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Examination of the Effects of Disturbance on Birds with Reference to its Importance in Ecological Assessments

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National, European and International legislation regarding the conservation of species and habitats requires professional statements to be made in respect of land use change, as, for example, illustrated by developments. Some developments may cause disturbance to wildlife. Knowledge of the way in which species respond to disturbance has been fragmented, yet is an important consideration in environmental impact assessments. This paper reviews what is known about disturbance factors on the best studied group, birds. A set of extensive appendices summarize the literature on disturbance effects on breeding, breeding success, nest-site choice, population density, community structure, distribution and habitat use. The paper considers human-induced disturbance, public access, water-based recreation, shooting and industrial developments. Mitigation measures are discussed.

Human-induced disturbance can have a significant negative effect on breeding success by causing nest abandonment and increased predation. Outside the breeding season, recreation (particularly power boating, sailing and coarse fishing on wetlands) reduces the use of sites by birds. Compensatory feeding at night by some species can probably recoup some of the energy losses caused by disturbance. Public and vehicular access to open landscapes has been shown negatively to affect grazing geese in winter and lowland and upland waders during breeding. Shooting disturbance has been shown to be most important for herbivore feeders which need to spend long periods of the day feeding in order to maintain their energy balance, e.g. wigeon. The provision of refuges devoid of shooting has been fundamental in attracting wildfowl away from non-refuge sites. The response of birds to scaring devices and other control measures is discussed.

Effects from industrial developments include direct loss of habitat, disturbance through the presence of humans during the construction process and the presence of artificial light used to illuminate construction sites. On estuaries, engineering operations should avoid the proximity to established roost sites of wading birds. A number of studies showed increased vigilance (and hence reduced feeding time) in flock members feeding near structures which impede their vision of the approach of potential predators.

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A number of principal management techniques used to reduce disturbance on a site, or to attempt to compensate for habitat loss, are given. For wetland sites, these include excavating new shallow lagoons and grading bank sides, flooding of low-lying pasture, reducing salinity levels in coastal lagoons thereby making them more attractive to the birds' food invertebrates, manipulating water levels to expose mud regularly and creating feeding areas for geese and wigeon, using manipulative livestock grazing. Also used are increasing nesting cover, planting macrophytes, providing islands, spits and promontories, purchasing more land to make a refuge bigger, concealing observers with banks and screens, zoning activities and prohibiting access and avoiding the obstruction of flyways between feeding and roosting areas.

Keywords: birds, disturbance, site management, ecological assessment.

1. Introduction

Britain has a well-developed set of policies on the countryside and nature conservation, which have recently been the subject of a recent white paper entitled "This Common Inheritance—Britain's Environmental Strategy" (HMSO, 1990). The emphasis of these policies is to integrate environmental and economic activity in rural areas, conserve and improve the landscape and encourage opportunities for recreation, provide extra protection to areas of special value, conserve the diversity of Britain's wildlife, particularly by protecting habitats, provide scientific monitoring and research to support these aims.

Within the strategy, special attention is focused on a variety of groups, and in particular there is discussion of the special requirements of birdlife and the measures which require implementation for its protection. Essentially, birds have been given special treatment over other taxa, largely because of political lobbying, and because more is known about them.

Such a commitment has been strengthened during the last decade by the passing of nature conservation legislation and through the signing of a number of national initiatives (Wildlife and Countryside Act 1981) and international conventions (Council Directive on the Conservation of Wild Birds, the Ramsar Convention 1971 and the Bonn Convention). These have extended greatly the legal protection given to birdlife within Britain and Europe and also to the protection of the habitats upon which they are dependent, particularly wetlands. Member State governments are committed to taking appropriate steps to avoid: (a) pollution or deterioration of habitats; and (b) any disturbances affecting birds. "Wise-use" of the land is therefore promoted.

Under these legislative systems, conflicts of interest are often raised by developments when commercial, industrial, agricultural and recreational activities are at odds with the former land use. This is particularly the case for developments that require a statutory environmental assessment. Since 1988 specific types of development as classified in Annex 1 of the Council Directive (85/337/EEC) on the assessment of the effects of certain public and private projects on the environment are subject to a mandatory environmental assessment. The legislation places the onus on developers to assemble and publish the available information about the likely environmental effect of the proposal.

In certain circumstances the issues to be weighed are clear cut and may involve total habitat loss by land-take or similar major impact. However, having dealt with relatively straightforward situations where the proposed development would have direct effects upon populations, the professional judgement becomes more subjective as either indirect or less well documented effects are considered.

The effects of disturbance on communities and their population processes, interactions and dynamics fall into these latter categories. Planning applications which would have significant impacts on bird populations through disturbance must be carefully weighed before being passed. Interpreting the ecological significance of a predicted impact to fit the legal context is still subjective and difficult. Disturbance issues continue to be grey areas in planning debates because of the subjectiveness that is apparent in interpretation.

Disturbance has been defined as: "Any relatively discrete event in time that disrupts ecosystem, community, or population structure and changes resources, substrate availability, or the physical environment" (White and Pickett, 1985). Disturbances are responsible for a change in the state of a system, and systems that are not in equilibrium may therefore be disturbed just as readily as those that are. Disturbance can be either natural, such as that caused by fires, avalanches which remove tracts of forest or floods, or man-induced such as that caused by industrial developments, public recreation and access.

An attempt is made in Figure 1 to categorize types of disturbance on the basis of: (a)

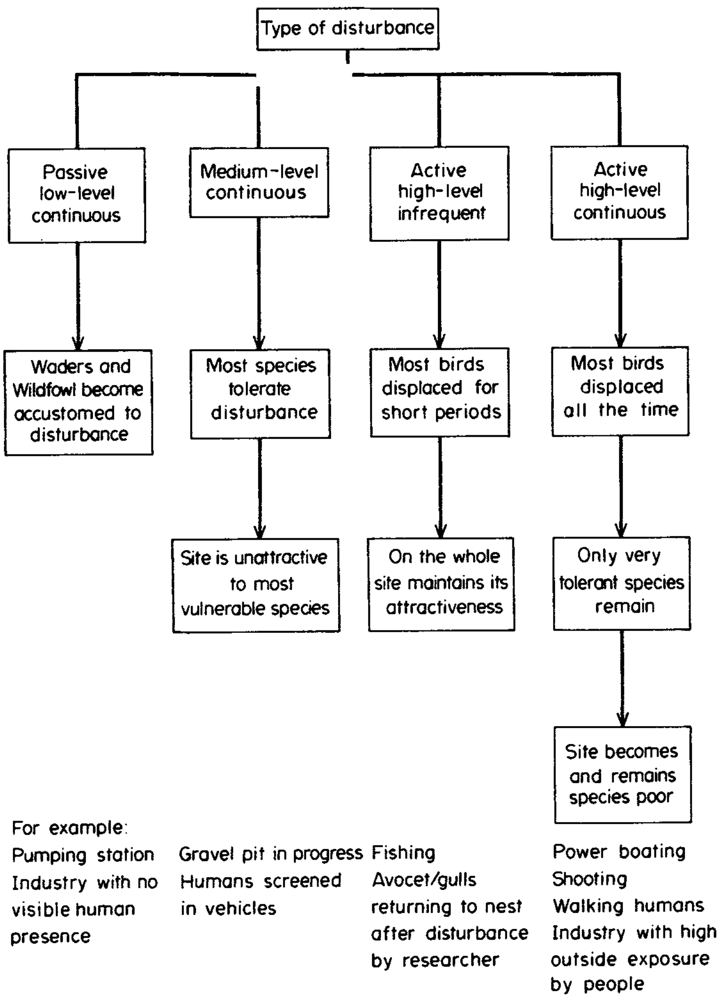

Figure 1. Types of disturbance of wildfowl and waders, likely responses and some examples.

their level; and (b) their frequency of occurrence. This subjective assessment identifies a gradient from passive, low-level disturbance at one end, to active high-level disturbance on the other. Examples of these would be, say, an industrial plant with no visible human presence for the former, and the operation of a power-boating school on a lake in the latter.

This paper aims to examine the evidence for disturbance and attempts to identify some clearer patterns of disturbance effects. Disturbance effects directly related to the presence of humans, both within and between bird breeding seasons, are first considered. Further sections detail the impact of industrial developments, water-based recreation, shooting and control measures and public access and vehicles. A final section outlines attempted methods for mitigating some of these impacts.

2. Review methods

The method adopted in the study is that of a literature review. The references were gathered through a number of means, but mainly from key-word searches of the *Biosis Previews* (1969–1990), *Ibis Abstracts* and *Ecological Abstracts* (1980–1990). Other material was identified from the reference lists of some of the major review papers (e.g. Tuite, 1981; Gotmark, 1989). Over 400 papers published before the beginning of 1991 were reviewed. The literature search yielded a high number of papers on the effects of researcher activities on the birds being studied, mainly effects on reproductive success. These were included only if they studied effects of investigator activities similar to the kind of disturbance which might be produced by human activities other than research.

Most of the information is presented in thematically grouped appendices containing the authors, the species studied and the main results or conclusions. Columns for the human activity were included where appropriate.

3. Human disturbance effects on birds during the breeding season

3.1. EFFECTS ON INDIVIDUAL BREEDING AND BREEDING SUCCESS

The studies investigating effects on breeding considered a variety of activities from walking, vehicular traffic, angling, swimming, boating and windsurfing, to disturbance by aircraft (Appendix 1). The methods most commonly used to assess effects of disturbance on reproductive success were comparisons of two or more areas or samples of nests with different levels of disturbance (see Gotmark, in press, for a discussion of the advantages and disadvantages of different methods). Several authors compared samples of experimentally disturbed nests or colonies with undisturbed controls (Anderson and Keith, 1980; Cairns, 1980). However, this approach is only feasible if reproductive success can be assessed without disturbing the breeding birds, e.g. by observing the nests from a distance.

More frequently, authors compared two or more areas with different intensities of disturbance. In most studies of effects of investigator disturbance the intensity of disturbance was varied by visiting the nests at different frequencies (Gillet *et al.*, 1975; Cairns, 1980; Poole, 1981; Frederick and Collopy, 1989). In studies which attempted to assess the effect of human activities other than research, the often necessary disturbance caused by the investigator measuring breeding success was kept constant for all nests. Breeding success was then compared for areas with different intensities of other human activities (Joensen, 1973; Robertson and Flood, 1980; Levenson and Koplin, 1984) or related to distance from a source of human disturbance such as roads and buildings (van Daele and van Daele, 1982; Anderson, 1988).

A few studies adopted different methods, such as comparing samples from different years with different intensities of disturbance (Ollason and Dunnet, 1980; Gotmark *et al.*, 1989), measuring the amount of human activity for successful and unsuccessful nests (Fraser *et al.*, 1985; Coleman and Fraser, 1989) or correlation of reproductive success with environmental variables indicating disturbance (Anthony and Isaacs, 1989).

Thirty six of 40 papers studying effects on breeding success showed it to be reduced by disturbance (Appendix 1). Gotmark (in press) calculated that the mean reduction from estimates from 28 papers reporting effects of investigator disturbance and found that, on average, reproductive success was reduced by approximately 40%. Many of the studies measuring effects on breeding success discussed possible mechanisms involved (e.g. increased mortality of eggs or young), but relatively few were combined with observational studies, quantifying reactions of breeding birds or their young to disturbance and documenting the mechanisms by which reproductive success was affected (Robert and Ralph, 1975; Titus and van Druff, 1981; Fetterolf, 1983; Flemming *et al.*, 1988). A number of studies did show the effects of disturbance on behaviour, predation rate and other factors which are likely to affect overall reproduction (Jungius and Hirch, 1979; Hobson and Hallinan, 1981; Verbeek, 1982; Anderson, 1988; Gotmark, 1989; Keller, in press). Hill and Player (1992) studied the effect of two methods of control of black-headed gull productivity on the behaviour of gulls and avocets which bred within the gull colony. The gulls responded differently to the two methods—one was much less disturbing to the birds than the other. The avocets showed no such consistent response to the disturbance.

The main reasons for the lower breeding success in the documented studies were nest abandonment and increased predation of eggs and young. Direct destruction of nests by human activities was only reported for waders and terns nesting on open beaches with high densities of off-road vehicle traffic (Burger, 1981; Jeffery, 1987; Buick and Paton, 1989; Burger and Gochfield, 1990). Complete abandonment of nests occurred mainly in the early part of the breeding cycle (Tremblay and Ellison, 1979; Anderson and Keith, 1980; Pierce and Simons, 1986; Anderson, 1988). Its frequency may have been underestimated, because in many studies nest checks were only carried out during incubation. The same applies to the possibility that disturbance may prevent pairs from breeding. Tremblay and Ellison (1979) found that in disturbed colonies of night herons fewer pairs started laying and Hobson and Hallinan (1981) showed that the number of prospecting adults in a colony of jackass penguins dropped after repeated disturbance. Increased predation of eggs was reported as the main cause of reduced hatching success in many studies (Appendix 1). In most cases the predators mentioned were gulls or crows. Crows were shown to follow researchers and rob disturbed cool nests (Salathe, 1987); on the other hand, this did not seem to be the case for disturbed eider nests (Gotmark and Ahlund, 1984). Intraspecific predation was considered to be a major cause of egg losses in disturbed gull colonies. Predation was also suspected as a cause for nest failures in several studies which showed that disturbance reduced the attendance of incubating birds at the nest (Titus and van Druff, 1981; Pfluger and Ingold, 1988; Gotmark *et al.*, 1989; Keller, 1989; Yalden and Yalden, 1990), although exposure to extreme temperatures has also been suggested as a cause for egg mortality during prolonged absence of the adults from the nest (Hunt, 1972).

Increased mortality of young was often also the result of increased inter- or intraspecific predation, mainly by gulls. Two studies on plovers showed that disturbance reduced the amount of feeding and brooding of young, resulting in increased mortality of small young (Flemming *et al.*, 1988; Yalden and Yalden, 1990). Other causes of mortality of small young chicks were running into cactus plants (Anderson and Keith, 1980) or other structures (Safina and Burger, 1983). Heimberger *et al.* (1983) studied the impact of a construction activity (cottage development) on the reproductive success of common loons (a diver) in central Ontario. Generally, the study found that hatching success declined as the number of cottages within 150 m of the nests increased. Once the eggs had hatched, however, chick survival was independent of cottage development. The authors compared the level of human activity near 18 nests within 150 m of at least three cottages with that around 18 nests with no development. There was a highly significantly greater activity effect around the former. They suggested though that some loons around the developed areas may have become habituated to humans (presumably during one season, although details are not given). Four other studies (Lehtonen, 1970; Vermeer, 1973; Bundy, 1979; Andersson *et al.*, 1980) found that the building of cottages at the waters' edge had a significant negative effect on the breeding success of divers, and reduced the lakes' utilization by them.

3.2. EFFECTS ON NEST-SITE CHOICE

Only a few studies have been carried out on the effects of disturbance on nest-site choice. Direct evidence that disturbance at the nest can effect the choice of a future nest site comes from a study on magpies (Knight and Fitzner, 1985; Appendix 2). Two studies on raptors showed differences in nest location between areas with different degrees of human disturbance (Fraser *et al.*, 1985; van der Zande and Verstrael, 1985; Appendix 2). Laurila (1989) showed that eiders preferred islands with a low degree of disturbance for nesting, and Alvo (1981) found that great northern divers avoided island nest sites, which are usually preferred, if they were too close to sources of disturbance.

Seven of 13 papers concerned gulls, terns and waders studied on the east coast of the U.S.A. All of them give evidence that increasing development of barrier beaches, leading to habitat loss as well as increasing disturbance, has driven these birds away from their traditional nesting habitat and that islands formed by the deposition of dredge soil provide important alternative nesting areas (Appendix 2).

3.3. EFFECTS ON POPULATION DENSITY

Studies of the effects of disturbance or developments on density of birds during the breeding season have mainly been carried out on waterbirds, waders and passerines (Appendix 3). Most studies compared densities of breeding birds in areas with different degrees of disturbance or used correlational methods.

Two studies, both in the same mountain area, did not find any differences in density of an upland bird community, between more and less frequently disturbed areas (Watson, 1979, 1988*b*). Negative effects of disturbance on density were found in four major studies. In an extensive survey of freshwater lakes and reservoirs in England, Tuite (1981) found lower densities of four species of waterbirds at sites with heavy recreation but no effect for other species studied. Van der Zande *et al.* (1980) found that roads had a depressing effect on the densities of lapwings and godwits for up to 2 km, while oystercatcher density was not affected. In two studies of passerines the majority of species had lower densities in areas with heavy recreational use or close to a car park (van der Zande and Vos, 1984; van der Zande *et al.*, 1984).

3.4. EFFECTS ON COMMUNITY STRUCTURE

Effects of human activities on the structure of bird communities has mainly been studied in passerines (Appendix 4). One study found that ditching increased species diversity in salt marshes (Burger *et al.*, 1982). Four studies compared bird communities in undeveloped areas and areas used as campgrounds with different degrees of developments for holiday cottages (Foin *et al.*, 1977; Robertson and Flood, 1980; Clark *et al.*, 1984; Blakesley and Reese, 1988). All these studies found, in general, a higher species diversity in disturbed habitats, which was mainly due to additional, usually common and hence opportunistic species moving in, while other species were negatively affected by developments.

3.5. OTHER EFFECTS

A number of studies looked at the reactions of breeding birds towards humans in relation to stage of incubation, type of disturbance or disturbance frequency. Vos *et al.* (1985) found that the intensity of reaction of great blue herons to disturbance decreased in the course of the breeding season, while Erwin (1989) studying terns, waders and skimmers and Byrkjedal (1989) studying lesser golden plovers did not find any significant changes in the course of incubation.

Several studies found differences in the behaviour towards humans which suggests a certain degree of habituation. In several species the distance at which birds reacted was found to be shorter in areas with a high degree of disturbance compared to undisturbed areas (Cooke, 1980; Titus and van Druff, 1981; Burger and Gochfield, 1981; Keller, 1989). Greylag geese seemed to habituate to people walking as long as they did not leave paths (Kuhl, 1979). Habituation to helicopter overflights was reported for red-tailed hawks, while least terns were found to nest on take-off pads of harrier jets despite their frequent use (Altman and Gano, 1984). It is also relevant to note that in the United Kingdom many of the Sites of Special Scientific Interest controlled by the Ministry of Defence and used as training areas and artillery ranges support diverse breeding bird populations (Fuller, 1982).

Repeated disturbance of nesting mallards, on the other hand, led to an increase in flushing distance, and Yalden and Yalden (1989) found that the distance at which golden plovers alarmed their young did not differ between pairs breeding close to footpaths and pairs further away. Knight (1984) found that American crows and ravens reacted more strongly towards people in sparsely populated rural areas than in suburban ones and related this to stronger persecution in rural areas.

Different types of activities may provoke different reactions. Vos *et al.* (1985) found that great blue herons were more disturbed by shore-based than by water-based activities. Pfluger and Ingold (1988) came to the same conclusion for coots, but to the opposite for great crested grebes. Windsurfers flushed common terns nesting on islands at greater distances than did rowing or motorboats (Dietrich and Keopff, 1986). Incubating golden plovers (Yalden and Yalden, 1990) and eider ducklings (Keller, 1990) reacted more strongly to dogs or people accompanied by dogs than to people on their own. Incubating herring and greater black-backed gulls reacted at greater distances when approached directly than when approached tangentially to the nest (Burger and Gochfeld, 1981).

A significant amount of work has been done on the effects of recreational disturbance on breeding waterfowl. A useful summary of the effects of water-based recreation on waterfowl is given in Owen *et al.* (1986). There are two short-term effects: (a) an indirect one through the alteration of habitat which affects the availability of food or nesting cover, such as created by excessive use of a waterway by boats via destruction of bank-side and emergent vegetation; and (b) direct effects through displacement or disturbance of the birds themselves such as caused by a variety of recreational pursuits from birdwatching to power-boating. High levels of recreation can reduce the carrying capacity of a lake for breeding wildfowl, by restricting their use of preferred areas of the site. Within a site some recreational pursuits, e.g. coarse fishing, have been shown to prohibit use of otherwise good feeding habitat by pochard, tufted duck and coot (Cooke, 1975).

4. Human disturbance effects on birds outside the breeding season

4.1. EFFECTS ON DISTRIBUTION AND HABITAT USE

The majority of the papers relating to disturbance effects on habitat use studied wintering geese and ducks with a few papers on gulls and waders (Appendix 5). In ducks, most authors studied the effects of water-based recreation, mainly of boating and angling. The methods used most frequently were direct observations or counts of the numbers of birds in situations with and without disturbance.

Ducks, geese and waders usually take to flight when disturbed. This has been shown to displace them from preferred feeding or roosting areas in winter (Tuite *et al.*, 1983; Galhoff *et al.*, 1984; Bell and Austin, 1985; Cryer *et al.*, 1987; Belanger and Bedard, 1989) or to abandon areas completely (Putzer, 1989; Bell and Austin, 1985; Korschgen *et al.*, 1985; Burger, 1986). A shift from preferred to less preferred feeding areas is likely to affect feeding efficiency; this has been shown to be the case for gulls feeding on mudflats (Burger, 1988). Three studies showed that wintering geese avoided areas close to roads for grazing (Mooij, 1982; Madsen, 1985; Keller, 1990). Madsen (1985) studied the impact of disturbance on field utilization of pink-footed geese in West Jutland, Denmark. Disturbance was broadly defined as both actual, which puts geese into flight (e.g. traffic, humans, aircrafts), and potential, such as landscape features. Disturbance effects on field utilization was examined where utilization of habitat was measured as the mean number of goose days per hectare per visit. The flight distance of goose flocks increased with flock size and was longer in autumn than in spring. Roads with a traffic volume of more than 20 cars per day disturbed birds up to a distance of 500 m in autumn, but less in spring. Lanes with 0–10 cars per day also reduced the use of adjacent fields by geese but less so than roads with heavier traffic. Windbreaks and banks etc., which hinder an open view, reduced use of land up to 200–300 m from such structures. It was concluded that the width of an area of habitat must exceed 500 m with no hindrances in order to be acceptable to flocks of pink-footed geese in autumn. In both spring and autumn larger flocks took off at a greater distance from a car than smaller flocks, presumably because larger flocks were capable of greater vigilance. In terms of providing suitable habitat for pink-footed geese the size of the area should depend on population size, shyness, proximity to other goose feeding or roosting areas. For example, the study concluded that 1000 pink-footed geese would need: (a) extensive feeding grounds at a distance of 500 m away from roads with traffic volumes greater than 20 cars/day; (b) traffic lanes should be regulated as even less than 1 car per day has a depressing effect on goose utilization, although generalization of this finding to other situations is probably likely to depend on lane size, quality of food in the fields and season; and (c) the width of the area should exceed 1 km and windbreaks, plantations and other structural features should not be established in the area. A number of studies provided evidence that birds avoided areas completely (Owens, 1977; Lovvorn and Kirkpatrick, 1981; Lok and Bakker, 1988).

An extensive analysis of the winter distribution of wildfowl in England showed that the distribution of at least some species of ducks was affected by water-based recreation (Tuite *et al.*, 1984). Multiple regression was used to separate out the effects of physical attributes of waterbodies and use by wintering wildfowl under varying levels of recreational pressure. The species most affected were teal, shoveler and goldeneye. The most tolerant were mute swan, tufted duck, pochard and mallard. Greatest impact was caused by power boating, with coarse fishing, sailing and rowing also important. In some cases recreational boating (power) could be considered to limit carrying capacity of a waterbody in winter. Goldeneye were found to take flight when power-boats were as far as 700 m away (Hume, 1976). Brent geese and shelducks feeding on mud in Langstone Harbour were found to take flight when humans approached on foot at about 200 m (Martin, 1973).

Owens (1977) studied the responses of wintering brent geese to human disturbance. The study found that disturbed areas of the shore, proximity to traffic and places with poor visibility were avoided in early winter but were used later when other areas became depleted of food. The geese became habituated to the proximity of people and to some loud noises but not to low-flying aircraft which had the effect of making them fly. Disturbance in the worst areas prevented geese from feeding for up to 11·7% of the time and caused a seven-fold increase in the amount of time spent flying. Overall levels of disturbance were much lower than this and would have been unimportant so long as adequate food was available on which geese could feed during undisturbed periods, and at night (by compensatory feeding). However, a shortage of food probably prevented complete compensation for the effects of disturbance. It was suggested that disturbance could be greatly reduced by: (a) restricting public access to the sea wall in certain areas around high tide when the geese are pushed further up the shore; and (b) by controlling the numbers of low-flying aircraft. Further, the significant increase in dark-bellied brent over the past decade has been suggested to have been as a consequence of the creation of disturbance-free refuges throughout its wintering range.

Cryer *et al.* (1987) reported on the disturbance of overwintering wildfowl by anglers at two reservoir sites in South Wales. The distribution of wigeon, pochard and mallard was strongly influenced by the presence of anglers, i.e. birds concentrated in the central sector of the reservoir. The feeding rate of wigeon is also reported to be reduced by human disturbance whereas coot are most tolerant (Cramp and Simmons, 1977).

Korschgen *et al.* (1985) investigated the disturbance of diving ducks by boaters on a migrational staging area, and found that human disturbance can be detrimental to the production of breeding waterfowl. Continued disturbance during migration and wintering periods can have a dramatic effect on a bird's energy balance. The study concluded that birds had to fly an additional 1 hour per day because of disturbances. In some situations under heavy disturbance in which ducks cannot feed profitably during the day, they have been reported feeding at night to make up the energy deficit. Diving ducks in the Upper Mississippi River altered their typical patterns of diurnal activity because of intensive hunting pressure.

Hulbert (1990) showed that, on average, ruddy shelduck in the Royal Chitwan National Park, Nepal, were disturbed for 11 min each day. Canoes filled with tourists on the downstream journey were responsible for 26% of the total time disturbed, but on the return journey, when the empty canoes had to be hauled back upstream, they were responsible for 74% of the total time disturbed.

As well as short-term effects, recreational disturbance can have long-term implications for a site. Long-term effects are manifested through continued high-level disturbance reducing available feeding time and raising energy expenditure above a threshold, beyond which the site becomes unprofitable as a feeding area. From the study of Tuite (1981), coarse fishing, sailing and rowing are the most disturbing activities on inland water bodies. This is because they are widely practised activities covering many sites. The low score of power-boating from Tuite's study, on the other hand, reflects its low incidence rather than a real lack of local effect. Birdwatching appears to have the least negative effect. The population impact of such disturbances could be important, but as yet remains untested. Given the significant increases in populations of many species of wildfowl (Owen *et al.*, 1986) it is probable that effects from disturbance are not unduly large. They may be, however, for those smaller-bodied wading birds which must feed at the edge of the shore in most instances, rather than the centre of the lake or other waterbody.

The intensity or the distance of reaction depends on the species and the type of human activity involved (Kuhl, 1979; Hubner and Putzer, 1985; Dietrich and Keopff, 1986; Keopff and Dietrich, 1986) and can also vary with the stage of the tide (Keopff and Dietrich, 1986). Burger and Galli (1987) found that the proportion of gulls flying away when disturbed was higher in areas where disturbances were infrequent than in a heavily disturbed area. Similarly, grey herons that were infrequently disturbed reacted more strongly than birds that were often disturbed (Draulens and van Vessem, 1985).

With specific reference to roosts of estuary birds, disturbance is the one factor apart from tide height which modifies greatly the distribution of roosts (Prater, 1981). Few specific studies on the subject have been undertaken, although Furness (1973) concluded that the quality of the roost site (habitat type and freedom from disturbance) modified the numbers and distribution of waders at Musselburgh on the Firth of Forth. He went further to suggest that the numbers of oystercatchers and redshanks, as observed at the sites, might be limited by disturbance which he observed caused birds to spend less time feeding in food-rich areas.

4.2. EFFECTS ON ENERGY BUDGETS

Only a few studies, all on geese and ducks, measured effects of disturbance on activity and energy budgets of wintering birds. Responses of birds to disturbance often involve activities that are energetically costly (e.g. flying) or affect the behaviour in a way that might reduce food intake (e.g. shift from preferred feeding sites). Four studies on geese and ducks showed that the time spent feeding was significantly reduced due to disturbance, while the time spent in flight was increased (Owens, 1977; Belanger and Beddard, 1989; Morton *et al.*, 1989).

Norris and Wilson (1988) calculated indices of disturbance for wintering Greenland whitefronted geese based on observed disturbance rates (number of disturbance flights made per hour) and the quality of feeding on refuges in Ireland. Agricultural disturbance was the single most important factor, with overall rates of disturbance highest on intensively managed land. Disturbance levels directly influenced the energetic costs of feeding, and hence the suitability of a site, by increasing flying time and reducing time available for feeding. Only two studies, however, combined these observations with calculation of energy expenditure or energy intake. Bell and Fox (1991) reviews the energetic requirements and hence vulnerability of a range of species to disturbance, particularly that caused by shooting (see below). Species which are herbivorous and need to feed for long periods, or which feed in exposed habitats, are generally the most vulnerable. Morton *et al.* (1989) showed that energy expenditure of disturbed black duck was increased. Belanger and Bedard (1990) showed that disturbance of staging snow geese led to both a significant increase in daily energy expenditure and a decrease in energy intake and concluded that disturbance had a significant negative effect on the overall energy balance. Watmough (1983) found that disturbance from recreational activity could increase the daytime energy expenditure of mallard by 20%. White-Robinson (1982) found that disturbance increased the daily energy expenditure of Brent geese by 31%.

4.3. EFFECTS OF SHOOTING AND CONTROL MEASURES

A review of shooting-related disturbance is presented in Owen *et al.* (1986), Mudge (1989) and in a recently published report (Bell and Fox 1991). This study aimed to investigate the effects of shooting disturbance on overwintering wildfowl. Field studies of the relationship of wildfowl to disturbance were undertaken in order to establish the extent of disruption of normal behaviour, particularly feeding, that was brought about by shooting disturbance and whether that disruption had a lasting effect on the energy budget of the birds. One of the problems is relating population density to disturbance at a spatial scale that relates to differences in habitat types which are likely to mask any effects caused by disturbance. Within a site, shooting was shown to re-distribute wigeon, teal and mallard.

Next to geese, in all reviewed cases wigeon were shown to be the most susceptible species to shooting disturbance; wigeon make extensive use of refuges. The birds concentrate in refuge areas whilst moving out to shot-over areas once the shooting season has ended. Disturbance by wildfowlers accounted for 36% of the time during which wigeon and brent geese were considered to be disturbed at unprotected sites, and was the most important cause of disturbance observed. The study used a correlational approach rather than an experimental one. The latter may have helped clarify some of the unexplained variance in the results.

In the study of Norris and Wilson (1988) disturbance from shooting contributed between 10–22% of all disturbance flights of white-fronted geese, whilst aircraft contributed 19–67% up to 31 January. The provision of feeding refuges produced stable or increasing populations. At a locality much used by wildfowlers, brent geese could not be approached within 500 m, whereas the same geese could be approached to within 150 m at an undisturbed location nearby (Owens, 1977). It is generally the case that species of wilfowl become more wary or stay closer to water once the shooting season has begun (e.g. Madsen, 1988; Mayhew, 1985).

Draulans and van Vessem (1985) deliberately disturbed grey herons either severely or lightly in order to investigate prevention of damage to fish farms. Increased frequency of severe disturbance reduced heron abundance at farms, whereas slight disturbance had no effect. At fish farms under artificial lights herons fed preferentially at night or at twilight periods. Herons responded more to slight disturbances when more birds were present (see also Owens, 1977), probably because of increased vigilance in larger groups.

Murton (1971) reviewed the effect of airport scaring devices on birds which cause airstrikes, as well as for agricultural crop protection. Various disturbance methods have been used including various noise machines, shellcraker cartridges and pyrotechnics such as Very lights, to bioacoustics involving the playback of recorded distress calls through a loudspeaker system. Murton concludes that on the whole scaring devices have the disadvantage that birds get used to them, supporting the statement on habituation in Section 3·5, so that their efficiency rapidly declines. Murton further refers to similar habituation being developed when the disturbing factor is traffic noise and aircraft engines. Reference is made to an experiment in which 10 automatic bird scarers, producing loud explosions by the combustion of acetylene in a pressure chamber, were sited on either side of an airfield runway. These proved effective for 1 week, after which birds even started perching on them. O'Connor and Shrubb (1986) suggest that scaring devices which rely on simulating shooting usually work best if they are mixed with real shooting, and that many birds become accustomed to ignoring harmless bangs which are regularly timed in one spot.

C. Thomas (pers. comm.) at Manchester Airport has been studying bird strikes during the 1980s. Lapwing and black-headed gull are the major source of bird strikes at airports and they are dispersed with the use of bird scaring cartridges fired from a Very pistol, and by the use of cassette tapes of birds in distress. Distress tapes have a longer lasting effect although the birds become habituated to the sound if it is used repeatedly without reinforcement from the presence of a human. Similarly, birds become habituated to automatic bird scaring equipment at airports.

5. The impact of industrial developments or processes

Few of the searched literature dealt specifically with disturbance from industrial plants, yet this is an important area for study, particularly with respect to environmental impact assessments.

There are few data on disturbance caused by estuarine engineering operations, yet estuaries are particularly under threat from developments and, in Britain, are internationally important for waders and wildfowl. Prater (1981) states that waders, and to a greater extent wildfowl, will move away from the vicinity of active workings, although no specific studies are quoted. On the intertidal flats of Lavan Sands, Conwy Bay, no long-lasting adverse effects were noted when an oil pipe was laid from Anglesey to the mainland, although only a narrow route was used and the work was completed in a few weeks. A much greater impact was shown where the pipe crossed a saltmarsh (Rees, 1978), although the species most affected were not quoted. Prater (1981) concludes that construction effects may be significant locally and engineering operations should avoid proximity to established roost sites. Because of direct habitat loss (35% of area), and change to intertidal habitat, Lambeck *et al.* (1989) demonstrated large-scale changes in the numbers of a variety of wading birds on the Oosterschelde (The Netherlands) after the closure of an estuary there.

Meire *et al.* (1989) investigated factors affecting birds on a delta in south-west Netherlands undergoing coastal engineering works. Only the density of diving ducks appeared unrelated to food supply, but densities did appear to be negatively affected by human disturbance.

Winkleman (1989) found significant disturbance was caused to wintering ducks by a new wind park at Urk in The Netherlands. Direct mortality was not considered a problem but it is suggested that the wind turbines interfered with flight lines and reduced the area's attractiveness to ducks.

One consequence of industrial development adjacent to a wildfowl and wader roosting or feeding site is the potential for disturbance effects caused by increased lighting of the industrial plant. In some instances the disturbance to feeding patterns can be harmful, in others it can be beneficial. In some cases direct mortality can result, as a consequence of birds being attracted to a light source. The presence of artificial lights has the potential to affect birds in two ways: (i) by providing more feeding time by allowing nocturnal feeding; and (ii) by causing direct mortality or disorientation. A combination of atmospheric "bad-weather" conditions does lead to kills among nocturnal migrant birds at artificial light sources (Imber, 1975; Verheijen, 1980, 1981; Mead, 1983; Elkins, 1983; Reed *et al.*, 1985; Telfer, 1987). The problem is particularly acute if the light source is from a tall structure such as a light house, which can attract birds from a large radius. Kills are also known to be correlated with the lunar cycle, which is in keeping with the effect that the phase of the moon has on the congregation of birds around lighthouses, and gas flares on oil rigs. At Bardsey, an area of gorse bush is artificially lit under weather conditions when bird "fall-outs" are expected, in order to reduce the number of birds which fatally strike the lit tower.

6. Methods of mitigating disturbance effects

A number of strategies are currently used to mitigate or ameliorate the effects of disturbance from recreational pursuits, public access or industrial developments (Ounsted, 1989), and they are considered together here. For example, for wildfowl and waders using sites under varying degrees of disturbance, a number of practical solutions can be implemented in the wetland management plan. Wetland management is concerned with the planning and sympathetic design of new habitats as well as the modification of existing ones, and these management actions have been most successfully employed on enclosed inland waters and marshes. A list of suggested principal management practices to reduce disturbance or to attempt to compensate for habitat loss as a consequence of industrial development is given in Table 1. These relate more specifically to reducing the impact of an existing disturbance factor, and how to control it, together with measures taken to create completely new habitats.

Essentially, mitigation practices on wetlands include the creation of disturbance-free areas providing safe feeding sites, thereby allowing more time to feed and reducing birds' physiological stress; providing good-quality nesting cover for ground-nesters; using livestock (cattle) to graze coarse grasses so as to produce highly nutritious young grass for feeding wigeon and geese, thereby reducing distances they travel for food; using summer grazing only and restricting access in the winter months; zoning of activities and enhancement of those areas devoted to wildfowl and waders; careful location of public access points (Carlson and Godfrey, 1989) and concealment of observers at all times (Scott and Matthews, 1976) using banks; provision of shallow scrapes near the top water-level to create wader feeding grounds and duck brood rearing areas; provision of islands, spits and promontories in order to increase the edge: volume ratio and therefore permit a greater number of breeding wildfowl pairs to establish "territories"; provision of shallow-graded banks planted with marginal cover and aquatic macrophytes to provide vegetation cover and food for aquatic invertebrates which are then eaten by the birds during the breeding season. The seeds of many macrophytes are also eaten by wildfowl in winter. Further details are given in Hill (1989).

7. Discussion

It is important to discriminate between the various disturbance factors, i.e. between loss

TABLE 1. Principal management techniques used to reduce disturbance on a site or to attempt to compensate for habitat loss

Technique	Reducing disturbance impact	Creating new habitat as compensation
Lagoon 'scrape' excavation		X
Shallow (0·2–1·5 m)		
Grade bank sides (< 1:10)		
Flooding of low-lying pasture		X
Sluice or surface pumping		
Reduction of salinity levels of some coastal lagoons		X
Manipulate water levels to regularly expose mud		X
Feeding areas for geese and wigeon		X
Use livestock		
Increase nesting cover	X	X
Planting of macrophytes	X	X
Islands, spits, promontories	X	X
Land purchase to make area a bigger refuge	X	X
Creating buffer zones	X	
Banking/screening—conceal observers	X	
Zoning/prohibit access	X	
Knowledge of where birds flight to feed, do not obstruct flyway	X	

of habitat (e.g. through the siting and building of a new industrial plant) and the loss of access to an otherwise good habitat as a result of some level of disturbance. The former represents irreparable damage to the birds concerned, whereas the latter might be reduced to tolerable levels by mitigating practices. Any environmental impact assessment should consider the implications of disturbance.

As food supplies diminish during the winter it is apparent that tolerance of disturbance in some species decreases. However, such tolerances are species-specific. Generally, rare, less opportunistic species are less tolerant of disturbance than commoner ones, often because they have less exposure to disturbance and less capacity therefore to habituate to it. Disturbed birds that move elsewhere to feed or roost may do so into less favourable or sub-optimal conditions. As such, the degree of compensation afforded by moving may be slight, and at present is poorly understood, as are the density-dependent responses of most bird species, and hence their ability to compensate for disturbance impacts at the population level. The best studied examples are of waders, in which models of the density-dependent responses of birds through mutual interaction whilst feeding is being used to predict the population effect of habitat loss as a result of tidal barrage construction (Goss-Custard, 1977, 1979, 1987; Goss-Custard and Charman, 1976).

With respect to new constructions of industrial plants or similar, the actual structures can play a significant role in reducing the attractiveness of a feeding area to waders and wildfowl. Wildfowl appear less tolerant of these than do waders. If their view of the approach of potential predators (and the proximity of neighbours with which they compete in the case of many waders) is impeded, it appears that such feeding and roosting grounds may become sub-optimal, perhaps causing birds to move elsewhere

(Lazarus, 1978; Metcalf, 1984). This has been considered in some detail with respect to ecological impact assessments, using estuary wading birds as a model (Goss-Custard and Durrell, 1990). However, the carrying capacity of the habitat is likely to vary between sites so that responses by birds might also differ. Further, habitat exploitation and carrying capacity has been more fully researched for waders than for wildfowl (BTO, 1989). In general, "good" feeding and roosting sites of large wader and wildfowl flocks need to be large open expanses.

Most studies have concentrated on the effects of disturbance to feeding birds outside the breeding season. Some of the material quoted suggested a disturbance effect of roads and building construction on breeding birds, e.g. loons and waders. In most studies such disturbance had a negative effect on reproductive output, and in some cases bird density. The ability of birds to habituate to disturbance is important and requires consideration, however. If human activity at industrial plants remains concealed, for example, it is quite possible that some species of birds could habituate to the disturbance. In a number of cases quoted in this report, e.g. least terns on Harrier jet pads, habituation and acceptance of the disturbance was rapid. It is well known for breeding birds generally that tolerance of disturbance during breeding increases with the progression of the breeding period. Incubating birds are much less likely to desert their clutch than birds which are laying. Further, colonial breeding species may be more likely to tolerate higher levels of disturbance than solitary breeding by the usual vigilance which prevails when compared to solitary breeders. The classic example of noise habituation is exemplified by tolerance to bird scarers whether used to protect agricultural crops or to disperse birds from airports. Habituation is common to disturbance (particularly noise) that is repeated with reinforcement by the presence of a human.

Attraction of migrants to artificial light sources, e.g. lighthouses during cloudy nights or as a new moon approaches, is reasonably well known. Such instances are reduced under full-moon conditions. First-year juveniles of some seabirds, notably petrels, were attracted to street lighting in a number of studies. This problem has been reduced significantly by shielding artificial street lights along coastal fronts. Consequently, such shielding should be incorporated into constructions of new roads which are close to bird breeding areas, although the benefits to waders and wildfowl are likely to be less evident than was the case with first-year petrels. It is anticipated that some nocturnal feeding may be permitted under red-light illumination of adjacent wader and wildfowl feeding grounds, as has been documented in a number of cases.

Finally, the success of many nature reserve designs has centred on the ability to allow large-scale public access to the site without disturbing the very birds people come to see. As outdoor recreational pursuits continue to gain popularity, it is even more important to manage visitors properly. Public access, adjacent to sites of importance for wildfowl and waders, can be a very serious disturbing factor, reducing the site's value to the birds. Likewise, an industrial plant adjacent to such an area, which may be creating a low-level, continuous form of disturbance such as noise, will be more disturbing to birds if people are not screened than if their presence is concealed. The same type of people management which nature reserve managers have practised for some time, could be used effectively in sensitive developments which are sited adjacent to important waterfowl sites. One mitigating practice could be to "re-site" the waterfowl site some distance from the industrial plant. Usually this is impractical and serious effort should be devoted to screening and reducing all sources of disturbance, as well as avoiding siting the plant between the birds feeding and roosting sites. In any event the impact of disturbance should be studied and predicted.

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Appendix 1. Effects of human disturbance on breeding and breeding success

KEY TO ABBREVIATIONS

Human activities: air, aircraft; ang, angling; boa, boating; dev, developments (roads, buildings, etc.); hun, hunting; inv, investigator (nest checks); orv, off-road vehicles; sai, sailing; sho, shore-based activities (various); sur, windsurfing; swi, swimming; wal, walking; wat, water-based activities (various); unsp, unspecified.

Methods: obs, direct observation dist./ und. colonies/, comparison of disturbed and undisturbed nests, etc; 2 areas/colonies/plots/samples, comparison of two samples of nests with different degree of disturbance; 2 areas/colonies/, comparison of three or more samples of nests with different degrees of disturbance; different years, comparison of samples from different years with different degrees of disturbance.

BS, effects on breeding success. HS, lower hatching success; FS, lower fledging success; RS, lower overall reproductive success; HS/FS/RS/no effect, no effect found.

Source	Species	Activity	Method	BS	Mechanisms/ behaviour, etc.
	Gaviiformes				
Lehtonen (1970)	*Gavia arctica*	dev		RS	
Vermeer (1973)	*Gavia immer*	dev		RS	
Bundy (1979)	*Gavia arctica*	dev		RS	
Andersson *et al.* (1980)	*Gavia arctica*	dev		RS	
Robertson and Flood (1980)	*Gavia immer*	sho/wat	>2 areas	RS	
Titus and Van Druff (1981)		boa	>2 areas	HS	Reduced nest attendance
Heimberger *et al.* (1983)	*Gavia immer*	cottage density	>2 areas diff. density	HS	
Gotmark (1989)	*Gavia arctica*	boa	diff. years	HS	Reduced nest attendance
	Podicipediformes				
Batten (1977)	*Podiceps cristatus*	sai	obs		Nest failures
Pfluger and Ingold (1988)	*Podiceps cristatus*	boa/wal	obs		Reduced nest building
Keller (1989)	*Podiceps cristatus*	boa/ ang/ wal	>2 areas obs	HS	Reduced nest attendance, increased predation of eggs
Putzer (1989)	*Podiceps cristatus*	ang	obs		Nest failures
	Procellariiformes				
Jungius and Hirsch (1979)	*Diomedea irrorata*	wal	Measurement of heart-beat rate/obs		Increased heart-beat rate before birds show change in behaviour

Appendix 1 contd.

Source	Species	Activity	Method	BS	Mechanisms/ behaviour, etc.
Ollason and Dunnet (1980)	*Fulmarus glacialis*	inv	Different years	RS	
	Pelecaniformes				
Anderson and Keith (1980)	*Pelecanus occidentalis californicus*	wal	dist./und. sub colonies	RS	Nest abandonments, increase in predation, chicks caught in cactus plants
Anderson (1988)	*Pelecanus occidentalis californicus*	sho	nests at diff. distances from disturb.	Increase in nest abandonments near disturbances	
Bunnell *et al.* (1981)	*Pelecanus erythrorhynchos*	air	obs	High egg mortality due to pelicans crushing eggs	
Boellstorf *et al.* (1988)	*Pelecanus erythrorhynchos*	inv	dist./und. colonies	HS	
Jungius and Hirsch (1979)	*Sula nebouxii Fregata magnificens*	wal	Measurements of heart-beat rate/obs	Increased heart-beat rate before birds show change in behaviour	
Kury and Gochfeld (1975)	*Phalacorcorax auritus*	inv	obs	Leave nest, egg losses due to cormorants stepping on eggs and gull predation	
Verbeek (1982)	*Phalacrocorax auritus*	boa/sai	obs		Increased predation of eggs
Hobson *et al.* (1989)	*Phalacrocorax auritus*	hun/ unsp	dist./und. colonies	RS	
	Ciconiiformes				
Tremblay and Ellison (1979)	*Nycticorax nycticorax*	inv	2 colonies	HS/FS	Inhibition of laying, nest abandonments, increase in predation of eggs and nestling mortality
Vos *et al.* (1985)	*Ardea herodias*	wal/boa	obs		Increased absence from nest
Frederick and Collopy (1989)	*Egretta tricolor*	inv	2 colonies	RS	No effect
	Anseriformes				
MacInnes and Misra (1972)	*Branta canadensis*	inv	obs		Predators of eggs attracted to nests
Balat (1969)	*Anas platyrhynchos*	inv/ang	obs		Anglers prevent ducks disturbed by investigator from returning to nest

Appendix 1 contd.

Source	Species	Activity	Method	BS	Mechanisms/ behaviour, etc.
Joensen (1973)	*Somateria mollissima*	sho	dist./und. area	HS	Increased predation of eggs
Ahlund and Gotmark (1989)	*Somateria mollissima*	boa	simulated dist/obs		Increased predation of young by gulls
Laurila (1989)	*Somateria mollissima*	sho	>2 areas	HS	Increased predation of 1989 eggs
Keller (in press)	*Somateria mollissima*	sur/ boa/ ang/ wal	obs		Increased predation of young, effects on activity budgets of young
	Falconiformes				
Poole (1981)	*Pandion haliaetus*	inv	>2 samples	HS	No effect
Van Daele and Van Daele (1982)	*Pandion haliaetus*	dev	Different distances from dist.	RS	
Levenson and Koplin (1984)	*Pandion haliaetus*	wal	>2 samples	RS	
White and Thurow (1985)	*Buteo regalis*	simulated agricultural act	dist/und nests	RS	Nest abandonments
Mathisen (1968)	*Haliaeetus leucocephalus*	unsp	>2 samples	RS	No effect
Fraser *et al.* (1985)	*Haliaeetus leucocephalus*	dev	Successful/ unsuccessful nests	No higher frequency of human activity for unsuccessful nests	
Anthony and Isaacs (1989)	*Haliaeetus leucocephalus*	dev	Correlation with variables indicat. dist	RS	
Coleman and Fraser (1989)	*Coragyps atratus* *Cathartes aura*	dev	Successful/ unsuccessful nests	Successful nests further from buildings	
Van der Zande and Verstrael (1985)	*Falco tinnunculus*	unsp	>2 samples	RS	
	Gruiformes				
Pfluger and Ingold (1988)	*Fulica atra*	wal/ boa	obs		Reduced nest attendance, no effect on nest building
	Charadriiformes				
Pienkowski (1984)	*Charadrius hiaticula*	sho	>2 areas	RS	

Appendix 1 contd.

Source	Species	Activity	Method	BS	Mechanisms/ behaviour, etc.
Flemming *et al.* (1988)	*Charadrius melodus*	sho	obs	FS	Increased mortality of small chicks; reduced feeding and brooding
Strauss and Dane (1989)	*Charadrius melodus*	orv/sho	2 areas	HS/FS	Higher territory abandonment;
Buick and Paton (1989)	*Charadrius ruficollis*	orv	obs/exp	HS	Nests run over by vehicles
Putzer (1989)	*Charadrius dudius*	ang	obs		Nest failures
Yalden and Yalden (1990)	*Pluvialis apricaria*	wal	obs		Reduced nest attendance, reduced feeding and brooding
Inversen (1986)	*Vanellus vanellus*	wal	obs		Reduced nest attendance
Jeffery (1987)	*Haematopus moguini*	sho	Different years		Decline in RS correlated to increase in orv
Safina and Burger (1983)	*Rynchops niger*	inv	2 sub-colonies	HS/FS	Increased chick mortality
Hunt (1972)	*Larus argentatus*	sho	> 2 areas	HS/FS no effect	Exposure to eggs to heat during absence from nest
Gillett *et al.* (1975)	*Larus argentatus*	inv	> 2 exp.	HS/FS plots	Intraspecific predation
Hand (1980)	*Larus occidentalis livens*	wal	obs		Intraspecific predation of eggs and young
Anderson and Keith (1980)	*Larus heermanni*	wal	> 2 colonies	S	Intraspecific predation of eggs and young
Fetterolf (1983)	*Larus delawarensis*	inv	2 exp plots	HS/FS	Intraspecific predation; chicks get lost and die
Burger and Gochfeld (1990)	*Sterna antillarum*	orv	Nest at different distances to tracks	HS	
Dunnet (1977)	*Rissa tridactyla, Uria aalge, Alca torda* and others	air	obs		No difference in No. of birds present before and after helicopter passing
Cairns (1980)	*Cepphus grylle*	inv	2 colonies	HR/RS	
Pierce and Simons (1986)	*Fratercula cirrhata*	inv	> 2 exp. plots	FS	Nest abandonments, lengthening of incubation period, retarded chick development

Appendix 1 contd.

Source	Species	Activity	Method	BS	Mechanisms/ behaviour, etc.
Piatt *et al.* (1990)	*Aethia pusilla*	inv	>2 exp. plots	RS	
	Passeriformes				
Loske (1980)	*Riparia riparia*	ang/swi	obs		Adults prevented from feeding chicks
Robertson and Flood (1980)	*Tyrannus tyrannus*	sho/ wat	>2 areas	FS	

Appendix 2. Effects of human disturbance on nest-site choice

Source	Species	Method	Results/conclusions
Alvo (1981)	*Gavia immer*	Description of nest sites	High frequency of marsh nests, available island nest sites (usually preferred) closer to cottages or boat traffic not used
Laurila (1989)	*Somateria mollissima*	Analysis of factors influencing nest-site choice	Preference of isolated islands with low degree of disturbance
Fraser *et al.* (1985)	*Haliaeetus leucocephalus*	Comparison of nest sites in developed/undeveloped areas	Nests on developed shorelines further away from water
Van der Zande and Verstrael (1985)	*Falco tinnunculus*	Nest sites in areas with different intensities of disturbance	Avoidance of areas freely to humans and close to human activities
Buckley and Buckley (1975)	Terns, waders	Comparison of dredge-spoil islands and natural beaches	As consequence of developments of beaches most nests on dredge spoil islands
Parnell and Soots (1975)	Gulls, terns, waders	Comparison of dredge-spoil islands and natural beaches	80% of nests on dredge spoil islands
Burger and Shisler (1979)	*Larus argentatus*	Analysis of nest sites in relation to ditching	Spoil deposition sites along ditches preferred, alternative to developed barrier beaches
Altman and Gano (1984)	*Sterna albifrons*	Nesting under high noise levels	Terns became habituated to disturbance from harrier jump jets and nested on take-off pad
Haworth and Thompson (1990)	*Charadriiformes*	Multivariate analysis of disturbance	Breeding waders on moorland avoid areas prone to disturbance, particularly golden plover and curlew
Erwin (1980)	*Sterna hirundo, S. albifrons, Rynchops niger, Larns argentatus*	Comparison of heavily and less developed coasts	On developed coasts most colonies on dredge-spoil islands, few on barrier beaches; on developed coast opposite
Jackson and Schardien Jackson (1985)	*Sterna antillarum*	Multiariate analysis of habitat	Dredge-spoil islands important nesting habitat
Kotliar and Burger (1986)	*Sterna antillarum*	Multivariate analysis of colony site characteristics	Dredge-spoil sites alternative nesting areas to developed beaches
Storey (1987)	*Sterna hirundo*	Comparison of nesting biology in "secondary" habitat with biology of *S. forsteri*	Increased nesting in marshes due to increased disturbance and development of barrier beaches; react less successfully to flooding than marsh-nesting terns (*S. forsteri*)
Knight and Fitzner (1985)	*Pica pica*	Experimental disturbance of nests	In the year following disturbance nest higher above ground and often in different trees

Appendix 3. Effects of human disturbances on nesting density or population density

Source	Species	Method	Results/conclusions
Hill and Rosier (1989)	*Puffinus pacificus*, *Anous minutus*	Comparison of nesting sites in developed and undeveloped halves of island	Similar numbers of nests on both halves of island, but nesting density in remaining suitable habitat on developed side higher
Reichholf (1970, 1975)	*Anatidae*	Correlation of duck numbers and use of sites by anglers	Decline in breeding population of ducks correlated with increase in angling
Tuite (1981)	*Anatidae*, *Podicipedidae* *Rallidae*	Comparison of sites with high and low intensities of recreational use	Significantly lower densities at sites with high recreational use for *Tachybaptys ruficollis* *Bucephala clangula*, *Anas crecca*, *Gallinula chloropus*. No effect for other species
Laurila (1989)	*Somateria mollissima*	Comparison of islands with differences in disturbance	Lower nest density on frequently disturbed islands
Witt (1984)	Seabirds	Comparison of developed/undeveloped coasts	Population sizes lower on developed coast
Safina and Burger (1983)	*Rynchops niger*	Comparison of colonies disturbed at different frequencies	Disturbance early in the season reduced nesting density in daily disturbed colonies and increased it in less disturbed one due to birds shifting
Van der Zande *et al.* (1980)	*Vanellus vanellus*, *Haematopus ostralegus*, *Limosa limosa*, *Tringa totanus*	Density of nesting pairs in relation to distance from roads	Nesting density increased with increasing distance from roads for three species (not for *Haematopus ostralegus*)

De Roos and Schaafsma (1981)	*Haematopus ostralegus*	Comparison of study plots open and closed to public	Increase in number of nests after prohibiting access to study plots
Watson (1988*b*)	*Charadrius morinellus*	Comparison of three areas with different intensity of use, comparison with years before development	No differences indicating disturbance effect
Watson (1988*a*)	*Tringa hypoleucus*	Monitoring of population over several years	Population decline at lake with increase in disturbance, but not at other lakes with no increase
Van der Zande and Vos (1984)	*Passeriformes*	Comparison of densities in years before and after opening of car park	For 11 out of 12 species density in study plots close to car park decreased after opening, but did so in plots further away
Van der Zande *et al.* (1984)	*Passeriformes*	Correlation between densities of common species and recreational intensity	Significant negative correlation for eight out of 13 species, differences in degree of reduction between species
Glue (1971)	*Anseriformes*, *Gruiformes*, *Falconiformes*, *Charadriiformes*, *Passeriformes*	Comparison of four different stages of reclamation of saltmarshes	Short-term increase in wildfowl and waders, followed by longer-term decrease, mainly in wildfowl
Watson (1979)	*Lagopus mutus*, *L l scoticus*, *Anthus pratensis*, *Oenanthe oenanthe*	Comparison of disturbed and undisturbed areas	No differences in spring densities

Appendix 4. Effects of human disturbance on community structure

Source	Species	Methods	Results/conclusions
Burger *et al.* (1982)	*Anseriformes, Gruiformes, Charadriiformes, Passeriformes*	Comparison of natural and ditched saltmarshes	Higher species diversity in ditched saltmarshes
Foin *et al.* (1977)	*Passeriformes*	Comparison of campground and non-campground areas	Slightly higher species diversity and higher bird density around campsites due to increase in common species
Robertson and Flood (1980)	*Passeriformes*	Comparison of shore lines with different degrees of cottage development	Higher species diversity in developed areas
Clark *et al.* (1984)	*Passeriformes*	Comparison of plots with different degrees of disturbance	Differences in species composition, species react differently to development
Blakesley and Reese (1988)	*Passeriformes*	Comparison of campground and non-campground areas	Differences in species composition, different species affected in different ways by campgrounds

Appendix 5. Effects of human disturbance on distribution and habitat-use outside the breeding season

Source	Species	Method	Results/conclusions
	Gaviiformes		
Lehtonen (1970)	*Gavia arctica*	Development	Reduced use of lakes with number of cottages
Vermeer (1973)	*Gavia immer*	Development	Reduced use of lakes with number of cottages
Bundy (1979)	*Gavia arctica*	Development	Reduced use of lakes with number of cottages
Anderson *et al.* (1980)	*Gavia arctica*	Development	Reduced use of lakes with number of cottages
Imber (1975)	*Procellariiformes*	Light	Disruption and disorientation by light sources
Reed *et al.* (1985)	*Procellariiformes*	Light	Disruption and disorientation by light sources
	Pelecaniformes		
Hubner and Putzer (1985)	*Phalacrocorax carbo*	Sailing, surfing, boating	Exponential fall in the number of cormorants after arrival of boats, first boat displaces vast majority of birds
Lok and Bakker (1988)	*Phalacrocorax carbo*	Water-based	Avoidance of lakes with many activities
Draulans and van Vessem (1985)	*Ardea cinerea*	Unspecified	On fish farms slight disturbance had no effect, severe disturbance reduces numbers present. More response was apparent for disturbances when more birds were present
	Anseriformes		
Scott (1980)	*Cygnus columbianus*	Shooting	A ban on shooting in refuges caused highly aggregated populations
Martin (1973)	*Branta bernicla, Tadorna tadorna*	Shore-based	Feed on mudflats, disrupted from up to 200 m away
Owens (1977)	*Branta bernicla*	Shore-based, aircraft	Avoidance of disturbed areas in autumn, but not later in winter
Mooij (1982)	*Anser albifrons*	Roads	Intensity of use of fields increased with increasing distance from roads
Madsen (1985)	*Anser brachyrhynchus*	Roads	Field utilization of geese affected by an area with reduced use greater in autumn than in spring
Keller (1990)	*Anser brachyrhynchus*	Roads	Avoidance of fields close to roads
Norriss and Wilson (1988)	*Anser albifrons*	Shooting, aircraft, agricultural	Agricultural disturbance most important factor, disturbance-free refuges have been considered an important factor for population increases
Belanger and Bedard (1989)	*Chen caerulescens*	Aircraft, hunting shore-based	Displacement from feeding areas, with rate of disturbance decrease in number of geese present on following day
Hulbert (1990)	*Tadorna ferruginea*	Boating	Repeated disturbance shifts birds until outside range of disturbance
Cook (1980)	*Tadorna* spp.	Angling	Activity on site prohibits use of site for feeding
Putzer (1989)	*Anseriformes*	Sailing	Exponential fall in the number of ducks present after start of sailing, first boat displaces vast majority of birds present

Appendix 5 contd.

Source	Species	Method	Results/conclusions
Galhoff *et al.* (1984)	*Aythya ferina*	Boating, surfing	Change day-time roost site
Hume (1976)	*Bucephala clanqula*	Boating	Power boats disturb birds up to 200 m away
Tuite *et al.* (1983)	*Anseriformes*	Water-based	With increasing human activity decrease in time spent in preferred areas
Tuite *et al.* (1984)	*Anseriformes*	Water-based	Winter distribution affected by water-based recreation, mainly by coarse fishing, sailing, rowing, most susceptible species: *Anas crecca*, *A. clypeata*, *Bucephala clangula*
Bell and Austin (1985)	*Anas penelope*, *A. platyrhynchos*, *A. crecca*, *Aythya ferina*	Angling	Angling shifts ducks from preferred feeding and roosting sites, start of angling season seemed to lead premature departure in spring
Joensen and Madsen (1985)	*Anseriformes*	Hunting	Disturbance caused mass displacement of ducks from feeding areas
Korschgen *et al.* (1985)	*Anseriformes*	Angling, boating, hunting	Ducks take-off when disturbed and sometimes leave area completely
Winkelman (1989)	*Anseriformes*	Development	Wind park reduced the attractiveness to ducks by interfering with flight lines
Schneider (1986)	*Anseriformes*	Hunting	Distribution of wildfowl on days with shooting different from days without shooting
Cryer *et al.* (1987)	*Aythya ferina*, *Anas penelope*, *A. platyrhynchos*	Angling	Presence of anglers shifts overwintering ducks from preferred to less preferred areas
Owen *et al.* (1986)	*Anseriformes*	Shore-based, water-based	Reduced carrying capacity of lakes, restricted use of preferred feeding and roosting sites.
	Falconiformes		
Stalmaster and Newman (1978)	*Haliaeetus leucocephalus*	Shore-based, water-based	Changes in distribution patterns due to displacement to areas with low disturbance
Paruk (1987)	*Haliaeetus leucocephalus*	Development	Developed river segments had fewer eagles than undisturbed stretches
	Galliformes		
Miquet (1988)	*Tetrao tetrix*	Skiing	Abandonment of areas after disturbance, larger home ranges in areas with intensive skiing

	Gruiformes		
Luvvorn and Kirkpatrick (1981)	*Grus canadensis tabida*	Hunting	Avoidance of roosts with wildfowl hunting
	Charadriiformes		
Burger (1988)	*Larus* spp.	Shore-based	Beach clean-up and demolition work shifts birds further out on mudflat, reduced foraging efficiency in areas where gulls shifted to than in original feeding area
Furness (1973)	*Haematopus ostralegus*, *Tringa totanus*	Shore-based	Observed disturbance might limit numbers on estuary by reducing feeding efficiency
Burger (1986)	*Charadrii*	Shore-based, aircraft	Per cent birds flying off increases with increasing frequency of distance, birds frequently leave area completely
Van den Heiligenberg (1987)	*Charadrii*	Bait-digging	Waders avoid areas around bait-diggers for feeding
	Various		
Burger (1981)	*Anseriformes*, *Charadriiformes*, *Passeriformes*	Shore-based	Number of birds using shore lower when people present, differences between species differences in reaction to different activities
Prater (1981)	*Anseriformes*, *Charadriiformes*	Developed	Active estuarine engineering causes birds to move away
Murton (1971)	Various	Noise	Bird disturbance devices are only effective if reinforced otherwise habituation occurs quickly
Verheijen (1980, 1981)	Various	Light	Disruption and disorientation of moving birds caused by light sources
Mead (1983)	Various	Light	Disruption and disorientation of moving birds caused by light sources
Elkins (1983)	Various	Light	Disruption and disorientation of moving birds caused by light sources
O'Connor and Shrubb (1986)	Various	Shooting	Simulated shooting only effective if mixed with real shooting
Telfer *et al.* (1987)	Various	Light	Disruption and disorientation of moving birds caused by light sources

Appendix 6. Effect of human disturbance on distribution and energy budgets outside breeding season

Source	Species	Methods	Results/conclusions
Owens (1977)	*Branta bernicla*	Shore-based	Reduction in time spent feeding, increase in aircraft time spent in flight
Norriss and Wilson (1988)	*Anser albifrons*	Agriculture, aircraft, shooting	Disturbance levels directly influenced the energetic costs of feeding by increasing flying time reduced feeding times
Belanger and Bedard (1989)	*Chen caerulescens*	Aircraft, hunting, shore-based	Increase in time spent flying, strongest disturbance by aircraft
Belanger and Bedard (1989)	*Chen caerulescens*	Aircraft, hunting, shore-based	Reactions to disturbance: fly away, interruption of feeding; significant effects on energy balance due to increase in energy expenditure and decrease in energy intake
Morton *et al.* (1989)	*Anas rubripes*	Shore-based	Reduction in time spent feeding, increase in time spent flying, increased energy expenditure
Burger (1988)	*Larus* spp.	Shore-based	Foraging efficiency of gulls drops after start of beach clean-up work