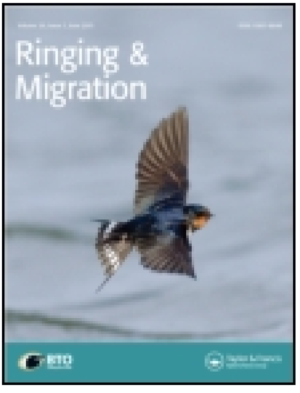

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A review of the use and the effects of marks and devices on birds

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A review of the use and the effects of marks and devices on birds

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This paper reviews the use and the effects of marks and devices on birds. Although most papers reporting research on birds make use of marks or devices, very few studies test for harmful effects or data biases caused by these. Many research projects have used marks and devices without encountering any harmful effects of these on the birds being studied. However, where assessments have been made it is clear that all of the methods of marking can have adverse effects, while most devices attached to birds do alter their behaviour to some extent. We conclude that more attention should be given to these effects before the normal assumption of no influence on the biological parameters being studied can be made with confidence. There is a need for careful tests of the effects of marking methods to be undertaken. We hope that this review will assist people studying birds to plan their use of marks and devices in such a way as to minimize problems caused by these research tools.

Ringing and dye marking of birds to assist in studies of survival, migrations and aspects of ecology are well-known and important techniques which have been used for many decades. In the vast majority of publications using these techniques there seem to be no adverse effects of marking on the birds. In more recent years, there has been an increasing development of much more sophisticated means of marking (leg flags, wing tags, back tags, neck marks, nasal marks and others) and also the construction of miniature data logging devices (altimeters, depth gauges, speedometers, activity recorders) and radio transmitter packages. It is immediately evident from the literature that many authors report research using these marks or devices without any consideration of the effects these may have on the birds. One reason for authors to omit reference to biases caused by marking may be the desire of editors to remove all unnecessary material from papers to save space in journals. Such a practice would seem sensible providing the technique used has been well established as not altering the aspects of bird biology being studied. It was because we felt that this may not always be the case that we undertook this review.

Gavin (1989), in a review of marking procedures and their use on different animals, says that publications on birds less commonly use marking than studies of reptiles or mammals. He attributes this to the fact that birds are more conspicuous, and so marking is not necessary for certain kinds of study. Nevertheless, up to 51% of the papers he reviewed used some marking method. Marking techniques for birds have been reviewed by Marion & Shamis (1977), Patterson (1978), Spencer (1978), Day *et al.* (1980), and MacClure (1984), but these reviews give little information on adverse effects of marking. Kenward (1987) recently reviewed the use of radio transmitters on birds and considered in some detail the effects of different tag attachment methods.

In many countries the licensing of individuals to use rings and particularly to use more complex marks and devices is strictly controlled by a national authority and all planned uses of marks and devices are screened to ensure that hazards to birds are minimized. The British Trust for Ornithology (BTO) has already adopted this review to assist them in assessing proposed studies. Such quality control procedures and the high standards of ringing training result in few studies in Britain producing marking-induced effects on birds; most of those reported here are from work carried out overseas, and many of the methods that caused problems with particular species in the past are no longer used for those species. Nevertheless, marking methods that can influence survival and behaviour are still used and deserve attention so that any hazards to birds can be minimized.

This review is in two parts. Firstly we briefly present a quantitative review of the marking methods and devices used in studies published in several selected leading bird journals in recent years, in relation to the authors' consideration of bias that marks and devices may induce. Then we consider the extent to which the methods have been demonstrated to provide unbiased results, by reviewing research published throughout the scientific literature.

Human presence can alter bird behaviour even when this is not immediately evident (Wilson *et al.* 1991). There have been several studies on effects of trapping and handling (Leberman & Stern 1977, Busch *et al.* 1978, Blokpoel 1981, Brubeck *et al.* 1981, Nisbett 1981, Ueda 1984), and this process can be disturbing, leading to nest desertion or changes in behaviour. Influences of disturbance, trapping and handling on subsequent behaviour are outside the scope of this paper, but it should be borne in mind that changes in behaviour of birds could be caused by human disturbance, by trapping and handling, by marks or devices attached, or by combinations of these.

METHODS

We reviewed 786 papers on birds in Auk 1979–1989, Ibis 1975-1990, Journal of Applied Ecology 1975–1989, Journal of Wildlife Management 1975–1989 and Ornis Scandinavica 1977–1989. From each paper we recorded the technique(s) used, the subject of study and any comments on effects. The subjects of the papers were classified into very broad groups: 1 Moult, age, body condition, growth patterns, morphology; 2 Movements and survival; 3 Ecological studies; 4 Papers on the development of techniques.

Papers were classified according to the consideration given by the author to effects of the mark or device on the birds as:NC – No comment, C – Comment on effects but without expressly testing ("...the birds seemed unaffected...", "...behaved normally after the..."), T – Tested in relation to any parameter(s) (predation, reproductive success, return rate, behaviour, etc.). In addition, we reviewed papers throughout the scientific literature, dealing directly with effects of marking techniques, papers using them for another purpose and finding effects on the birds, and papers describing techniques. We did not consider papers based on individuals kept in captivity, unless the results were relevant for the aim of this review. Neither do we consider those in which the mark was internal (e.g.implanted radio–transmitters) or involved clipping or removing of feathers or nails, although such techniques undoubtedly can have effects on bird behaviour and survival.

We grouped the techniques as follows: 1 METAL RINGS, 2 COLOUR RINGS, 3 MARKS ATTACHED TO THE LEGS (Tape, leg streamers, leg strips, leg flags, flipper bands, thread around the leg, web tags, toe banding), 4 WING TAGS, 5 BACK TAGS, 6 NECK TAGS, 7 NECK COLLARS (Including laces and bands), 8 NASAL MARKS (Saddles, discs) 9 DYES, 10 OTHER MARKS, 11 DATA LOGGERS (Digital watches, altimeters, depth gauges, speedometers), 12 RADIO–TRANSMITTERS.

RESULTS

Frequency of use of marks and devices

Of the 786 papers reviewed, 39.6% used colour rings, and 38.3% used metal rings. 98% of the studies in which rings were used did not mention possible effects of the rings, 1.3% made a brief comment, and only 0.7% tested for any bias caused by rings (Table 1). Similar patterns were found for most of the other marks, although slightly more authors considered problems caused by wing tags and neck collars. Transmitters have been used for many years and some side effects have been found on birds wearing them (see below). Data loggers have started to be used more recently. This group has the highest percentage of studies in which effects have been checked or commented on (75%).

The consideration given by authors to biases caused by marks or devices shows a historical trend in two cases: neck marks and radio transmitters. The former were tested in many papers in the 1970s (67%) and rarely subsequently. The latter has a high percentage of papers in which the method is either tested or with comments about effects, although there seems to be a slight tendency for those without any comment to have increased in recent years.

Metal rings

Rings are by far the most common means of marking birds, but are often combined with other marks. Most of the authors assume that rings have no effect on the birds, and make no comment at all about this (98%). Even when they have been used in works considering the

Table 1. Frequency of use of different marking techniques and employment of devices on birds in 786 papers published in Auk 1979–89, Ibis 1975–90, J. appl. Ecol. 1975–89, J. Wildl. Manage. 1975–89 and Ornis Scand. 1977–89.

Mark	*Number of papers in which technique was used*	*No Comment*	*Comment*	*Harmful effect reported/ tested*	*Breeding or feeding ecology*	*Movements or survival*	*Morphology moult, growth age or body condition*	*Technique develop-ment*	*Percentage papers with references*		
									<1980	*1980-1984*	*>1984*
Metal ring	301	98.0	1.6	0.3	67.1	21.9	10.2	0.6	3.5	0.0	2.7
Colour ring	311	98.0	0.9	0.9	81.6	11.5	4.5	2.2	0.0	0.0	3.5
Leg flag	32	96.8	0.0	3.1	75.0	12.5	3.1	6.2	20.0	0.0	0.0
Wing tag	65	87.6	3.0	9.2	72.3	15.3	3.1	9.2	0.0	26.6	3.1
Back tag	8	75.0	12.5	12.5	62.5	25.0	0.0	12.5			
Neck collar	33	78.7	3.0	18.1	39.3	33.3	9.1	18.1	66.6	13.3	9.1
Nasal mark	20	90.0	5.0	5.0	85.0	5.0	0.0	10.0	0.0	10.0	14.3
Dyes	64	90.6	9.3	0.0	85.9	7.8	4.7	1.5	0.0	13.0	10.0
Other marks	40	97.5	2.5	0.0	85.0	7.5	7.5	0.0			
Data logger	8	25.0	12.5	62.5	50.0	12.5	0.0	37.5			
Radio transmitter	187	66.3	15.5	18.1	40.6	43.8	1.1	14.4	42.4	33.9	30.6

effects of certain types of marks on birds, the effects of the rings have almost always been ignored, and the ringed birds have generally been used as controls against which to compare the effects of more substantial marks or devices. Although the vast majority of studies using rings give no reason to suspect that any adverse effects are caused, some problems with a few species wearing rings have been reported. The use of metal ring can cause leg irritation as reported by Law (1929) in Rufous-sided Towhees *Pipilo erythrophthalmus*. Reed (1953) and Elder (1984), reported some cases of leg mutilation when using two rings, one above the other on the same leg. The rings deformed producing sharp edges that caused injuries to the leg. Metal rings used singly also wear as a result of abrasion against the leg, and the rate of wear varies among species (Harris 1980). Worn rings become sharp and will eventually open and slide off the leg. Perdeck & Wassenaar (1981) showed that ring wear is less on the tibia than on the tarsus, but no mention was made of any effects of this on the birds, though rings which wear less quickly are likely to be less hazardous to birds. Incorrect adjustment of the ring can cause injuries to the bird's leg. Herholdt (1987) found a dead White Stork *Ciconia ciconia* whose ring had not been closed properly and it had slipped over the tibial joint, damaging the leg tissue.

Rothstein (1979) noted that White-crowned Sparrows *Zonotrichia leucophrys* with metal rings developed a grey cast on the tarsus, presumed to be due to an oxide produced from the ring. He also detected that the tarsus with the ring increased in diameter, although no deleterious effect was observed. Swelling of the leg has also been found with Red-winged Blackbirds *Agelaius phoeniceus* (Cummings 1987) and Spruce Grouse *Dendragapus canadensis* (Robinson 1980), in both cases due to the ring being too tight.

In species which "defecate on the legs" such as Turkey Vultures *Cathartes aura*, the excrement can accumulate between the leg and the ring (Stewart 1985). Schulz (1986), studying White Storks, observed that 50% of all the birds carrying a ring had injuries caused by the accumulation of excrement in the ring, and he estimated that this increased the annual mortality rate by at least 5%. In vultures the accumulation can cause the foot to swell (Sweeny *et al.* 1985) and eventually the use of the leg or foot is lost (Henckle 1976).

Accumulation of ice in the ring and subsequent leg injuries and even leg loss, has been reported in tits *Parus spp.* by Dunbar (1959) and in American Goldfinches *Carduelis tristis* by MacDonald (1961).

No effect of metal rings on behaviour was noted by Robinson (1980) in a study of Spruce Grouse, or by Prendergast (1975) who reports how Chiffchaffs *Phylloscopus collybita* and Kestrels *Falco tinnunculus* resumed their feeding activities immediately after having been caught and ringed, showing no interest at all in their rings. Dhindsa & Boag (1989), in an experiment with Magpies *Pica pica*, found that ringed and unringed individuals showed no differential sensitivity to observer approach.

Dickson *et al.* (1982), in an evaluation of marks for Cardinals *Cardinalis cardinalis*, did not comment on any effect of metal and colour rings on the birds. By contrast, a very strong reaction to metal rings has been described several times for this species (Young 1941, Laskey 1944, Lovell 1948). Wiseman (1977) attributes the problem of band removal by Cardinals to "individual temperament", as only some birds would not accept the rings (he considers colour rings as well). Another species which has shown a strong reaction to the ring is the Black-capped Chickadee *Parus atricapillus* (Carpenter 1981).

Moore and Koening (1986) and Dunn & Hannon (1989) did not register any nest desertion due to the capture and ringing of flickers *Colaptes sp.* and Magpies respectively, though Imber (1976) found that 10% of the Grey-faced Petrels *Pterodroma macroptera gouldi* he ringed deserted their nests, probably due to handling and observation. Burtt and Tuttle (1983) and Lombardo (1989) recorded the same effect with Tree Swallows *Tachycineta bicolor*. In these three studies birds ringed earlier in the nesting cycle abandoned their clutches more than those ringed later in the nesting cycle. Imber (1976) found that males seemed more prone to desert the nest than females.

A few Slate-coloured Juncos *Junco hyemalis* chicks ringed early in the nesting cycle were removed from the nest by their parents (Smith & Andersen 1982) and the same was observed in Song Sparrows *Zonotrichia melodia* by Lovell (1945).

Little research has been done to study the long-term effects of metal rings on birds. Houston (1974) says that the mortality associated with ringing studies "receives less attention than it deserves". Although metal rings seem to present hazards particularly in very cold or arid regions, the extent to which metal rings may affect survival rates of temperate birds seems to be unknown. The BTO ring recovery files include such records as a Redshank *Tringa totanus* recovered dead 'suspended from a barbed wire fence by its ring'. While the effect of such incidents on survival rates of the ringed component on the population may be slight or trivial, these unquantified biases are generally ignored when ring recovery data are used to assess species population dynamics.

Colour rings

There are not many reports of coloured plastic rings causing adverse effects. Sandhill Cranes *Grus canadensis* pecked at the rings in the first few days (Hoffman 1985) and Magpies did even months after being ringed (Reese 1980). Atherton *et al.* (1984) found that the colour rings they used on doves (Fam. *Columbidae*) constricted and damaged the leg of the birds. They solved this by treating the rings with acetone to seal them. Komen (1987) reported injuries to Cape Gannets' *Sula capensis* feet due to the rings: colour rings slipped down and unwound around the foot constricting the web, sometimes piercing it. Other authors (e.g. Robinson 1985, Strong 1987) did not find any adverse effect when using colour rings.

The effects of colour rings on behaviour are mainly related to the possible interference of the colour of the ring with individual recognition, status signalling, or mate choice. The well-known studies on captive Zebra Finches *Poephila guttata* by Burley showed that male birds wearing red bands were more attractive to females than unringed ones (Burley *et al.* 1982). Birds carrying rings of typical colours of the species (e.g. red) attracted conspecifics while others, carrying colours non-typical of the species (e.g. green), were avoided (Burley *et al.* 1982, 1986a). This in turn affected sex-ratio (Burley 1981, 1986b) and mortality (Burley 1985). Soon after Burley's first paper was published her results were challenged (Immelman *et al.* 1982, Thissen & Martin 1982). Harvey (1986) questioned the results, claiming that they are of great importance but that they should have to be demonstrated under natural conditions.

Watt (1982) evaluated the effect of colour rings on individual recognition in a group of White-crowned Sparrows, not finding any relationship between them. Ratcliffe & Boag (1987) did not find any correlation between ring colour and the Zebra Finch male's ability to gain a female or a nest, but they state that these results "do not falsify Burley's basic finding that Zebra Finches find certain colour bands more attractive than others".

The physical annoyance of the ring can alter the agonistic behaviour of Magpies. Reese (1980) observed how they pecked at their rings repeatedly when unringed birds, under the same circumstances, were hammering their bills against branches or the ground.

Sandhill Cranes marked with colour rings and vinyl flags around standard rings avoided unmarked cranes and these in turn, avoided the marked ones (Wheeler & Lewis 1972).

Beletsky & Orians (1989) made an evaluation of the influence of colour rings on male mortality and reproductive success in Red-winged Blackbirds, failing to find any relationship among rings and these parameters. However, they say that "among species in which males, rather than the resources they control, are the primary basis of mate choice, band colours may be more influential". The results obtained by Brodsky (1988) support this. He found that male Ptarmigans *Lagopus mutus* with red and orange rings gained more mates than those without them. Males with the largest supraorbital combs – a target for sexual selection – get the highest number of mates. Male's mating success can be altered by using rings of a similar colour to that of the supraorbital combs.

Finally, Hagan & Reed (1988) found a lower reproductive success in male Red-cockaded Woodpeckers *Picoides borealis* wearing red colour rings. It did not happen with other colours, and no effect was observed in adult females. Hill & Carr (1989) suggest that this study should not be taken into account as evidence of an effect of colour leg rings. They criticize some aspects of the data collection and the analysis. Hagan & Reed (1989) answered these criticisms and reaffirmed their conclusion.

No correlation between the colours of rings and mortality was found by Hoffman (1985) or Beletsky & Orians (1989). Hagan & Reed (1988) noted that nestling Red-cockaded Woodpeckers with red rings were less likely to be sighted as fledgings.

Other marks attached to the leg

Tape. Colour tape has been used around the leg (Dowing & Marshall 1959, Fankhauser 1964, Johnson 1971) or around leg rings (Gullion 1965, Vestjens 1978). None of the authors make any comment on possible effects of the markers on the birds.

Thread. Oniki (1981) proposed this method to mark nestlings. He found that dull colours were better accepted; red, for instance, attracted the adult's attention. Birds that peer in the nest were seen pecking or pulling at the marks, although they never ejected the young from the nest.

Leg streamers, strips and flags. Many different types of leg tags have been described (Campbell 1960, Thomas & Marburger 1964, Guarino 1968, Royall 1977, Swepston *et al.* 1978 Clark 1979, Goodyear *et al.* 1979). Although most of the authors do not even consider the possible side effects, and Campbell (1960) did not find any, a few problems have been described.

The leg tag has been found to be an excessive drag for Starlings *Sturnus vulgaris* and Red-winged Blackbirds when flying with winds greater than 20 mph. Marked birds were seen to fly behind and below the main flock (Guarino 1968). This author suggests that tags could increase mortality in these species because of shooting by man. Leg streamers can also affect flight in Cranes *Grus grus* (Wheeler & Lewis 1972), as well as their social behaviour. They observed how colour marked birds were avoided by unmarked ones.

Red (or near colours in the spectrum) leg streamers were pecked more often than other colours by Common Grackles *Quiscalus quiscula* (Royall 1977).

Stiles & Wolf (1973), in an evaluation of 2 methods for marking hummingbirds (paint on the back and leg tags), did not observe any change in social behaviour or reproductive activities. Nevertheless, Waser & Calder (1975) reported abnormally loose and flat nests of leg-tagged hummingbirds. Apparently leg tags impaired nest construction and repair.

Dickson *et al.* (1982) evaluated marking techniques for Cardinals. The birds did not show any strong reaction to colour streamers around normal rings, which contrasts with the reaction described by several authors when marking Cardinals with metal rings.

Spottedbacked Weavers *Ploceus cucullatus* marked early in the nesting cycle tended to desert the colony, while those marked late in the nesting season continued their activities (Bruggers 1980).

Willsteed & Fetterolf (1986) used velcro leg tags on gull chicks. The tags were considered not to affect survival.

Flipper bands. Flipper bands have been used on many species of penguin (Sladen & Tickell 1958, Sladen & Penney 1960, Cooper & Mordant 1981, Sallaberry *et al.* 1985). Some feather wear has been reported by Sladen & Penney (1960) and Cooper & Mordant (1981), although in both cases it was slight and did not harm the birds. Nevertheless, Bannash & Oddenig (1981) and Bannash & Lundberg (1984) (both in Sallaberry *et al.* 1985) found that 65% of the birds marked with flipper bands during 1979 and 1980 had wounds by the breeding season of 1981–82. Salaberry *et al.* (1985) present more data on wounded penguins wearing flipper tags and record one case of death due to tags. No consideration seems to have been given to the additional hydrodynamic drag effects that flipper bands may create for swimming penguins.

Web tags. Haramis & Nice (1980) described a method for attaching tags to waterfowl webs, but they did not comment on their effect on the birds. Grice & Rogers (1965) used web tags for marking Wood Ducks *Aix sponsa* ducklings.

A technique to web-tag ducklings in pipped eggs has been described by Alliston (1975). He tested it on 7 species of wild ducks (151 ducklings) and no decrease in hatching success occurred. The process did not affect their survival once they had left the nest.

Others. Toe banding was used by McIntyre (1977) for Great Northern Diver *Gavia immer* chicks. She passed a band through the webbing and around the toe. She notes that the band did not impair movement, have any harmful physical effect, or impede their fledging and survival until the autumn migration.

Wing tags

Adult and juvenile American Coots *Fulica americana* lost weight while wearing patagial tags (Barlett & Rusch 1980). No significant difference in weight between tagged and control birds was found in Band-tailed Pigeons *Columba fasciata* (Curtis *et al.* 1983) or Eastern Willets *Catoptrophorus semipalmatus* (Howe 1980) and no adverse physical effect was observed in raptors and Ravens *Corvus corax* wearing patagial tags (Kochert *et al.* 1983).

Patagial tags did not seem to impair mobility or flight when used on Starlings, Mottled Ducks *Anas fulvigula,* Eastern Willets, Band-tailed Pigeons, egrets or Red Grouse *Lagopus lagopus* scoticus chicks (Hester 1963, Weeks 1972, Boag *et al.* 1975, Howe 1980, Curtis *et al.* 1983, Stiehl 1983, Maddock 1989). Nevertheless, some cranes marked with patagial streamers (Tacha 1979) were reluctant to fly, affecting their migration behaviour.

An initial discomfort has also been described in birds wearing wing marks. This involves frequent preening, body shaking or pecking at the tag for some time after the attachment (Howe 1980, Stiehl 1983, Maddock 1989). For some Ring-billed Gulls *Larus delawarensis* the wing markers were a constant annoyance (Southern & Southern 1983). Knowlton *et al.* (1964) did not observe any discomfort with Turkeys Meleagris gallopavo given wing tags.

Wing tags can cause abrasion of the skin and feather wear (Southern 1971, Mudge & Ferns 1978, Curtis *et al.* 1983, Kochert *et al.* 1983, Hart 1987), although this has not been observed in other studies (Knowlton *et al.* 1964, Hewitt & Austin-Smith 1966, Weeks 1972, Boag *et al.* 1975, Morgenweck & Marshall 1977, Baldasarre *et al.* 1980). Hart (1987) found that using two patagial pins rather than one reduced the amount of feather wear and skin callousing in Herring Gulls *Larus argentatus,* but he also reported three cases of deaths due to wing tags; one bird became entangled with wool around the tag and leg and two trapped primary feathers in the tag fixing pins. Mortality rates for tagged gulls in his study colony were about four times higher than for herring gulls metal ringed at another colony, but breeding success of tagged birds equalled that of unmarked controls in the same colony.

Morgenweck & Marshall (1977) tested the susceptibility to recapture in American Woodcock *Scolopax minor.* No significant difference between wing tagged birds and only ringed birds was found.

Social behaviour can be altered in some species by wing tags. Anderson (1963) observed that 3.4 per cent of the total of tagged Eiders *Somateria mollisima* became solitary. Tacha (1979) also observed this in marked Sandhill Cranes, and those that integrated in a flock were in the lowest levels of the dominance hierarchy. Lockhart & Kochert (1979) documented how Golden Eagles *Aquila chrysaetos* tagged as adults would abandon their territories or be displaced by conspecifics.

Nevertheless, in most of the papers that evaluate or describe a new wing marker or an attachment technique, no effects on behaviour – apart from, in some cases, the initial discomfort described before – have been noted (Hewitt & Smith-Austin 1966, Boag *et al.* 1975, Rowley & Saunders 1980, Howe 1980, Kochert *et al.* 1983, Stiehl 1983). Wallace *et al.* (1980), referring to aggressive behaviour, did not find any difference between tagged and untagged birds.

Although no difference in breeding success was found between wing tagged and ringed birds by Rowley & Saunders (1980), Wallace *et al.* (1980), Kochert *et al.* (1983) or Maddock (1989), some problems that have a negative effect on breeding success have been reported. Golden Eagles tagged as adults can abandon their territories (Lockart & Kochert 1979). Tagged Eiders had a higher rate of nest desertion than ringed ones (Anderson 1963), and Red-winged Blackbirds with wing tags prolonged the interval required to renest (Jackson 1982). Southern & Southern (1983) found that tagged Ring-billed Gulls had smaller broods than ringed ones, but this was not the case in a later study on the same species (Southern & Southern 1985) or for the Willow Ptarmigan *Lagopus lagopus alleni* (Bergerud 1970).

Two long term studies have shown adverse effects of wing tags on the reproductive success of Ring-billed Gulls (Southern & Southern 1985, Kinkel 1989). The results are from one and four years after marking, respectively. In both studies fewer tagged birds returned to the colony site and those that returned arrived later than ringed birds. 60% of the females wearing a wing tag were unable to acquire mates. This did not happen to males. Pair bonds were broken more often when tagged birds were involved. Hatching date was later in tagged birds and a high proportion of them failed to raise any young. Kinkel considers that the tags may interfere in the migration of the birds, as well as having a pronounced long-term effect on their behaviour and reproduction. By contrast, Southern (1971) evaluated a wing tag for the same species and none of these effects were observed.

In one study, the reproductive success of tagged birds (White-tailed Black Cockatoos *Calyptorhynchus funereus*) turned out to be higher than that of untagged ones (Saunders 1982). The authors attribute this result to the age and experience of the birds being different in the two samples.

There have been quite a few studies showing that wing tags may increase mortality (Bolen & Derden 1980, Saunders 1982, Curtis *et al.* 1983). None of the first 29 Eastern Willets marked for Howe's study (Howe 1980), returned to the area the following year (17 had been expected when comparing them with the ringed birds that returned). He suggests that the wing tags may have increased mortality by increasing the drag or by causing abnormal feather replacement during the moult on the wintering grounds. Saunders (1988) obtained a low return rate to the breeding areas of tagged birds: 59% of adult females compared with 100% of unmarked ones. Also immature females that were tagged before fledging had a return rate (4 years later) of 1.3% compared with 12.7% of untagged (ringed) ones.

Szymczak & Ringelman (1986) reported a mortality for tagged female Mallards *Anas platyrhynchos* 15 times that of untagged ones. They observed changes in behaviour of the marked birds that led to changes in the habitat used. The area where they moved was being heavily used by hunters and consequently, the mortality rate increased. If the hunters had not been there, this increase in mortality might not have existed. Bergerud (1970) found equal numbers of marked and unmarked juvenile Willow Ptarmigans shot by hunters.

Anderson (1963), Bergerud (1970) and Rowley & Saunders (1980) found an increase of predation on wing tagged birds. This may be due to the conspicuousness of marked birds or to effects of the marks on the physical condition of the birds (Baldasarre *et al.* 1980). No effect on mortality has been found with wing tagged Red-winged Blackbirds (Cummings 1987) or with Red Grouse chicks (Boag *et al.* 1975).

Havlin (1968) succeeded in fitting miniature wing-tags to ducklings when still in the eggs, during the stage of pipping. He tested the technique on 110 ducklings and coots and reported that the process did not affect the bird's survival.

Back tags

Back tags have been frequently used for game birds (Blank & Ash 1956, Labisky & Mann 1962, Gullion & Marshall 1968, Parker 1981). No physical or behavioural effects were observed by Labisky & Mann (1962) in Pheasants *Phasianus colchicus* (3 died out of 2689). Boag *et al.* (1973) compared the survival of tagged and untagged birds. There was no significant difference between them. Parker (1981) suspected that back tags on nesting Willow Ptarmigan hens might have increased their mortality, although he does not present any data supporting this. Gullion *et al.* (1962) compared the fates of colour ringed Ruffed Grouse *Bonasa umbellus* and back-tagged ones. The latter had a lower chance of survival due to an increased vulnerability to predation. Gullion and Marshall (1968) presented evidence indicating that grey-phase males of this same species marked with back-tags had a lower survival than that of the red-phase. They explain that "the back-tagging made the birds (grey) just as conspicuous as their red-phase brethren, but, because they were inherently less wary, they were taken by predators more readily than the red-phase birds. In these, the conspicuous back-tag did not appreciably alter their chance of survival".

Back tags have also been used in hummingbirds (Baltosser 1978), Blackbirds (Furrer 1977) and young gulls (Cuthbert & Southern 1975). No short-term side effects were observed by Furrer and the chicks did not show any damage to their skin or plumage after the attachment. Some adults removed the tags from their chicks. Although the tags did not seem to attract predators, the authors warn that the possibility of predation should be taken into account when back-tagging birds in an environment where predation is known to occur.

Furrer (1979) described a vertical tag for passerines and he tested it on Starlings and Fieldfares *Turdus pilaris.* The only side effects he observed were some skin abrasion and feather loss that did not seem to affect the birds. The tag did not interfere with flight or affect behaviour.

Neck tags

This technique has been described for gamebirds by Taber (1949), waterfowl by Gullion (1951), pheasants by Nelson (1955) and woodcocks by Westfall & Weeden (1956). It has not been used widely thereafter. An acute tissue reaction to the pin occurred in some American Coots (Gullion 1951). Taber (1949) reported weight loss in Pheasants for a short period after being marked. The marked cocks were successful in establishing territories. He suggests that "cocks do not labour under any important physiological handicap because of being marked", although he warns of the vulnerability to predation of marked birds. No physical or behavioural effects were observed by Westfall & Weeden (1956) in neck tagged Woodcocks.

Neck collars

Neck collars have mainly been used on long-necked waterfowl. Some physical problems have been reported. Ballou & Martin (1964) noted loss of neck feathers when marking Canada Geese *Branta canadensis* with plastic collars, though other authors (Craighead & Stockstad 1956, Maltby 1977, Pirkola & Kalinainen 1984) did not observe any damage to the feathers.

Ankney (1975) suggested that the neckbands worn by Snow Geese *Anser caerulescens* contributed to their death by starvation, although this interpretation has been criticized by Raveling (1976). Some other authors did not detect any physical problem: Lensick (1968), Maltby (1977), Owen (1980), Summers *et al.* (1985).

Canada Geese and Snow Geese have been

seen chewing their collar, and getting their bill stuck in them (Helm 1955, McInnes 1969). Helm (1955) also reported ducks getting their bill stuck in their collars.

As occurs with nasal markers, under severe weather conditions ice can accumulate in the neck collar (McInnes 1969). This can cause the bird's death as reported by Ballou & Martin (1964), Greenwood & Bair (1974) or Zicus *et al.* (1983). These last authors consider that "neckband icing can be a serious mortality factor". They obtained a range of 30% to 68% (for 1979) and 17% to 29% (for 1980) mortality due to neckband icing. Sherwood (1966) and Craven (1979), on the other hand, did not consider this process a significant mortality factor.

An adjustment period may be required by birds fitted with neck collars (Helm 1955). After the attachment, one bird was observed snapping its rubber band repeatedly while preening (Heusmann 1978). On the contrary, Pirkola & Kalinainen (1984) failed to detect any abnormal behaviour.

Although initial adjustment may be required, no long lasting behavioural effects have been found by Helm (1955), Craighead & Stockstad (1956), Ballou & Martin (1964), Maltby (1977), Heusmann (1978), Pirkola & Kalinainen (1984), Johnson & Sibly (1989) or Ely (1990).

Hawkins & Simpson (1985) describe an aggressive reaction against a marked Tundra Swan *Cygnus columbianus* by a conspecific. Eventually, the marked bird flew away and did not go back to the area during that breeding season. Aggressive interactions have also been observed by Neumann (1982). Black-headed Gulls *Larus ridibundus* marked with collars were isolated by other members of the group (unmarked). The author suggests that "acclimatisation to this type of conspicuous behaviour in fellow members of the species, if possible at all, is only so in the long term".

Neckbands can also affect the courtship behaviour in Brent Geese *Branta bernicla* (Abraham & Ankney 1983). The neckbands used could cover the necklace (important in threat displays, which, in turn, establish the rank of competing birds) or increase the amount of white – contrast – on the bird's neck. If the pattern of the bird's neck is important in mate choice or in individual recognition, the band could interfere in these processes. The authors point out that, eventually, these problems can make marked birds have lower productivity than unmarked ones because they would have lower success in agonistic encounters. In fact, Lensick (1968) found that Black Brant *Branta bernicla nigricans* with neckbands had a significantly lower nesting success than that of leg ringed controls or unmarked birds.

In other geese (Sherwood 1966, Chabrec & Shoer 1975, McInnes & Dunn 1988) and in American Coots (Barlett & Rusch 1980), no effect on reproductive success has been observed. Johnson & Sibly (1989) reported a tendency for collared Geese to have a higher breeding success than uncollared ones, but they think this can be attributed to the greater age and experience of collared individuals in their sample.

Heusmann (1978) considered that the presence of collars on nesting Wood Ducks could have been the cause of nest abandonment.

Another important mortality factor can be the selection by hunters of marked individuals (Craven 1979), although McInnes & Dunn (1988) found the opposite result working on geese as well. Heusmann (1978) did not find differences in survival indices between marked and unmarked Wood Ducks. Barlett & Rusch (1980) found a difference in duck survival, but they attributed it to the method used. Finally, McInnes & Dunn (1988) suggest that the lower frequency of capturing neckbanded geese on the nesting grounds (compared with that of leg ringed individuals), could result from increased mortality, or emigration of neck banded geese.

Nasal marks

Nasal discs and saddles have mainly been used for ducks and geese. No physical or behavioural effect has been found on Shovelers *Anas clypeata* (Sugden & Poston

1968), Canada Geese (Raveling 1969), Marabou Storks *Leptoptilos crumeniferus* (Pomeroy 1975), Mallards (Byers & Montgomery 1981) or Barrow's Goldeneyes *Bucephala islandica* (Savard 1988).

Most of the problems reported are generally physical. One of these is the entanglement of the marking device (Evrard 1986), which can cause injuries to the bird's nostril (Sherwood 1966) or its death (Lee 1960). Nevertheless, this has not been reported in most of the studies using nasal markers.

Erskine (in Bartonek & Dane 1964) considered that caution was necessary in using nasal discs for diving ducks, but Bartonek & Dane themselves did not find any impairment of diving ducks wearing nasal discs.

Under severe winter conditions, ice accumulated on the nasal marks can have negative effects (Byers 1987). He reports that 2 to 32% of Mallards developed ice on their nasal saddles; the figure was correlated with windchill conditions. The weight of the ice on the mark can be high enough to cause the death of the animal (Greewood & Bair 1974), although birds appeared able to de-ice the nasal saddles in most instances.

Difficulty in dislodging leeches from the nares when wearing a nasal saddle has been seen in Teals *Anas crecca* by McKinney & Derrickson (1979). The birds increased the time spent scratching, more during feeding (when the leeches enter the nares), than during preening or resting. Apart from this increase in scratching, they did not observe any other behavioural abnormality.

Some discomfort has been reported following the attachment of the mark, though after a short period the birds got used to them and behaved apparently normally (Lee 1960). Thus, Bartonek & Dane (1964) observed Blue-winged Teals *Anas discors* dipping their bills into the water and forcing the air out through their nostrils, occasionally shaking their heads, or their nasal discs being pecked by other individuals. Koob (1981) observed that Ruddy Ducks *Oxyura jamaicensis* wearing nasal saddles spent more time in maintenance activities and less in locomotory ones. These birds suffered from behavioural differences as well. The marked birds were less successful in obtaining mates than unmarked ones. Female Ruddy Ducks seemed to prefer males without the mark. Five males that were paired previously to the attachment of the saddle, lost their mates to unsaddled males within 2 hours. The author suggests that these effects may be due to the Ruddy Duck being a small species, and that this does not necessarily happen in bigger duck species. For instance, Lee (1960) followed the breeding of Canada Geese marked with nasal markers and did not observe any apparent effect on their breeding behaviour. Also Bartonek & Dane (1964) did not detect any effect on pair formation of Blue-winged Teals with nasal discs.

Reproductive success was not affected in Canada Geese (Lee 1960), Long-tailed Ducks *Clangula hyemalis* (Alison 1975) or Pacific Black Ducks *Anas superciliosa,* Grey Teals *Anas gibberifrons* and Chestnut Teal *Anas castanea* (Davey & Fullagar 1985), although Doty & Lee (1974) found a lower success (83%) in Mallards in the year of attachment of the mark than in subsequent years (90%).

Bartonek & Dane (1964) found no significant difference in mortality between marked and unmarked birds, though Erskine (in Bartonek & Dane 1964) found that, after a year, sawbills *Mergus spp.* marked with nasal discs had a recovery rate less than half of that for untagged ringed birds, suggesting a high mortality of birds with nasal discs in the first months after marking.

Dyes

Dyes can be very useful, not only to provide individual or group markings, but also to increase recovery rates. Handel & Gill (1983) estimated that Western Sandpipers *Calidris mauri* that had been dyed yellow were about 16 times more likely to be seen by observers than birds that had only been colour ringed. However, dyes can cause an initial discomfort. Birds may spend much time preening the painted feathers (Moffitt 1942, Swank 1952, Stiles & Wolf 1973, Dickson *et al.* 1982). It is well known that dyes in organic solvents present a potential risk to birds from solvent fumes, so that good ventilation is important while dyes dry. No research seems to have been done to assess any influence of dye–marking on aerodynamic drag of birds, or on buoyancy of waterfowl or seabirds after application of dyes. Anecdotal evidence suggests that picric dye, or alcohol used as a solvent, or physical disturbance to the body plumage may cause ducks to sink in water, at least if they enter water before preening, as is usually the case when waterfowl or seabirds are released after dye–marking (R.W. Furness pers. obs. of Goosanders *Mergus merganser,* Eiders, Fulmars *Fulmarus glacialis* and auks).

The main problem caused by dyes seems to be the consequences of colour change. Bennet (1939), working with captive doves, noted changes in the behaviour of marked birds. The social hierarchy of the flock was upset by the colouring of some individuals. Neumann (1982, 1985) has presented evidence of how dyeing feathers can alter social behaviour in Black–headed Gulls. Marked birds were attacked by conspecifics, and were isolated. The time it took before the bird reintegrated into the group, and the degree of violence of the attacks, varied with different markings. A gull extensively painted in pink was still being attacked 11 days after marking it (Neumann 1982).

Raveling (1969) used dyes on Canada Geese and did not observe any social rejection of the marked individuals. The same was reported by White *et al.* (1980) marking Blackbirds and Starlings, and by Brown & Brown (1988) marking Cliff Swallows *Hirundo pyrrhonota.*

In a few studies, important impacts on reproductive success have been documented. Noble (1963) painted male moustache markings on female Flickers, affecting sex recognition. Oystercatchers *Haematopus ostralegus* copulated more often after marking compared to normal conditions (Neumann 1985). The use of yellow markers on females Mourning Doves' *Zenaida macroura* heads altered pair bonds (Frankel & Baskett 1963). Once the nesting stage had started, marked Black–headed Gulls abandoned their nests or brood more frequently than their non-marked partners: ringed birds without dyed feathers were used as controls, so this side effect is not the result of capturing and handling, but of the colour marking (Neumann 1985).

In Tree Swallows, female subadults had the same probability as female adults of deserting after being ringed and having their feathers dyed. Other authors have also failed to find a higher nest desertion rate among birds with their feathers dyed (Mossman 1960, Paton & Planck 1986, Rodgers 1986, Reynolds 1987).

Dyes have also been used for Red–winged Blackbird chicks (Haigh 1968), Hen Harrier *Circus cyaneus* chicks (Picozzi 1980) and egret chicks (Ploger & Mock 1986). The relationship among siblings or between the chicks and their parents was not upset by the colour marks.

A technique for dying embryos has been used by Evans (1951) and Rotterman & Monnett (1984). In neither of the studies was the embryo mortality increased significantly. Rotterman & Monnett weighed the marked and unmarked nestlings, not finding any significant difference between groups. The same result was obtained when considering the probability of predation during the nestling stage. In spite of these results, the authors consider that this does not necessarily happen in other birds. So, it should be borne in mind that nestlings marked with certain colours might be rejected, and that an increase in conspicuousness could attract some predators. The latter was reported by Eklund (1961) who showed that dye–marked downy South Polar Skua *Catharacta maccormicki* chicks were more likely to be eaten by predators (conspecifics) than were naturally–coloured chicks.

Other marks

Adhesive tags on the bird's head have been used on Mourning Doves (Goforth & Baskett 1965) and on nestling Pied Flycatchers *Ficedula hypoleuca* (Gottlander 1987). Pair bonds were disrupted when using yellow markers on female Mourning Doves' heads during the first attempts to incubate. They did not observe any effect on male's behaviour or in either sex when they used other colours or other locations for the markers. No changes in behaviour were observed by Gottlander.

Yellow markers on Pheasants seemed to attract predators, and more birds were killed when wearing yellow markers than other colours (Kessler 1964).

Poncho markers have been used for game birds. They can interfere with the air exchange in displaying male Sage Grouse *Centrocercus urophasianus* (Pyrah 1970) or contribute to the mortality of the birds (1–2%) when they get their bill stuck into the poncho (Biadi 1973). He also observed that the poncho was an impediment when the birds wanted to put their head under the wing to sleep; and birds became stuck in bushes or wire nets.

Wright (1939) described a marking technique by imping feathers. This has been used to colour mark birds, adding coloured feathers to the bird's feathers (Bendell & Fowle 1950), and to make the bird's feathers longer (Andersson 1982). Andersson's study of Widowbirds *Euplectes sp.* showed that individuals with longer tails can increase their breeding success at the expense of normal ones because they are preferred by females.

Heydweiller (1934), Edminster (1938) and Leopold *et al.* (1938) attached a bright coloured feather to a birds' tail feather. Tripensee (1941), Ritchison (1984) and Best (1990) used a similar method but, instead of attaching a feather, they attached a tag or tape. The last author did not observe any side effect. The others do not make any comment on the possible effects of the markers on the birds, either in terms of aerodynamic drag (which might be considerable) or of influences on mate choice.

Data loggers

In this section we consider different data logging devices and their effects on birds. Various recorders have been used on Adélie *Pygoscelis adeliae* and Jackass *Sphenicus demersus* Penguins and some negative effects of these and of human disturbance have been reported in detail by Wilson & Wilson (1989a, 1989b), Wilson *et al.* (1989, 1990, 1991). Wilson *et al.* (1989) describe a method to determine the number of pecks directed to devices as a measure of abnormal behaviour due to it. They used this to determine which package colour was best accepted by Adélie Penguins (Wilson *et al.* 1990) and to assess the effect of attaching devices of different size (Wilson *et al.* 1989). Culik & Wilson (1991) tested the effects of implanted and external instruments on the swimming performance and energy consumption of Adélie Penguins, showing that both systems have a pronounced negative effect on the variables measured, and reviewing the likely effects of similar packages used in other studies.

Altimeters. A device attached to the bird's back for measuring flight altitude was described by Gustafson *et al.* (1973). It has been used on homing Pigeons & Swifts *Apus apus* (Gustafson *et al.* 1973, 1977, Kristiansson *et al.* 1977). The effects of the device on the birds, if any, are not described in these papers.

Activity recorders. Lefebvre *et al.* (1967) developed a device to measure the time spent in flight by birds, but they did not test it on free–flying birds. An activity recorder based on it was used by Prince & Francis (1984) to study the foraging activity budgets of Grey headed Albatrosses *Diomedea chrysostoma*. There are no comments on possible effects on the birds in either of these papers.

A different activity recorder for measuring attentiveness to the nest was described by Morris & Hunter (1976). They found no significant difference in parental behaviour of experimental and control birds.

Electronic activity recorders based on watches have been described by Cairns *et al.* (1987a, 1987b) and tested on Guillemots *Uria aalge* and Gannets *Sula bassana*. The device did not seem to affect the birds' locomotor activities or their behaviour. Cairns *et al.* (1987a) warn that "instruments carried by pursuit diving animals may alter diving ability through hydrodynamic drag". Cairns *et al.* (1987b) estimated that the instrument they were using increased the costs of flight by 6%, requiring a consumption of 11% of the available surplus power, but did not quantify additional costs of swimming.

Gales *et al.* (1990) used electronic activity recorders to study the foraging behaviour of the Little Penguin *Eudyptula minor.* They found that tagged birds had a significantly lower water influx and metabolic rates. Foraging efficiency decreased even when small attachments were used. Anderson *et al.* (1991) describe a miniature recorder to study plunge–diving seabirds, but they do not consider its possible effects.

Wilson & Wilson (1988) used a remote–sensing device that gave information on swimming speed and heading of the birds. Nine Jackass Penguins were tagged and all of them returned in good condition.

Distance meters. A distance meter for large marine animals was described by Wilson & Achleitner (1985), and its effects are considered by Wilson *et al.* (1986).

Depth recorders. Different kinds of depth recorders have been described by Kooyman *et al.* (1983) for marine birds and mammals, Wilson & Bain (1984a) for penguins and Montage (1985) for Little Penguins. These devices have mostly been used on penguins: Kooyman *et al.* (1971, 1982), Adams & Brown (1983), Lishman *et al.* (1983), but also for Puffins *Fratercula arctica,* Shags *Phalacrocorax aristotelis,* Razorbills *Alca torda,* Common and Brunnich's Guillemots *Uria lomvia* (Burger and Simpson 1986, Barrett & Furness 1990, Wanless *et al.* 1991).

The depth gauges described by Wilson & Bain (1984) were tested by the authors on 32 penguins which seemed unaffected by the device. It has been assessed by Burger & Wilson (1988) and used by Barrett and Furness (1990). Wanless *et al.* (1991) used depth gauges for studying diving depths of Shags and they considered that the cross–sectional area of the gauges would have little effect on the diving behaviour. They consider that the small size of the gauges avoids some problems associated with larger devices.

Croxall *et al.* (1988) compared the mass of prey taken ashore by tagged and untagged Gentoo Penguins *Pygoscelis papua* and Macaroni Penguins *Eudyptes chrysolophus,* and did not find a significant difference between them. They estimated that the cross–sectional area of the depth histogram recorder they used would reduce travelling speed by 9% (5%–6% in the larger Gentoo Penguins).

Speed meters. Wilson & Bain (1984b) described a speed meter for penguins at sea. The device was tested on 25 birds and no apparent adverse effect was observed. Speed meters have also been used on penguins by Nagy *et al.* (1984) and Adams *et al.* (1988).

Wilson *et al.* (1986) used speed meters to test the effect of recording devices on the foraging performance of Jackass Penguins, showing that the recorders significantly reduced swimming speed. They pointed out the need to alter streamlining as little as possible by keeping the device volume and cross–sectional area to a minimum. The same result was obtained for Gentoo and Adélie Penguins (Wilson *et al.* 1989).

Radio transmitters

Kenward (1987) reviewed different attachment methods and their effects on birds. Other papers deal with telemetric technique for animals in general (Tester 1971, Macdonald & Amlaner 1980, Cheeseman & Mitson 1982, Mech 1983) for birds (Marion & Shamis 1977), grouse (Lance & Watson 1978), owls (Nicholls & Fuller 1987) and galliformes (Hill & Robertson 1987).

In Table 2 we have summarized the different adverse effects reported in the 187 papers reviewed for this section. For each one we give the number of papers where the effect has been found, the number in which it is specifically said that it has not been found, and those in which the effects are not considered. 24% of the papers do not consider any possible deleterious effects of the package.

Many of the papers that comment on general behaviour or physical condition do not find adverse effects (Giroux *et al.* 1990, Hill & Talent 1990). The most reported effect is an initial discomfort (Dwyer 1972, Dumke & Pils 1973, Nenno & Healy 1979, van Dyke 1981,

Table 2. Effects of radio transmitters on birds as indicated in 171 papers published in Auk, Ibis, Journal of Applied Ecology, Journal of Wildlife Management and Ornis Scandinavica.

Effects	*Some effects*	*No effects*	*Not reported*
Initial discomfort	28	4	155
Injuries	3	7	177
Feather wear/loss	6	1	180
Weight loss	3	5	179
Transmitter drag	12	1	174
Locomotion	8	16	163
Aerial or transmitter removed/broken	6	1	180
Mandible caught in neck–collar/harness	3	0	184
Effect of harness	6	1	180
Dispersal	0	1	186
Habitat use/choice	0	5	182
General behavioural/physical effects	10	41	136
Foraging behaviour	8	6	173
Reproductive behaviour	8	18	161
Reproductive Success	4	12	171
Brood size	0	2	185
Nest/brood desertion	5	1	181
Growth rate	1	3	183
Metabolic rate	2	0	185
Survival	14	13	160
Predation	7	3	177
Survival+predation	21	16	150

Perry *et al.* 1981, Johnson & Caslick 1982, Iverson *et al.* 1985, Watson 1985, Kirby & Cowardin 1986) that can last from a few minutes (Smith & Gilbert 1981) up to a few weeks (Siegfried *et al.* 1977), though usually the birds recovered normal activity 2 to 7 days after attachment. This discomfort is mainly shown as an increase in preening activity and pulling at the device. The device can be such an annoyance for some birds that they may end up breaking part of it or even removing it (Raim 1978, Morris & Black 1980, Perry 1981, Slaugh *et al.* 1989, Sorenson 1989). It can affect locomotion (Graber & Wunderle 1966, Greenwood & Sargeant 1973, Bray *et al.* 1975, Smith *et al.* 1983), food consumption (Boag 1972) or display (Hirons & Owen 1982).

Other physical problems include skin abrasion due to the attachment, feather wear or loss, external and internal injuries, impairment of movement, and weight loss (Appendix 1).

To minimize bias it has been suggested that transmitters should weigh less than 5% of the weight of a small bird (Hill & Robertson 1987), and a smaller percentage for large birds (Hedin & Caccamise 1982, Caccamise & Hedin 1985). However, Pennycuick *et al.* (1989) suggest that the acceptable radio mass for birds should be expressed as a fraction of the food load mass they can carry, not as a percentage of the body mass.

Gessaman & Nagy (1988) calculated the metabolic rate of homing Pigeons *Columba livia* during long distance flights and found that the birds produced 90% more carbon dioxide when fitted with a transmitter and harness weighing less than 5% of the bird's body weight. The flight speed was 15% slower when covering a distance of 90 km with a transmitter attached by glue, and more than 31% slower when wearing a transmitter fitted by a harness. An experiment carried out in a wind tunnel by Obtrecht *et al.* (1988) showed how radio transmitters can increase the drag of the bird. Nevertheless, Sedinger *et al.* (1990) did not find any effect of transmitters on Black Brant energy expenditure or on changes in body mass.

Transmitters can alter the bird's breeding behaviour or their breeding success (Amlaner *et al.* 1978), though many authors have not reported any such effects. As with other markers, the time of capturing and marking during the reproductive cycle can cause different effects. Kuck et al. (1970) and Wanless *et al.* (1985) found that birds were more prone to desert their nests when trapped and fitted with a transmitter when laying or incubating, while this rarely occurred later in the breeding cycle.

Only a few authors have looked at the brood size of equipped birds and the growth rates of their chicks. Pennycuick *et al.* (1989) suggest that the weight of the radio transmitter may affect the chick's growth rate by a reduction of prey delivered by their parents. Radio–tagged Guillemots and Razorbills *Alca torda* brought fewer fish to their chicks (Wanless *et al.* 1988a, 1988b), returned more often without a prey for their chicks, made longer foraging trips than those of control birds (Wanless *et al.* 1989, 1990). Swallows *Hirundo rustica* also made fewer but longer foraging trips when attached with a radio transmitter (Brigham 1989).

Survival can be reduced due to the weight of the transmitter or the method of attachment method (Hessler *et al.* 1970, Johnson & Berner 1980, Hirons and Owens 1982, Angelstam 1984, Small & Rusch 1985, Pekins 1988, Conroy *et al.* 1989, Eberhard *et al.* 1989, Marcström *et al.* 1989, Slaugh *et al.* 1989, Sorenson 1989). In some cases authors have demonstrated an increased vulnerability to predation (Hessler *et al.* 1970, Erikstad 1979, Odom *et al.* 1982, Marks & Marks 1987) or to hunting (Schultz *et al.* 1988).

DISCUSSION

This long review has found many examples of marks and devices influencing the behaviour of birds, and in some cases reducing their survival rates. It would be wrong to suggest that these examples should be used to argue against marking of birds. There are, of course, tens of thousands of scientific studies where no such effects appear to have occurred. We ourselves use rings, colour rings, dyes, depth recorders, radio transmitters and other devices on birds and we believe that in the vast majority of studies using such methods biases in the data and hazards to the birds are negligible.

However, this review shows that marking techniques may have a wide range of effects on birds, from a short term discomfort to effects on breeding and survival. Some general points seem to emerge. For example, hydrodynamic drag is more critical than mass when designing devices to study diving behaviour of penguins, harnesses cause more problems in radio telemetry studies than attachment to feathers, wing tags are particularly problematical on migratory birds, and so on. In many cases it has been possible to reduce harmful effects by careful design of the mark, in terms of its hydrodynamic drag, its colour, position of attachment, mass, season of application and so on. It is obviously to the benefit of researchers, as well as the birds they study, if marking can be done in a way that minimizes the risk of altering ther normal behaviour and ecology of birds. We consider it is desirable that bodies regulating marking of birds should encourage research specifically to assess effects of marks and devices; such work could readily be carried out in association with current research programmes. For example, professional researchers may use dyes on seabirds to study their foraging ranges from a colony but it would be appropriate for an adjunct study to be set up into the time budgets and social interactions of dye–marked individuals compared to controls, making use of the same marked birds. A greater body of detailed data collected with the specific aim of testing for effects of marks would improve confidence in the suitability of these techniques for bird research.

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APPENDIX

Reported effects of radio transmitters on birds

General (initial discomfort not included)

Alonso et al. 1987, Amstrup 1980, Anderson & Ricklefs 1987, Anglestam 1984, Archibal 1975, Brander 1968, Bray et al. 1975, Cochran 1972, Cochran et al. 1967, Diehl et al. 1986, Dumke & Pils 1073, Dunstan 1972, Dwyer 1972, East & Hofer 1986, Enderson & Kirven 1983, Erikstad 1979, Fuller & Tester 1973, Gilmer 1974, Heath 1987, Herzog & Boag 1978, Hessler et al. 1970, Hines & Zwickel 1985, Hirons 1980, Hudgins et al. 1985, Jordan 1988, Karl & Clout 1987, Kenward 1978, Lance 1970, Marshall & Kupa 1963, Martin 1978, Maxon 1978, McCrary 1981, Melvin et al. 1983, Nenno & Healy 1979, Nesbitt et al. 1982, Nicholls & Barner 1968, Nicholls & Warner 1972, Perry et al. 1981, Raim 1978, Rohwer 1985, Sayre et al. 1981, Slaugh et al. 1989, Smith & Gilbert 1981, Snyder et al. 1989, Wanless et al. 1988b, Watson 1985, Ward et al. 1986, Widen 1982, Wilson et al. 1989b.

Initial discomfort
Amlaner et al. 1978, Boag 1972, Bray & Corner 1972, Bray et al. 1975, Diehl 1986, Dufty 1982, Dumke & Pils 1973, Dwyer 1972, Dyke 1981, Gilmer 1974, Graber & Wunderle 1966, Greenwood & Sargeant 1973, Hirons & Owens 1982, Iverson et al. 1985, Johnson & Caslik 1982, Kirby & Cowardin 1986, McCrary 1981, Morris & Black 1980, Nenno & Healy 1979, Perry 1981, Perry et al. 1981, Raim 1978, Schultz et al. 1988, Siegfreid et al. 1977, Smith & Gilbert 1981, Smith et al. 1983, Sorenson 1989, Watson 1985, Williams 1974, Wooley & Owen 1978.

Skin abrasion/injuries/feather wear/feather loss
Amstrup 1980, Anderson & Ricklefs 1987, Diehl 1986, Gilmer 1974, Greenwood & Sargeant 1973, Hessler et al. 1970, Hines & Zwickel 1985, McCrary 1981, Nicholls & Warner 1968, Nicholls & Warner 1972, Pekins 1988, Perry 1981, Wanless et al. 1985.

Weight loss
Diehl et al. 1986, Erikstad 1979, Greenwood & Sargeant 1973, Johnson & Berner 1980, Kenward 1978, Perry 1981, Raim 1978, Royall & Bray 1980.

Aerial/transmitter removal or broken by birds
Karl & Clout 1987, Morris & Black 1980, Raim 1978, Royall & Bray 1980, Slaugh et al. 1989, Sorenson 1989, Watson 1985.

Mandible caught in neck radio collar/harness
Hirons & Owen 1982, Sorenson 1989, Wallestad & Schladweiler 1974.

Effect of harness
Heath et al. 1989, Hessler et al. 1970, Hines & Zwickel 1985, Hirons & Owen 1982, Kenward 1985, Kenward et al. 1982, Slaugh et al. 1989.

Transmitter weight – drag
Amlaner et al. 1978, Caccamise & Hedin 1985, Hedin & Caccamise 1982, Hill & Robertson 1987, Johnson & Berner 1980, Michener & Walcott 1966, Nesbitt et al. 1978, Obrecht et al. 1988, Pennycuick & Fuller 1987, Pennycuick et al. 1989, Slagle 1965, Sibly & McCleery 1980, Snyder 1985, Warner & Etter 1983.

Locomotion
Diehl 1986, Dufty 1982, Dwyer 1972, Dunstan 1972, Greenwood & Sargeant 1973, Heath et al. 1989, Herzog & Boag 1978, Hessler et al. 1970, Jackson et al. 1977, Jordan 1988, Lord et al. 1962, Marks & Marks 1987, Melvin et al. 1983, Michener & Walcott 1966, Morton 1989, Owen & Morgan 1975, Pekins 1988, Perry 1981, Raim 1978, Royall & Bray 1980, Schultz et al. 1988, Slagle 1965, Woakes & Butler 1984.

Habitat choice/use
Boag 1972, Dwyer 1972, Gilmer 1974, McCrary 1981, Siegfreid et al. 1977.

Foraging behaviour
Anderson & Ricklefs 1987, Boag 1972, Brigham 1989, Jackson et al. 1977, Karl & Clout 1987, Massey et al. 1988, Nesbitt et al. 1982, Pennycuick et al. 1989, Perry 1981, Siegfreid et al. 1977, Swanson et al. 1976, Wanless et al. 1988a, Wanless et al. 1988b, Wanless et al. 1991.

Metabolic rate/enegetic costs
Hedin & Caccamise 1982, Gessaman & Nagy 1988, Obrecht et al.1988, Sedinger et al. 1990.

Breeding ecology
1.Breeding behaviour.
Amlaner et al. 1978, Archibal 1975, Brander 1968, Dwyer 1972, Gilmer 1974, Herzog & Boag 1978, Hirons 1980, Jordan 1988, Kis et al. 1989, Karl & Clout 1987, Lance 1970, Morris et al. 1981, Nesbitt et al. 1978, Raim 1978, Ramaka 1972, Sayre et al. 1981, Siegfreid et al. 1977, Smith & Gilbert 1981, Sorenson 1989, Wallestad & Schladweiler 1974, Wanless et al. 1985, Wanless et al. 1988b, Wanless et al. 1990, Wanless et al. 1991, Ward et al. 1986, Wegge & Larsen 1987.
2.Breeding success.
Amlaner et al. 1978, Ball et al. 1975, Enderson & Kirven 1983, Erikstad 1979, Green 1984, Hines & Zwickel 1985, Johnson 1971, Karl & Clout 1987, McCrary 1981, Massey et al. 1988, Pennycuik et al. 1989, Sibly & McCleery 1980, Taylor 1991, Wanless et al. 1988a, Wanless et al. 1988b, Wanless et al. 1989, Wanless et al. 1990, Wanless et al. 1991, Warner & Etter 1983.
3.Nest/Brood desertion.
Kuck et al. 1970, Horton & Causey 1984, Massey et al. 1988, Wallestad & Schladweiler 1974, Wanless et al. 1985, Ward et al. 1986.

Predation
Erikstad 1979, Hessler et al. 1970, Horton & Causey 1981, Marks & Marks 1987, McEwen & Brown 1966, Odom et al. 1982, Rappole et al. 1989, Siegfreid et al. 1977, Slaugh et al. 1989, Sorenson 1989.

Survival
Anglestam 1984, Conroy et al. 1989, Eberhardt et al. 1989, Erikstadt 1979, Herzog 1979, Hessler et al. 1970, Hines & Zwickel 1985, Hirons & Owen 1982, Horton & Causey 1981, Johnson 1971, Johnson & Berner 1980, Kirby & Cowardin 1986, Lance 1978, Marcström et al. 1989, Morris et al. 1981, Pekins 1988, Ringleman & Longcore 1982, Schladweiler & Tester 1972, Schultz et al. 1988, Slaugh et al. 1989, Small & Rusch 1985, Snyder 1985, Snyder et al. 1989, Sorenson 1989, Speake et al. 1985, Warner & Etter 1983, Wegge & Larsen 1987, Wiley & Causey 1987.