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REVIEW Because of its applied character, wildlife science needs opportunities to summarise existing knowledge by reviewing, either by presenting leading ideas and results of study teams, or summarising advanced knowledge of selected scientific or management problems. Reviews should be concise.

The biology of canada geese *Branta canadensis* in relation to the management of feral populations

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Feral populations of the canada goose *Branta canadensis* continue to grow at around 8% per year in the UK. The growing feral populations in Europe and non-migratory populations of 'urban' canada geese in North America are beginning to conflict with human interests. In response to increasingly frequent calls for control of this species, we review the scientific literature concerning the biology of feral populations in an attempt to determine why such rapid population growth has occurred. We also examine the available evidence about the problems caused by canada geese and the published information on the management techniques already tested. Feral canada geese are highly fecund, producing up to six young per pair, and have high fledging success. This allows populations to continue to grow even in areas with high levels of mortality in both adult and immature birds, mostly as a result of shooting. Population growth has been most rapid in urban areas with little shooting pressure and correspondingly low adult mortality. Site faithfulness, particularly in females, has probably slowed the spread of canada geese to new habitats, many of which have been created by man. Many apparently suitable sites remain unoccupied at present, and the factors which govern the carrying capacity of existing sites are not fully understood. The upper limits to the growth of feral populations are therefore difficult to estimate, but there is little evidence that density-dependent factors are acting to regulate population size except at long-established breeding sites. Canada geese can cause damage to agricultural crops and amenity areas resulting in significant localised economic loss particularly in areas close to water bodies. In most countries the extent and cost of the damage caused has not been fully evaluated, and evidence in support of the need for control on a national or international level is currently weak. Work on the impact of canada geese on other waterfowl and on the possibility that they may transmit diseases to humans is continuing. In Britain, research into management has concentrated on reproductive control by treatment of eggs. Results have shown that, even if the control is highly efficient, it takes a number of years for any reduction in the population size to occur. Most researchers suggest that reproductive control needs to be combined with an increase in adult mortality if the population size at a site is to be reduced in an acceptable time. We suggest that Integrated Management Strategies (combining habitat management, behavioural modification of the birds e.g. by scaring and, where necessary, by population reduction) need to be developed. These strategies should be specific to the particular location concerned. Current research in progress in the UK is summarised and areas where further research is needed both to quantify the problem and develop effective management strategies are identified.

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The canada goose *Branta canadensis* is native to North America where a number of morphologically different races exist (Delacour 1959, Palmer 1976, Madge & Burn 1988). There is considerable overlap between the races, but the birds tend to be smaller and darker towards the north and west of the breeding range, and larger and paler towards the south and east. Most of the races are highly migratory, breeding in Canada and the northern states of the USA and wintering as far south as Texas. Recent years have seen the establishment of many non-migratory populations of canada geese in the USA. These birds are from the larger races (e.g. the giant canada goose *B.c. maxima*) and are usually resident in city suburbs where they graze on lawns and other amenity grassland areas and breed on ponds and ornamental lakes (Addison & Armernic 1983, Laycock 1984). Urban canada geese are now causing significant problems in the USA (Addison & Amernic 1983).

Canada geese were first introduced to the UK as an addition to the waterfowl collection of King Charles II in St. James's Park, London in 1665. Introductions to waterfowl collections elsewhere in London, Norfolk, Yorkshire and Nottinghamshire followed (Owen 1983). The morphology and colouration of the current British population suggests that the original introductions were from the larger southeastern races: the nominate *B. c. canadensis* and the giant canada goose *B. c. maxima*; included in *B. c. moffitti* by some (e.g. Palmer 1976). Natural vagrancy also occurs, but its true extent is masked by the presence of the large feral population.

The population remained relatively small (<4,000) until the 1950s when the first deliberate relocation of birds occurred. At least 700 birds were moved by the Wildfowl Trust (now The Wildfowl & Wetlands Trust) to relieve local agricultural problems (Ogilvie 1969). Many hundreds were also translocated to provide sport shooting in southern Britain by the Wildfowlers Association of Great Britain and Ireland (now the British Association for Shooting and Conservation) (Ruxton 1962). These forced movements, which acted to break the natal-site fidelity of the geese, together with the creation of wetland areas combining breeding lakes with feeding areas within walking distance for the flightless goslings (e.g. following construction of reservoirs in proximity to farmland, or reinstatement of gravel workings as amenity areas and nature reserves), are thought to have enabled rapid population growth.

Total population size is best assessed during the moult period when most birds are flightless. The first organised moult census in Britain was carried out in 1953, when a population size of 2,200-4,000 was estimated (Blurton-Jones 1956). Discrete subpopulations were apparent, probably with little or no movement between them. Surveys in 1967-1969 provided an estimate of 10,500, with occupation of many new localities (Ogilvie 1969). A census in 1976 produced 19,400 (Ogilvie 1977), whilst 63,581 were recorded in 1991(220% more than in 1976) (Delany 1992, 1993). The average growth rate since 1976 has been 8% per year (Delany 1992). The national population index for winter numbers of canada geese since 1966 (Fig. 1) shows a steady increase over the period which corresponds with the count data from the summer surveys of moulting flocks. The winter distribution of canada geese in Britain since 1960 (Fig. 2) shows that the population has continued to increase its geographic range as numbers have risen.

As the size and range of the British canada goose population has increased, conflicts with human interests have become more frequent and the first calls for control, by the Wildfowl Trust, were made in the 1960s. The number of requests to the Ministry of Agriculture for licences to control canada geese has increased from 35 in 1988 to 111 in 1993 and calls for a national strategy to reduce the population size and/or prevent further spread are now commonplace amongst landowners, municipal authorities and some biologists.

Damage by canada geese has rarely been quantified, nor financially evaluated, and no national assessment has ever been attempted in the UK. There is, however, no doubt that localised damage can be severe and incur significant costs to the farmer or landowner (Simpson 1991). Many individuals and interested groups remain implacably opposed to the management of canada geese if this involves the destruction of birds, whilst most conservation organisations require better scientific proof of damage before supporting a national management programme. In the meantime, those bearing the cost of accommodating increasing numbers of geese grow impatient. Elsewhere, the establishment of large, non-migra-

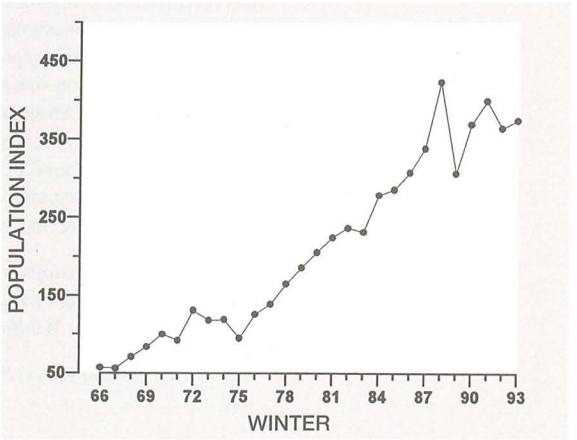

Figure 1. National population index for the winter numbers of canada geese in Britain between 1966 and 1993, based on data collected between September and March for the annual Wetland Bird Survey. See Kirby et. al (1995) for further details.

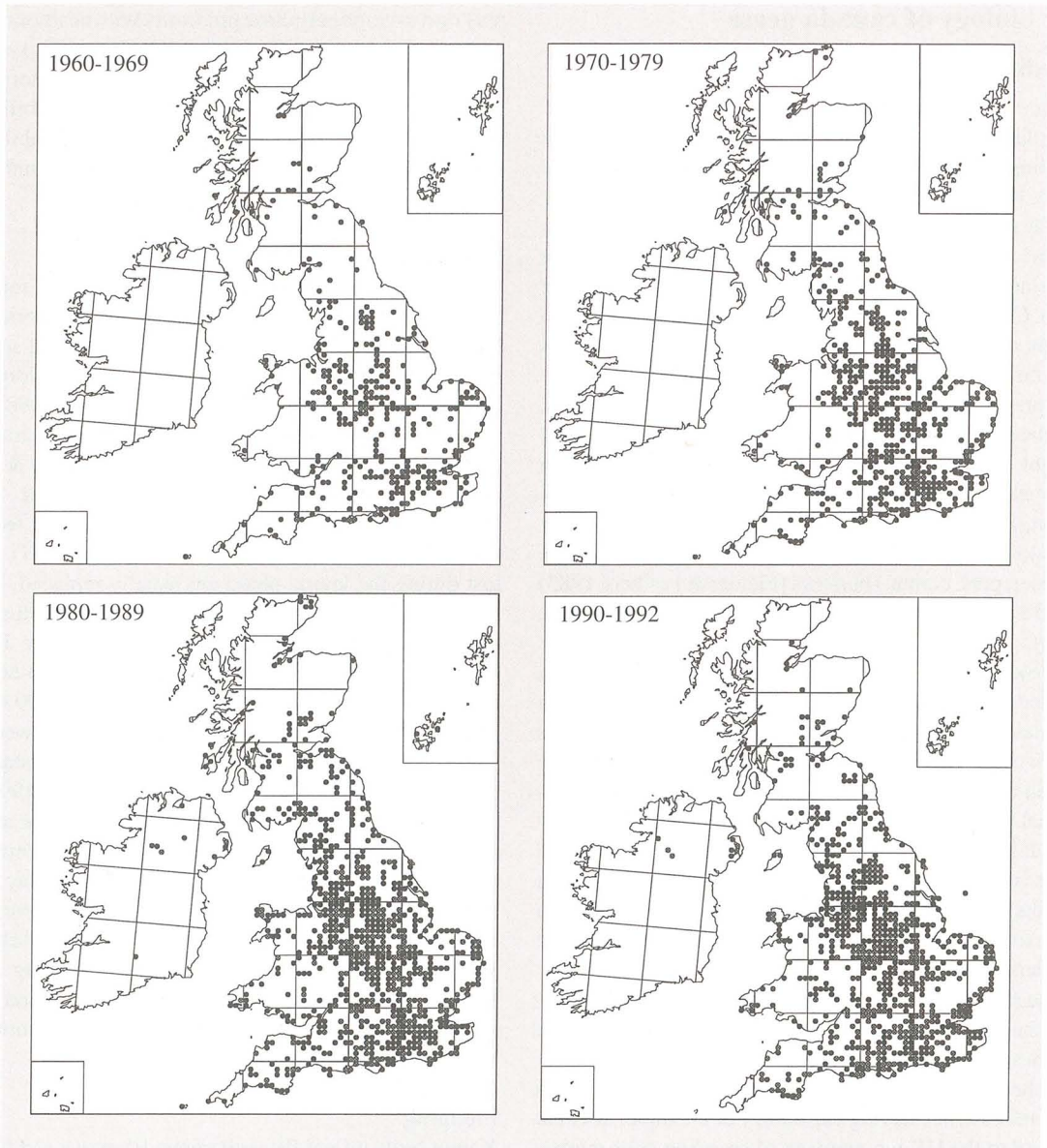

Figure 2. Winter distribution of canada geese recorded during the annual Wetland Bird Survey, conducted September-March during 1960-1992. Filled circles represent 10-km squares containing sites where canada geese were recorded during each 10-year period.

tory flocks of canada geese in the USA has resulted in damage to amenity grasslands in areas where the species was previously rare (Addison & Amernic 1983, Conover & Chasko 1985). In Scandinavia, autumn populations have been estimated at 40,000-60,000, and, as in the UK, result from earlier deliberate introductions (Madsen & Andersson 1990). Here the canada goose is considered responsible for 'serious' agricultural damage, public nuisance problems and interference with native waterfowl (e.g. Godo 1978, Haland 1979, Olsen 1982, Fabricius 1983).

There is a vast body of literature on the biology of canada geese, particularly from North America and, to a lesser extent, Scandinavia and the UK. We have drawn upon this literature to: a) review aspects of canada goose biology that are especially relevant to the management of feral populations; b) describe the ways in which canada geese impact on human interests; and c) describe management options available to address such impacts. Finally, we outline the need for research that will evaluate the need for, and assist in the development of, management strategies for canada geese.

The biology of canada geese

Breeding ecology

Choice of breeding site

From late February, canada geese begin to prospect for breeding sites and become territorial (Cramp & Simmons 1977). Nest sites are contained within territories, and territorial defence against both conspecifics and other waterfowl may be quite violent. Recent studies indicate that such interactions are uncommon, however (Stevens, in prep). Canada geese normally nest on the ground close to a body of water, showing preference for low flat islands far from the shore where they are protected from terrestrial predators (Johnson et al. 1978, Giroux et al. 1983, Combs et al. 1984, Giles & Wright 1986, Reese et al. 1987 Wright & Giles 1988, Getz & Smith 1989). They can show extreme adaptability in their selection of nesting location, however, choosing sites as diverse as trees (Capainolo 1991, Goodwin 1979, pers. obs.), buildings (R. Dolbeer, pers. comm.) burrows (Fielder & Perlberg 1983) and the nests of other birds (Airola 1987, Schmutz et al. 1988).

Lessells (1985) found that canada geese tend to return to their natal site to breed, this tendency being stronger in females than in males Understanding the mechanisms which cause birds to abandon their natal site is vital if the spread of canada geese is to be managed as it is this dispersal that initiates the formation of new breeding colonies. It is also important to establish whether the application of management strategies, such as intensive shooting or culls, will break the tendency to breed in one location and cause birds to move to new sites, thus spreading the problem further.

The number of breeding pairs supported by a long-established site seems to remain fairly constant (Hughes & Hughes 1981, Hughes & Watson 1986), whilst newly-established breeding sites may take many years to reach their maximum carrying capacity. For example, at Great Linford in the UK the numbers of breeding pairs continued to grow throughout a 16-year study period (Wright & Phillips 1990). Once the carrying capacity of a site is reached, many birds of breeding age are unable to establish a territory and a large population of non-breeding adults may accumulate (Smith 1985, Watola 1993). Natal-site fidelity presumably prevents most of these birds from moving away to establish new colonies elsewhere. Population growth amongst canada geese seems, therefore, to be associated with the accumulation of large numbers of non-breeding birds at existing sites and the gradual establishment of new colonies, either by natural processes (Hansen 1991) or by forced introductions (Haland 1979, Heggberget 1991, Hughes & Watson 1986). The factors which govern the number of breeding pairs that a site can support are not fully understood. Canada geese may nest in extremely close proximity with nests only two or three metres apart (Lessells 1985, pers. obs.) which suggests that a requirement for a minimum territory size is not a limiting factor. Their extreme adaptability in choice of nesting site also suggests that the availability of suitable nest locations is unlikely to limit the number of breeding pairs.

Nesting

Canada geese may first breed at 2-3 years old (Cramp & Simmons 1977) but breeding attempts by inexperienced birds are usually less successful, with the bulk of surviving goslings arising from experienced adults (Aldrich & Raveling 1983, Hardy & Tacha 1989, Hofman 1982). In early April, most canada geese in the UK lay a clutch of typically 4-7 (mean 5.9) eggs (data from Cramp & Simmons 1977, White-Robinson 1984, Owen et al. 1986, Wright & Giles 1988). Incubation, solely by the female, takes about 28-30 days (Cramp & Simmons 1977). Eggs lost during the laying phase are usually replaced, but if the clutch is lost after more than a week of incubation, the laying of a replacement clutch is rare (Brakhage 1985). Hatching success is highly variable, typically 40-60% in the UK (Johnson & Sibley 1991, Baker et. al 1993), depending upon factors such as nest-site location, weather, predation pressure and the experience and social status of the parent birds (Wright & Giles 1988, Warren 1994).

The quality of winter food supplies may also be important in determining breeding success as this governs the condition of the birds in spring. Fatter females lay more and bigger eggs, start breeding earlier and may have higher survival rates than thinner geese (Aldrich & Raveling 1983, Johnson & Sibley 1991, Murphy & Boag 1989, Warren 1994). Also, fatter males are able to spend more time guarding their territory which leads to improved breeding success (Johnson & Sibley 1990).

Fledging

Young birds do not fly until about 10 weeks old (Owen et al. 1986) and are tended by the parents close to the breeding site. At this time the adults moult and become flightless. Both adults and young are therefore dependent on food resources in, or within walking distance of, the breeding water, and the availability of those resources may be extremely important in governing the number of breeding pairs that a site can support. The mortality of goslings is very low in typical British conditions (Walker 1970). Johnson & Sibley (1991) estimated that 77% of goslings survive to the first moult, whilst Thomas (1977) determined that after moulting young birds had only a slightly higher mortality than adults in their first year. As with hatching success, data vary from site to site; for example Warren (1994) found a far lower gosling survival of 45%. In all cases the bulk of gosling mortality occurs

in the first few weeks after leaving the nest. Gosling survival may be enhanced by canada geese forming their young into large creches. These creches are tended by older dominant adults which contribute their greater experience to the safety in numbers provided by the creche itself (Warren 1994).

The instances of low gosling survival described above (Wright & Giles 1988) may result from the early nesting of canada geese, leading to high mortality during poor weather (Lessells 1986, Giles 1992, Warren 1994). There has been at least one instance of mass gosling mortality in a public park in the UK when, after a large number of pairs hatched young successfully, dry weather limited the local food supply and many goslings starved to death (M. Street, pers. comm.). In a separate study, experimental variation of brood size during good conditions had no effect on gosling survival, neither during the rearing period nor subsequently, but pairs with larger broods bred later in the following year, possibly as a result of impaired body condition (Lessells 1986).

The high potential clutch size, high hatching success and gosling survival under normal conditions, and low first-year mortality all contribute to the rapid population increase shown by feral canada geese.

Post-breeding ecology

The moult

The annual feather moult is a primary post-breeding activity. For successful breeders, choice of moult site is limited to the distance that they can walk with their goslings, and so is usually confined to the breeding water. The availability of safe moulting sites with an adequate food supply may be important in governing the selection of waters as breeding sites by canada geese. In one UK population, birds which breed on moorland sites may walk their broods considerable distances to find a safe moulting site, whilst others remain on the moorland to moult (Garnett 1980, pers. obs.). Moult migrations over greater distances are performed by some birds in the UK population, reflecting the moult migrations of their North American ancestors (Salomonsen 1968). In the early 1960s, ringing of a moulting canada goose flock on the Beauly Firth in northern Scotland led to the discovery that these birds originated 450 km further south in Yorkshire (Dennis 1964, Walker 1970), and it is now known that some birds from the English Midlands also moult on the Beauly Firth (a movement of 600 km). This northward moult migration involves mainly immatures, non-breeders and failed breeders which depart in May and June (Walker 1970).

Post-breeding dispersal

Once young birds are able to fly they may move away from the breeding water, though they usually remain in loose family groups. The juveniles possibly gain experience of foraging and roosting locations from their parents. Later in the season, family parties break up. Most adult birds return to the same wintering sites each year, but some birds, especially juveniles, may wander over hundreds of kilometres. Most movements are under 50 km in extent, however (Cramp & Simmons 1977). In general, females move shorter distances than males (Lessells 1985). Research in progress in Britain (Watola et al. in prep) has shown that clearly defined subpopulations exist within the broad regional groups identified by Ogilvie (1969, 1977). These groups frequent regular breeding, moulting and wintering sites with comparatively little interchange with neighbouring subpopulations. Whilst the number of canada geese leaving their home range is small, it may be important in terms of the rate at which new colonies are established and hence for the rate of population spread. The factors triggering this process are not understood and if population management practices influence this process the management itself could result in a faster rate of geographical spread of the population. Further research in this area is therefore urgently needed.

Wintering

In the UK, most canada geese winter close to their breeding areas, perhaps ranging over distances of only a few kilometres (Owen et al. 1986). Some populations undertake short migrations, for example from upland to lowland areas (Garnet 1980, Watola 1993), and ringing recoveries provide evidence of some longer-distance movements e.g. from northern Scotland and the English Midlands to London (Baker 1985). In adverse weather some UK ringed birds have been recorded in continental Europe (Cramp & Simmons 1977, Lack 1986) and some move between regions within the UK (Watola 1993).

Adult survival

Canada geese are long-lived birds; ringing studies have shown that birds frequently survive to ten years old (pers. obs.) and exceptionally to 20 years (M. Fletcher, pers. comm.). The average lifespan is 3.9 years (Cramp & Simmons 1977).

Thomas (1977) estimated a value of between 10% and 20% for the annual mortality of fully grown birds in a population of canada geese in the UK. Mortality rates were similar for adult and juvenile birds after the first annual moult. The main causes of mortality were shooting (67.2%), unknown (23.0%), hitting power lines (4.3%), and other, including predation by e.g. dogs and foxes (5.5%). As would be expected, the bulk of mortality occurs during the hunting season, but a smaller peak in reported deaths occurs during April and May suggesting

that a significant mortality is associated with the breeding process. Studies on other populations have drawn similar conclusions, with a national mortality rate of 22% quoted by Cramp & Simmons (1977) and an estimation that 4-16% of the total UK population is taken by hunters each year (Giles & Street 1990). Bag returns from the British Association for Shooting and Conservation indicate a higher figure, as 16,000 canada geese were reported shot during 1986-87 and 1987-88 out of an estimated population of 58,000. This estimate of shooting mortality, when combined with other causes of death, suggests that the true figure for adult mortality rates in Britain may be in the region of 35-40%. Whatever the true figure, high fecundity and good juvenile survival have ensured that the canada goose population in Britain has continued to increase at around 8% per year (Delany 1993). Studies elsewhere in the world have also shown that canada goose populations can withstand imposed adult mortality rates of over 40% whilst maintaining or increasing their total population size (Chapman et al. 1969, Nelson & Oetting 1982, Sheaffer et al. 1987). The UK population studied by Thomas (*op. cit.*) frequented rural areas and country estates where sport shooting was common. In urban areas, where shooting is not permitted, mortality rates may be far lower and population growth rates correspondingly higher.

Limits to population growth

Because of the current poor understanding of the population biology of feral canada geese, the upper limits to population size can only be guessed at. Despite an estimated adult mortality rate of 15-40% (see above), the present growth rate of the British population shows no sign of slowing at present (Delany 1993), and the population is currently doubling in size every 10 years.

Upper limits to recruitment are set, in part, by the carrying capacity of available breeding sites. Many apparently suitable breeding sites remain unoccupied at present (Delany 1993), and since the factors that influence the suitability of a water body for breeding canada geese and the number of pairs that it can support are not fully understood, it is not possible to make an estimate of the final carrying capacity of any region in terms of breeding pairs. Comparative studies of well-established colonies with differing numbers of pairs are needed to provide the necessary information.

Natural mortality (excluding shooting) in feral canada geese is very low (Thomas 1977), and the availability of large amounts of apparently suitable grazing in the form of pasture, lawns and arable crops suggests that the point at which density-dependent factors will begin to influence adult mortality is not likely to be reached soon. The possible exception to this is the availability of food resources around breeding and moulting sites, where flightless birds cannot forage elsewhere and large populations may reduce food availability to the point where it begins to influence the fitness of adult birds. In America, the metropolitan area of Minneapolis St. Paul alone supports a population of non-migratory 'urban' canada geese greater than the entire British population (J. Cooper, pers. comm.). This suggests that the potential for considerable further expansion of feral populations in Europe exists, which will undoubtedly result in increasing levels of conflict with man.

In summary, although more research is needed, it is not unreasonable to speculate that the British Isles alone has a minimum carrying capacity of several hundreds of thousands of canada geese. The final limit to the size of the population is likely to be imposed by human intervention, either through hunting, deliberate population management or as a result of changes in land use, rather than by natural processes.

The problems caused by canada geese

Canada geese can cause a variety of problems depending upon the number of birds present and the type of site occupied (Harradine 1991). These problems are summarised below and the data concerning the nature and extent of the damage reviewed.

Agricultural damage

Canada geese have been recorded feeding in stubble fields, on root crops and grazing newly-sprouted winter cereals (White-Robinson 1984, Owen 1991). Despite this, there have been few studies of the effects of grazing by canada geese on crop yields. Kear (1970) reported no significant grain losses attributable to winter or spring grazing by canada geese, though White-Robinson (1984) concluded that significant agricultural damage can occur in certain situations. Simpson (1991) cited instances of crop damage in the UK costing £15,000 and yield losses of 20% on winter cereals continuously grazed by canada geese, though no details are given.

In North America, yield loss of 15-70% following grazing of sprouting winter wheat (Bell & Klimstra 1970, Kahl & Samson 1984, Flegler et al. 1987) and 40-80% biomass loss in rye grass (Conover 1988) have been measured as a result of grazing by canada geese. When canada geese grazed dormant winter wheat no significant yield loss was measured (Pirnie 1954), and the presence of canada geese resulted in improved yields of winter wheat in areas with low nutrient levels due to fertilisation of the soil with their droppings (Bell & Klimstra 1970). Grazing by migrant canada geese did little damage to crops in the St. Lawrence Valley, Canada (Reed et al.

1977), whilst grazing improved the yield of rye grass seed in one investigation (Clark & Jarvis 1978).

The evidence from North America suggests that the timing of grazing, crop type and growing conditions are all important in determining the impact of canada goose grazing on arable land. Whilst canada geese clearly have the potential to cause severe localised damage, our understanding of their overall agricultural impact remains inadequate.

Damage to amenity land

Damage to grasslands close to water bodies, such as public parks, golf courses and domestic lawns, is a phenomenon associated with sedentary flocks of canada geese (Conover & Kania 1991). Such damage includes removal of grass by grazing (Conover 1991), fouling areas with droppings (Conover & Chasko 1985) and erosion of lake shores and other areas by trampling. As with agricultural damage, there has been little attempt to quantify its extent, but a total cost of £40 per bird per year was calculated for reinstatement of damaged grassland and cleaning of fouled paths in one London park (P. Clarke, pers. comm.).

Damage to other habitats in amenity areas, for example reed beds, may also constitute a problem but is poorly documented. At one UK site, canada geese trampled and consumed young shoots and rhizomes of *Phragmites australis*, causing considerable damage resulting in increased erosion and habitat loss for other species (Wall 1984).

Hazards to human health and safety

Concern has been expressed that canada geese may transmit diseases to humans, via contact with faeces. Whilst American studies have shown the presence of *Actinobacillus suis* (causing conjunctivitis) and *Clostridium botulinum* (resulting in botulism) (Maddux et al. 1987, Shayegani et al. 1984), and work in London's public parks has indicated the presence of several potential human pathogens in canada geese faeces (Central Science Laboratory, in prep.), there is no conclusive evidence for transmission to humans. Furthermore, there are no data on pathogen loadings, and those of canada geese may be no higher than those of other waterbird species or the rest of the water environment.

Canada geese may impinge on public health in other ways. Faeces may make paths or grassed areas slippery, resulting in injuries from falls, and attacks on young children by territorial birds could be dangerous and frightening. Such attacks could also result in accidents to individuals trying to escape the birds' attentions. Whilst these problems may well be serious, they remain unquantified and may apply equally to other birds in the urban environment.

Since canada geese are large and habitually form flocks they constitute a risk to air safety in the event of a bird-strike (Milsom 1990). For example, from 1986-89, canada geese were involved in 11 strikes at Reno-Sparks airport, Nevada USA, costing $250,000 and this resulted in the US Federal Aviation authority threatening to close the airport if control measures were not instituted (Fairaizl 1992). These problems coincided with the arrival of large numbers of migrant geese, but the rising population of feral birds in Britain has the potential to cause serious hazards to aircraft (Allan 1995).

Competition with other waterfowl

Canada geese consume large quantities of vegetable matter to satisfy their daily requirements and may defend their breeding territories aggressively against intruders. Concern has been expressed that feral populations may be depriving native waterfowl of food or nesting-sites. In Britain, there is only circumstantial evidence in support of this. Owen (1991) and Owen et al. (in press) found evidence for competition with mute swans *Cygnus olor* for winter grazing, but no competition with mute swans or feral greylag geese *Anser anser* during the breeding season.

In Scandinavia, Fabricius et al. (1974) documented considerable interspecific aggression when canada and greylag geese nested together on islands off the Swedish coast, but found no evidence of negative consequences on the numbers of breeding pairs of either species. It has been suggested, therefore, that there is little competition between the two species for resources (Udo 1979). However, the study was performed when both species were still increasing in numbers, and it is possible that the competitive situation and outcomes may well change when these populations reach a more "saturated" state.

The incidence of hybridisation between feral canada geese and other goose species is becoming more frequent in the UK (Delany 1993). Because there are few non-feral geese breeding in the UK most of these hybrids are between canada geese and feral greylag or barnacle geese *Branta leucopsis* and are not considered to be significant in terms of conservation of the wild populations. The situation could be very different in the Scandinavian countries where significant breeding populations of native geese occur.

Overall, the evidence in support of the theory that canada geese are deleterious to other waterfowl is contradictory. Research in North America concentrates on the maximisation of canada goose numbers for hunting (see e.g. Hine & Schoenfeld 1968) and little attention is paid to the effect of large numbers of wild canada geese on

other species. Concern surrounding sedentary urban geese in America centres on damage to golf courses and lawns and on threats to public health. In Europe, there is a greater concern about the impact of canada geese on other species, based largely on anecdotal evidence and observations of aggressive interactions between individual birds. Recent research in the UK has shown that rates of interaction between canada geese and other waterfowl at Central Science Laboratory study sites are very low (CSL, in prep.). Indirect effects of canada geese on other species, for example through modification of vegetation on breeding islands, have yet to be investigated.

Eutrophication of water bodies

Large flocks of canada geese may transfer significant quantities of semi-digested vegetable matter to water bodies via their droppings. The high nutrient loadings that may result can significantly alter the biological balance of water bodies and may have catastrophic consequences where oxygen depletion becomes severe. Algal blooms may result in poisoning of wildlife and prohibition of the use of affected sites for recreation or for water extraction.

Kear (1963) recorded a maximum faecal deposition rate for canada geese of 175 g/bird/day (dry weight). Analysis of the droppings indicated that they contained 1.6% nitrogen 1.9% $P_2O_5^-$ and 3.3% K_2O^- and, though probably insufficient to affect soil chemistry, such levels were thought to be sufficient to influence the fertility of water bodies.

In America, Manny et al. (1994) found that over 6,500 canada geese and 4,200 ducks (mostly mallards) added 4,462 kg carbon, 280 kg nitrogen and 88 kg phosphorous per year to Wintergreen Lake, Michigan, mostly during their migration (see also Manny et al. 1975). These amounts were sufficient to account for the hyper-eutrophic state of the lake. These data suggest that eutrophication of waters may be a significant problem if large flocks of canada geese and other waterbirds are present. This situation is likely to be especially acute at sites where feral birds occur and the nutrient inputs occur throughout the year.

Management options to reduce canada goose damage

The establishment of large, non-migratory flocks of canada geese in many North American cities (Laycock 1984, Sheaffer et al. 1987) has stimulated researchers to investigate damage alleviation strategies (Nelson & Oetting 1982). However, in contrast with Europe, the geese are highly valued in America, both as a native wild species and as a hunting resource, and effort is directed towards non-lethal techniques. Relocation of urban flocks has frequently been employed with limited success in reducing local populations (Addison & Amernic 1983, Cooper 1986, 1991), but the long-term viability of translocation is now questioned due to reduced availability of rural sites, the continued growth of the migratory population, and the resultant increase in conflicts with agriculture (Rusch et al. 1985, Converse 1985). Greater emphasis is now put on the development of integrated control programmes combining techniques such as scaring (Mott & Timbrook 1988, Heinrich & Craven 1990), use of repellent chemicals (Conover 1985, Cummings et al. 1991) and population control to prevent urban goose damage at sensitive sites (Conover 1993).

Feare (1991) reviewed the options for the control of canada geese in the UK but research into damage prevention has concentrated on only one option: reducing reproductive output (Giles & Street 1990, Baker et al. 1993). *Ad hoc* population management has been undertaken but usually without proper experimental design and with little or no follow-up or publication of the data. Although research into the effectiveness of population control techniques is under way (e.g. Watola 1993), current assessments of the likely effectiveness of canada goose management lean heavily on American research, and on experience with other waterfowl species in Europe.

The control methods currently available fall into two categories: 1) behaviour modification by scaring, use of chemical repellents, physical exclusion and habitat management, and 2) population management control by prevention of hatching of eggs, shooting in or out of season, culling at moult, culling with other capture techniques and/or by relocation.

Behaviour modification techniques

Scaring with acoustic and visual stimuli

The most commonly used bird scarer is the gas cannon, a device designed to emit one or more explosive reports, at set or random intervals. Other acoustic scarers include devices that produce a variety of loud shrieks, that broadcast tape-recorded or digitised distress calls, and machines that produce infrasound and ultrasound. The responsiveness of canada geese to these devices has not been assessed. Heinrich & Craven (1990) detected no habituation of migrant canada geese to a sonic scarer over a seven-week trial period. These bird scarers were developed mainly to protect agricultural crops, many of which are vulnerable to bird damage for a relatively short period. If acoustic scarers are to be deployed for long periods, they should be regularly moved (ADAS 1987) or combined with other techniques to reduce the rate at which the birds become habituated to the scaring stimulus. Urban canada geese, which are not hunted and are accustomed to a wide variety of auditory stimuli associated

with living in close proximity to man, may very quickly learn to ignore gas cannons and other noise-producing devices, which in any case are not appropriate for use in urban areas since people find them offensive.

Many species habituate less rapidly to scarers which incorporate their own distress calls. The structure of these calls is being examined to increase their effectiveness further through the synthesis of superstimuli, in which particular segments of the calls are enhanced (Aubin 1990). Distress calls of gulls *Larus sp.*, starlings *Sturnus vulgaris*, corvids *Corvus sp.* and lapwings *Vanellus vanellus* are extensively used to deter them from airfields (Bridgman 1980). Mott & Timbrook (1988) successfully used the alarm calls of canada geese to deter birds from vulnerable areas for 2-3 week periods, but the birds moved only a short distance and returned immediately after scaring stopped. In a second study, the use of tapes containing 'distress' (possibly also alarm) calls failed to scare canada geese from the area at all (Aguilera et al. 1991). Such techniques are unlikely to work against long-term cumulative damage caused by resident feral geese.

Visual scarers can take a variety of forms, from the familiar scarecrow to plastic strips attached to poles, kites or balloons representing birds of prey, and even inflatable human figures which rise, carrying an imitation firearm, from a box in the ground. As with acoustic scarers, these devices are effective in deterring birds from areas for as long as the birds natural neophobia persists. Heinrich & Craven (1990) found that canada geese were deterred from landing in fields by brightly coloured flags, but were not deterred if they landed in nearby fields and walked into the protected area. In the same study, scarecrows were also found to deter migrant canada geese, particularly from small fields with tall boundary features such as trees. As with the flags, the deterrent effect only occurred if the birds saw the scarecrow from the air and birds that landed nearby simply walked into the field. The trials described above were conducted on migratory canada geese subject to hunting pressure. Urban geese may be far less easy to scare using passive acoustic or visual stimuli.

Although shooting is more usually regarded as a means of population control, it can also be used to reinforce scaring. Shooting combines visual with acoustic stimuli and is reinforced by the occasional killing of a bird. Increased shooting pressure at a particular site is widely believed to increase responsiveness to other scaring techniques, particularly gas cannons and scarecrows, but there is no scientific evidence to support this. For safety and public perception reasons, shooting is rarely likely to be practicable in urban areas.

Use of chemical repellents

Attempts have been made for many years to develop a harmless chemical repellent with which to treat crops in order to prevent wildlife damage. So far none has proved wholly successful, either due to lack of repellency, toxicity to plants or to the birds themselves, or lack of persistence of the effect.

While the concept of chemical repellency is attractive, few chemicals that will successfully deter birds from feeding have so far been identified. Methiocarb, a carbamate insecticide and molluscicide, was sometimes effective in deterring birds (e.g. Conover 1985) but proved to leave unacceptable toxic residues on foodstuffs (Mason & Clark 1992) and clearance for use as a bird repellent has been withdrawn in many countries. Diazinon, an organophosphorus insecticide, was effective in protecting golf courses and resulted in no observed mortality to canada geese (Kendall et al. 1993). However it was found to be the cause of poisoning in american wigeon *Anas americana* and approval for this use has recently been withdrawn by the US Environmental Protection Agency. To overcome such problems, naturally occurring plant products, or their derivatives, are now being sought, which are aversive to birds, show low toxicity to crops, humans and other wildlife, and are humane in their action. Methyl anthranilate has been successfully employed against canada geese in America (Cummings et al. 1991). Whilst this chemical appears to show great promise as a repellent, more extensive field trials are required to establish true effectiveness in operation. Research in the UK has shown cinnamamide to be effective in preventing many bird species from feeding on treated foods (Crocker et al. 1993, Crocker & Reid 1993, Gill et al. in press). Long-term field trials to evaluate cost effectiveness of using both cinnamamide and methyl anthranillate to control damage caused by canada geese are needed.

Physical exclusion and habitat modification

Canada geese can be excluded from an area either by fencing to prevent the birds from walking in, or by the use of wires or tapes strung across the area to prevent them from landing. Such techniques are frequently and successfully employed to restrict access of a variety of bird species to small areas such as ponds or ditches (Rochard & Irving 1987), and have been effective in deterring brent geese *Branta bernicla* from feeding on cereal fields (Summers & Hillman 1990). It is probably impractical to attempt to exclude geese from large water bodies and neighbouring fields, and this would also restrict access to the public, farm machinery and other bird species. Nevertheless, research on potential barriers that would selectively exclude canada geese from particular areas is needed since this technique could have value in protecting small areas, for example golf greens or islands used for breeding by the geese.

In extreme cases of canada goose damage, it may be possible to modify the habitat to make it less attractive to

the geese or less susceptible to damage. Planting of dense scrub on the banks of lakes may deter geese from walking out of the water on to grass or into crops, but such scrub would require adequate protection from the geese during establishment. In North America, Conover & Kania (1991) have shown that feeding sites are chosen on the basis of their proximity to water and their openness in terms of both predator detection and the angle of climb needed to fly out of the site. Separating grassed areas from water bodies with a belt of trees high enough to require a climb out angle of over 13° is suggested as a way of reducing damage on foraging sites near water. Replanting grass areas with plant species unpalatable to canada geese could reduce damage levels (Conover 1991) and modification of cropping patterns, so that vulnerable crops are not available to canada geese in the vicinity of water, could be included in damage alleviation programmes (Feare 1994, Trump et al. in press).

To prevent breeding, nesting cover could be removed or islands could be removed by raising water levels in order to flood them. Research into the mechanisms which limit the number of breeding pairs at a site may assist with the development of new habitat management techniques to limit the number of canada geese which breed at certain locations and prevent the establishment of new colonies. These techniques could, however, limit access by other waterfowl.

Many of the above solutions present problems with respect to the impact on other bird species, restriction of public access, or loss of recreational or landscape value in public areas. Some of these disadvantages may, however, be counteracted by benefits to other species, not only birds. It is clear that each case needs careful evaluation on the basis of management priorities for the site; the cost effectiveness of measures such as enclosure fencing will form an important part of such evaluations.

Population management techniques

Reproductive control

Humane methods available to limit the production of young include the prevention of adults from breeding or eggs from hatching. Surgical sterilisation of male canada geese may be an effective means of reducing productivity, but breeding males must first be identified and caught, so there are considerable limits on this technique as a management option (Converse & Kennelly 1994). While chemical inhibition of reproduction is conceptually attractive, an effective and humane chemosterilant is not available for canada geese.

Adults may also be prevented from producing young by shooting them at the nest, a technique that has dual advantages in both reducing breeding output and at the same time reducing the breeding component of the adult population. The shooting of geese at close range while they are defending their nest would be emotive but, in that a quick, clean kill could be achieved, this could be one of the most humane ways of killing adults.

One of the commonest ways of attempting to control canada goose numbers has been the destruction of eggs or their treatment to prevent hatching. Such treatment usually involves pricking the eggs and destroying the embryo. Treated eggs are left in the nest and the female allowed to incubate as normal; if eggs are removed or destroyed the female may re-lay. Other techniques used include the replacement of eggs with wooden dummies, or hard boiling newly-laid eggs to prevent hatching. Hatching can also be effectively and humanely prevented by coating the eggs with liquid paraffin (Baker et al. 1993).

Canada geese are long-lived birds with relatively low annual mortality at many urban sites, so that when reproduction is prevented many years may elapse before population size falls. If a small number of broods is missed, the limited recruitment that results may be sufficient to replenish the annual losses through mortality. Giles & Street (1990) found that experimental egg destruction had a dramatic effect on gosling production, with fewer than 50 birds fledging from over 150 nesting attempts. It required a very large amount of effort, however, leading Wright & Phillips (1991) to consider that the chances of significant population reduction would only be attained by combining egg removal with increased winter shooting. Barnard (1991) used computer simulation to assess the likely effectiveness of these egg-removal programmes. Modelling showed that the population could be held at 1990 levels by collecting 72% of eggs each year and, if 95% of eggs were collected, numbers would fall to 75% of 1990 levels by the year 2000. This illustrates that population control is possible, but only with considerable effort and with the cooperation of all managers of sites in the vicinity of the target area. Since the effectiveness of reproductive control in reducing population size is heavily dependent on the rate of adult mortality, and because the geese may be able to increase their fecundity to compensate for any mortality increase, both reproductive control and control of mortality will need to be combined in any proposed programme to manage canada goose numbers.

Shooting, culling and trapping

At least 6,000 wildfowlers shoot canada geese annually in the UK (J. Harradine, pers. comm.), but the species is not highly regarded as quarry (Harradine 1991). The relative importance of the species in the total goose bag has increased, from 11% in 1980-81 to 36% in 1987-88 (Harradine 1991). Thus, there is potential for increasing adult mortality by raising the levels of shooting of canada geese. If canada geese were shot more regularly, they

might become more wary and provide better sport; wild canada geese are regarded as a prime quarry in North America (Hine & Schoenfeld 1968).

Little research has been conducted on the effect of intensive shooting on populations of feral canada geese. Because the geese would rapidly become extremely wary, it would be difficult to shoot enough birds at a site to achieve a rapid reduction in numbers. In America populations have been shown to withstand heavy long-term hunting pressure, with annual harvests of up to 40% causing no reduction in overall numbers (Chapman et al. 1969, Nelson & Oetting 1982, Sheaffer et al. 1987). In Finland, winter shooting alone was not sufficient to control canada goose numbers (Vikberg & Moilanen 1985), whilst in New Zealand, extensions to the hunting season have been granted to increase the number of canada geese shot, but the population size remained stable despite a doubling of adult mortality (Imber & Williams 1968). At many urban sites shooting may be impossible for reasons of safety or public reaction. Thus, shooting alone does not appear to offer either short or long-term solutions to the problems posed by canada geese.

Large numbers of canada geese can be easily captured during the moult, when they are flightless for 3-4 weeks (Cramp & Simmons 1977). Once caught the birds can be humanely dispatched by cervical dislocation, lethal injection or shooting at close range; licenses may require the presence of a veterinary surgeon. Culling at the moult, although controversial, results in an immediate reduction in population, and hence a reduction in local damage, and is likely to remove a high proportion of breeding adults which may reduce recruitment in future years. Problems may arise if this technique is applied on a water with a large surplus of non-breeding birds and failed breeders, since these birds may moult away from the natal site and return to fill available breeding sites in future seasons necessitating further culling operations. Such difficulties may be exacerbated by combining egg control with culling since those individuals which fail to rear young successfully may move away from the breeding site to moult (pers. obs.). Though a number of culls have been undertaken under license in the UK, with varying success, none has been followed-up to determine the number and frequency of culls needed to reduce the population to a predetermined level. Such information is needed to assess the cost effectiveness of culling as a control technique.

Humane traps such as drop nets (Nastase 1982) or stupefacient baits (Woronecki et al. 1990) can be used to capture small numbers of geese where capture of moulting birds is not possible, or where the birds causing damage moult elsewhere. These techniques may be employed successfully at sites where killing needs to be carried out discreetly, but they require the birds to be attracted to bait. This may be relatively easy in public parks where the birds regularly receive food from people, but may be more difficult in rural areas where geese have less contact with the public and less experience of novel foods. The use of stupefacients (Woronecki et al. *op. cit.*) warrants study as a potential canada goose management technique.

Relocation

One of the most successfully used means of reducing problems with non-migratory canada geese in North America is relocation, either to form new colonies or to increase the size of hunted populations (Addison & Amernic 1983, Laycock 1984, Converse 1985, Cooper 1986, 1991, Conover 1993). The geese can be captured alive and then transported to areas where damage is not anticipated. Mass relocation is an expensive operation and it is unlikely, given the problems currently being encountered with canada geese in Europe, that many landowners would be willing to take more birds. Further redistribution is likely to encourage the geographical spread of the geese, and for this reason should be discounted as a control option.

Integrated management strategies (IMS) for canada geese

There are costs and benefits associated with all of the management options currently available for canada geese. In general, behavioural modification techniques such as scaring have the advantage that they are non-destructive, and therefore publicly acceptable. The main problem associated with scarers is habituation, where birds become accustomed to the stimulus if it is not reinforced by something that causes pain or threatens life (e.g. shooting). Scaring and exclusion techniques are also unselective and influence the behaviour of other species, and may conflict with public access or land use requirements. Moreover, all behavioural modification techniques have the disadvantage of transferring the problem elsewhere and, possibly, encouraging the further spread of canada geese. Population reduction, on the other hand, can offer permanent solutions to local problems with less risk of moving geese elsewhere, and the effects are immediate. Unfortunately, the techniques are often difficult to apply and those involving the destruction of birds can be controversial. It seems likely that a combination of techniques, tailored to individual sites, is the way forward. The choice of the most appropriate combination of techniques to form an Integrated Management Strategy (IMS) will depend on the nature of the site, type of damage occurring and on the population biology of the local birds. A thorough understanding of the processes involved in the population biology of canada geese is required if successful management strategies are to be de-

veloped. Expert advice should be sought before expensive and potentially controversial control programmes are implemented.

Research required for integrated management strategy development

Population biology

Research into the factors important in the selection of breeding and moulting sites, and into what controls the carrying capacity of these sites, is needed. The latter is most important if the upper limit to population growth is to be estimated. Knowledge of the factors governing the carrying capacity of a site will also help develop habitat management techniques to limit the number of canada geese at a particular location.

Quantification of damage

The amount and geographical distribution of damage by canada geese, both in urban and rural areas, has yet to be evaluated and analysed in economic terms. Research is in progress in the UK to evaluate the extent of damage to amenity land, to evaluate the risk to human health from canada goose droppings and to determine the significance of behavioural interactions between canada geese and native species. Further work is needed on the role of canada geese in the eutrophication of wetlands, especially in urban areas.

Management techniques

The Central Science Laboratory (in collaboration with the University of Leeds) is currently researching the effectiveness of various population management strategies and how these techniques should be combined with other methods to achieve specific population reduction goals. Work on visual and acoustic stimuli and chemical repellents that might prove aversive to canada geese continues elsewhere (e.g. Aubin 1990, Cummings et al. 1991), but the responses of canada geese to cinnamamide need urgent evaluation. Further work on habitat modification techniques, and wider landscape modification, also needs to be undertaken.

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