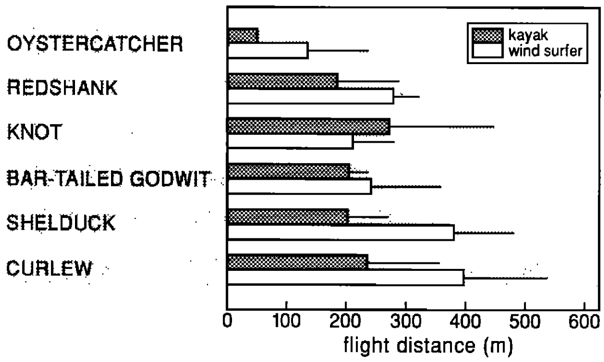

Figure 5. Distances (mean values in m and standard deviations) at which flocks of roosting waders were recorded to take flight when approached by a kayak or wind surfer. Data from the Jadebusen (German mainland coast) (from: Koepff & Dietrich 1986).

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 m²)
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)

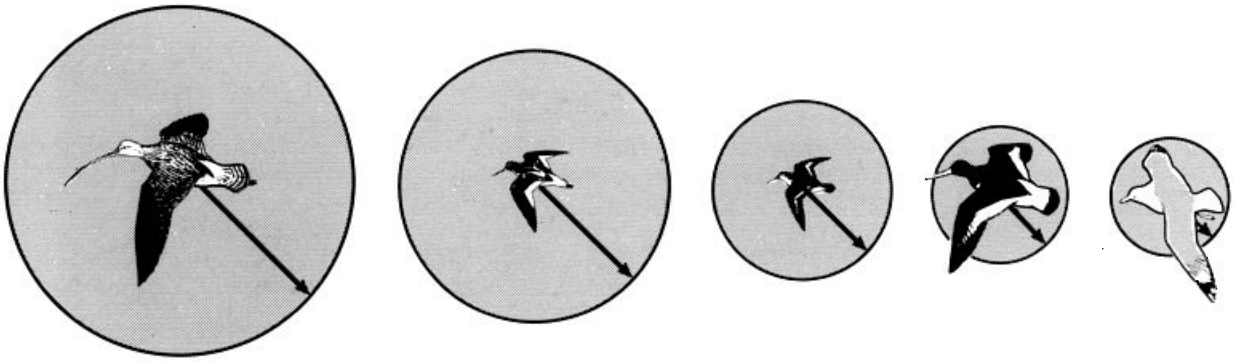

Figure 6. Theoretical size of areas without any birds for five shorebird species, using the information from the Wadden Sea from Table 4.

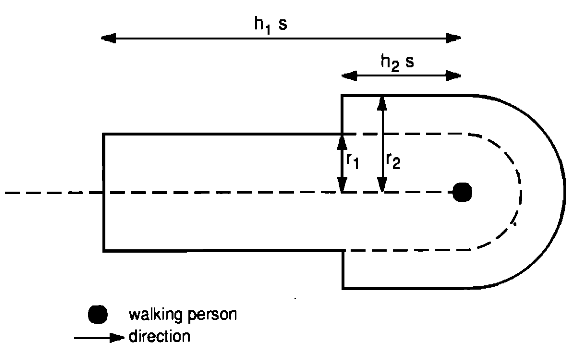

Figure 7. Theoretical size of the area without birds, after disturbance from a single person or a group walking over the tidal flats. See text for additional information (from: Van der Meer 1985)

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

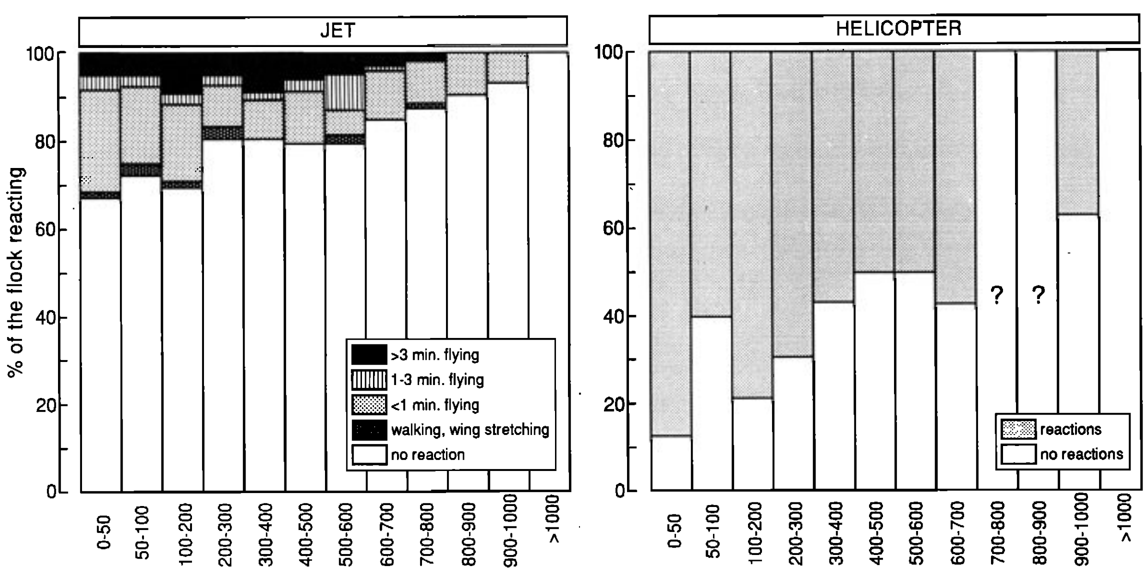

Figure 8. Distances (in m) at which military jets and helicopters caused disturbance among roosting Bar-tailed Godwits at the Noordvaarder, Terschelling. Data were collected from 1980-84 and represent 925 (jets) and 100 (helicopters) potential cases of disturbance (data from Visser 1986).

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

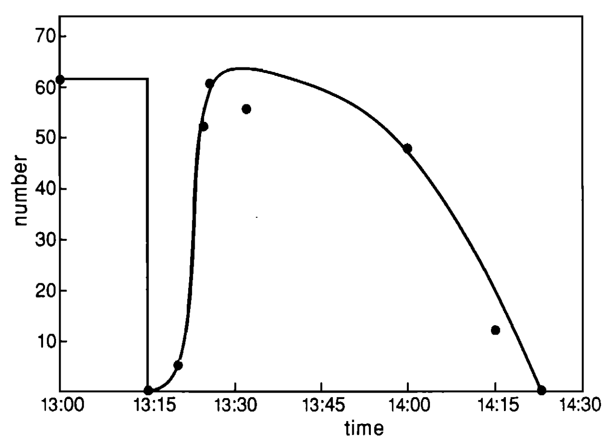

Figure 9. The number of foraging Curlews in the Zandkreek (Delta area) before and after disturbance of a small civil aircraft on 9 March. Effects on Oystercatchers were much longer lasting (from: Van der Meer 1985).

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

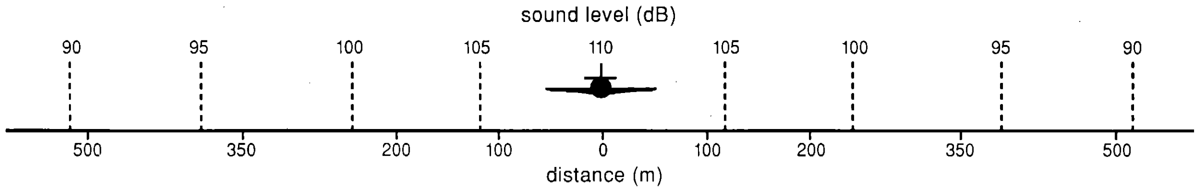

Figure 10. Sound levels of a completely loaded overflying jet at an altitude of 50 m, in relation to the distance at which the plane is flying (from Hoffmann, in Küsters & von Raden 1986).

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

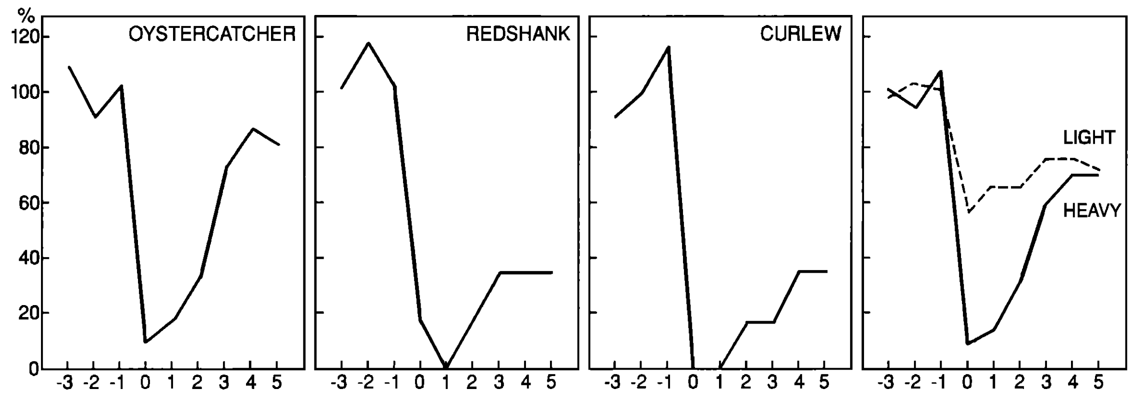

Figure 11. Effects of heavy disturbance on the number of Oystercatchers, Redshanks and Curlews in study plots on mussel beds close to Schiermonnikoog. Light disturbance: dotted line, heavy disturbance: straight line. The mean number of birds prior to disturbance is set at 100%, the figures at the abscissa 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

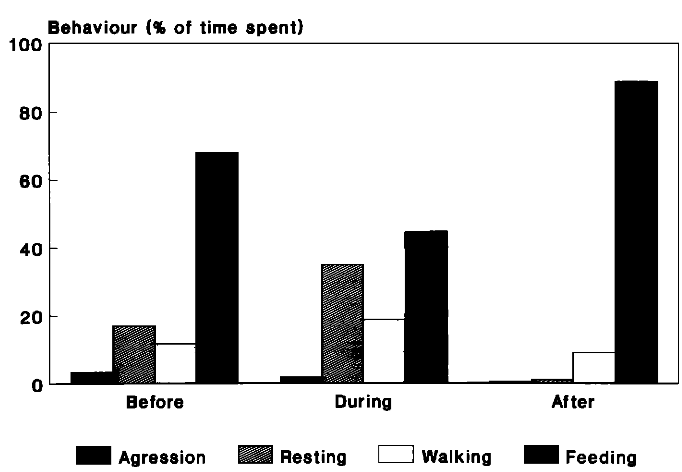

Figure 12. Behaviour (in % of time spent) of an individually marked Oystercatcher (LYCB) when forced out from its 'territory' on a mussel bed in the Mokbaai, Texel. The behaviour was registered for a whole low tide period, the disturbance was initiated artificially (from: Hooijmeijer 1991).

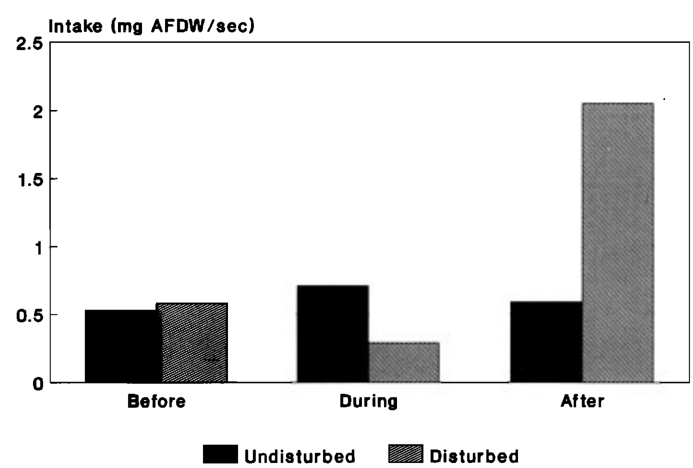

Figure 13. Intake rates (mg Ash Free Dry Weight/s) of an individually marked Oystercatcher (LYCB) in an undisturbed low tide period (artificially cut into three parts) and during a low-tide period in which the bird was forced out from its 'territory' on a mussel bed in the Mokbaai, Texel (from: Hooijmeijer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

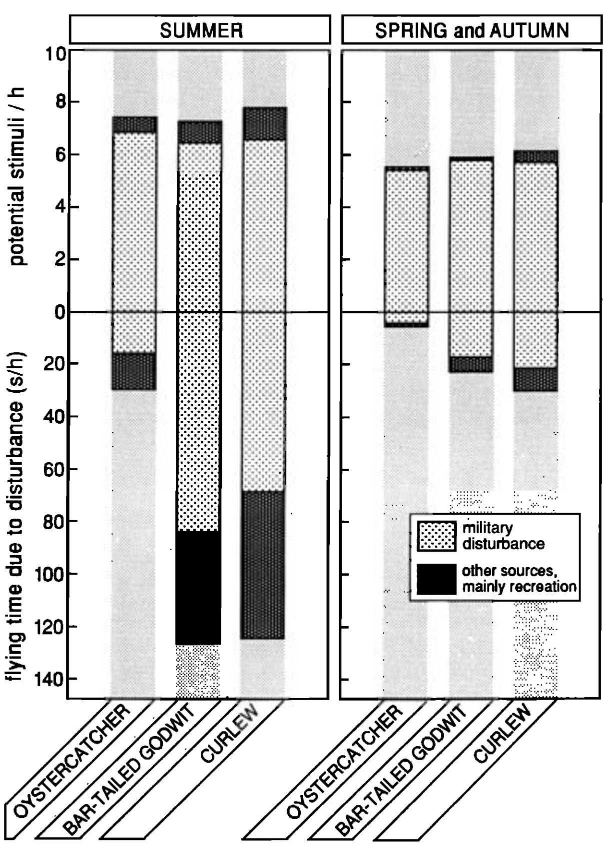

Figure 14. Number of potential disturbance cases per hour and the time these cases actually resulted in disturbance (seconds per hour) in summer and spring/autumn at the Noordvaarder, Terschelling for Oystercatcher, Bar-tailed Godwit and Curlew (data: Visser 1986).

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,

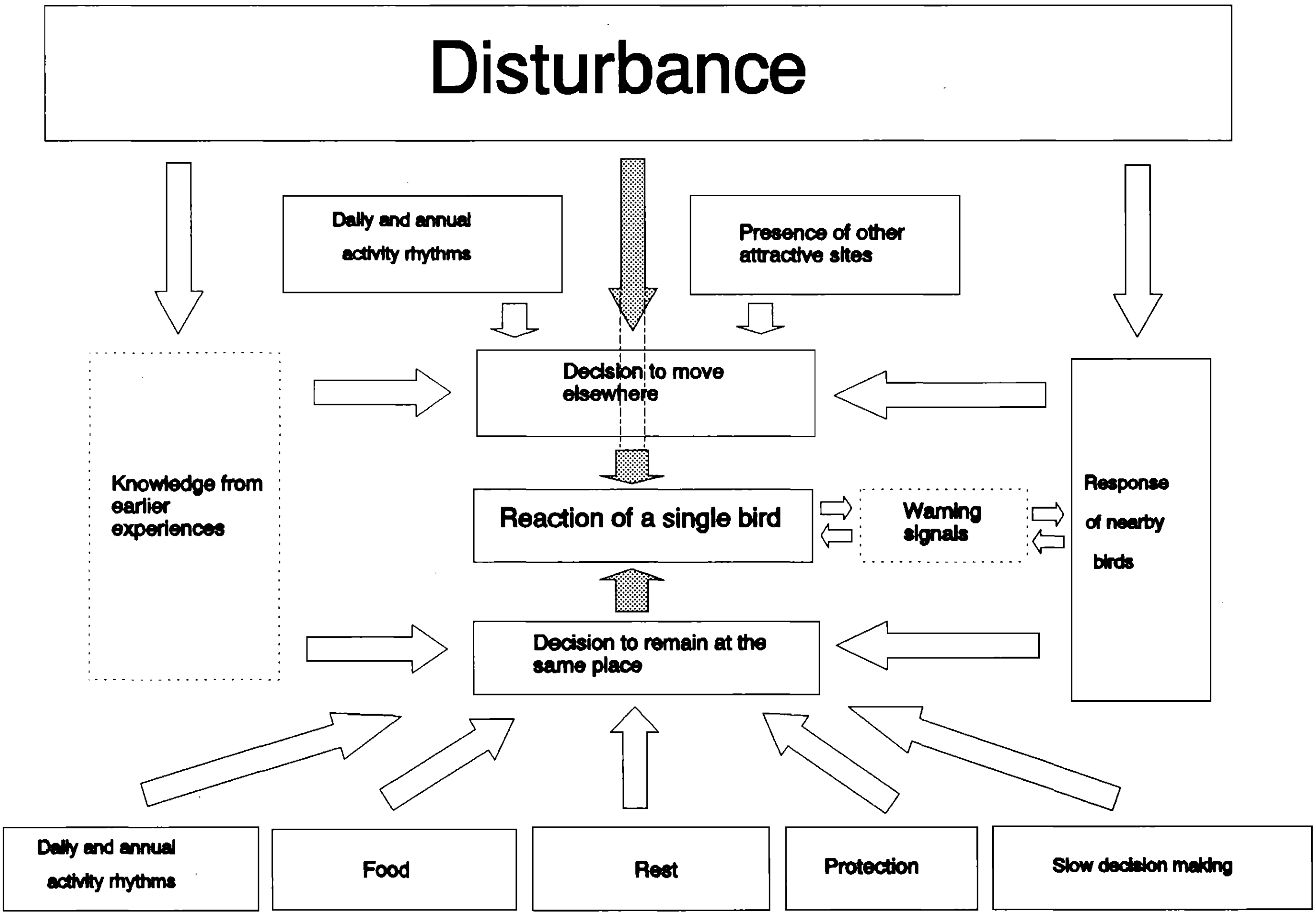

Figure 15. Reactions of a single bird on disturbance and the factors potentially affecting its behaviour (modified after Küsters & von Raden 1986)

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.

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