CHAPTER 1: ECOLOGICAL EFFECTS OF AVIATION

TOM KELLY¹ & JOHN ALLAN²

¹Department of Zoology, Ecology and Plant Science, University College Cork, Lee Maltings, Prospect Row, Cork, Ireland
²Central Science Laboratory, York, UK

1. Introduction

The technological equilibrium that existed in the middle of the 19th century was punctuated by a series of momentous discoveries and inventions including oil as a lubricant and fuel, the internal combustion engine, Bell’s telephone and Edison’s electric light bulb. Kerosene and the internal combustion engine were vital contributors to the first powered flight, at Kill Devil Hills, near Kitty Hawk in North Carolina on December 17 1903 (Anderson 2004). Orville and Wilbur Wright’s outstanding achievement was quickly followed by a spectacular sequence of inventions in aeronautical engineering leading to, for example, Concorde and commercial supersonic aviation, within 70 years of their inaugural flight (Pascoe 2003). Every step (apart from those which remain classified for military reasons) in the development of aviation is known (e.g. Anderson 1997, 2003). Over this time air transport has become faster, safer, more fuel efficient, less polluting and less noisy. An improving understanding of aerodynamics led to rocketry and ultimately to space exploration and therefore “transport beyond the earth” (Hobsbawm 1994). Satellite imagery of the Earth is now commonplace and is widely used by science to monitor the global landscape, its biodiversity and a wide range of environmental variables including, in particular, the effects of climate change. In a sense the Space Shuttle and associated satellite technology are continuing Darwin’s pioneering voyage in the Beagle (1831-1836).

This account aims to describe the positive and negative ecological effects of aviation. These impacts occur on different scales ranging from the global (aviation’s contribution of global warming gases to the atmosphere) to the local (airfield habitat and wildlife control measures). It should be stated at the outset that this subject is overwhelmingly dominated by so-called ‘grey’ i.e. mostly non-peer reviewed literature; relatively little has been published in the mainstream scientific journals. In addition, the stimulus or stimuli that cause animals to respond to aircraft are still, to our knowledge, imprecisely understood.

2. A brief history of aviation and its ecological impacts

The military were the first to make use of the air – despite General Foch of France dismissing aviation as “good sport, but for the army the aeroplane is worthless” (Yergin 1991). In 1915, Britain possessed only 250 planes but by the end of the First World War had produced 55,000 aircraft; broadly similar numbers had been assembled in Germany and France. Initially aircraft were non-combatant and were merely used for reconnaissance but soon these aeroplanes were armed with machine guns and bombs (Yergin 1991; Bilstein 2001; Grant 2004).

However, it was in America that aircraft were put to their first major practical non-military uses, most notably in the delivery of mail, aerial photography and crop spraying (crop dusting) with insecticides against the cotton leaf worm, a noctuid moth caterpillar (Spodoptera sp). According to Bilstein (2001) a pilot could “dust” “from 250 to 500 acres per hour”. Eventually, the main target became the cotton boll weevil (Anthromonus grandis) and the weapon “a swath of lethal white dust (arsenate of lead powder)” (Bilstein op.cit) with 500,000...
acres being ‘treated’ in 1927. Such activities continue throughout the world today, though due to problems of wind drift, as little as 40 per cent of the biocide (including until recently the persistent organochlorines like dichloro-diphenyl-trichloroethane (DDT)) may actually land on the target area. This led to the evolution of insecticide resistance among pest insect species including the Anopheles mosquito vectors of malaria and no doubt other species that transmit micro-pathogens to domestic animals and wildlife. It is in this way that aviation began to have a significant negative environmental impact, albeit as an instrument of ever intensifying agricultural production.

2.1 COMMERCIAL CIVIL AVIATION

Gore Vidal (1993) was a passenger on what is claimed to be “the first commercially scheduled airliner” – on July 7 1927, which flew from New York to Los Angeles, less than two months after Charles Lindbergh’s pioneering “Spirit of St Louis” non-stop 5,760km flight from New York to Paris. Despite the investment and banking catastrophe incurred during the “Great Crash” of 1929, and the following years of severe economic depression, there were sustained progressive improvements in the airworthiness and design of paying passenger aircraft. Examples include the remarkable DC-3 which first flew in 1935, and the pressurised cabin, in the B-307 “Stratoliner”, the first commercial airliner capable of flying at the height of the stratosphere. Competition from the airship industry collapsed with the very public fire, explosion and loss of life, on the Hindenburg in May 1937 (Grant 2004). However, it was not until after the end of the Second World War, and especially in the 1950s, that commercial civil aviation began to grow into an alternative form of transport, particularly to travel by ship. The exponential increase in commercial aviation was largely due to the use of the gas turbine ‘jet’ engines – first used in military aviation – which substantially increased the range of aircraft and halved the time it took to make these journeys (Bilstein 2001). The first commercial jet airliner was the de Havilland D.H. 106 “Comet” which had its inaugural flight in Britain on July 27 1949 (Gunston 2001). Other designs quickly followed including Boeing’s “Dash 8” in 1954 and the highly successful 707 in 1957. In 1955, the French Sud-Est SE 210 Caravelle and the Douglas company’s DC-8 had undergone inaugural flights (Gunston 2001). Comparable aircraft were being produced in the USSR.

In what Richard Dawkins (2004) has defined as a progressive process, aviation continued to ‘evolve’ e.g. in airframe design, electronic transmission systems, hydraulics, and the incorporation of on-board computing leading eventually to the “fly by wire” concept.

Engine design also improved leading to the high-bypass ratio turbofans which are found on the Airbus A320 and more modern Boeing 737 series (e.g. the 300 to 800) (see MacKinnon, 2001). These engines are more fuel efficient, less noisy and less polluting than their predecessors. Overall, air-safety has increased with the notable exception of acts of terrorism. Hijacking of aircraft, the placing of bombs on aircraft and the shooting down of aircraft by terrorists has affected the numbers of people flying, but these reductions are transient and the market appears to recover quite quickly.

Some 1.6-1.8 billion passengers fly on commercial aircraft every year (Robinson 2000; Gunston 2001), and although there was a marked reduction following the September 11 2001 atrocity in New York, growth in the budget travel (e.g. easyJet and Ryanair) market has led to a sharp recovery in the numbers of people travelling by air (Nugent 2005).

A new phase in commercial aviation opened in late April 2005 with the inaugural flight of the Airbus A380 a double-decker “fly by wire” jumbo jet capable of carrying at least 555 passengers. It remains to be seen if this venture will prove to be commercially successful, but all the existing projections indicate that the commercial aviation sector is likely to undergo a sustained expansion-particularly in Africa, South America and Asia (e.g. Robinson, 2000;
Mackinnon 2001). For example, Africa holds only 4% of “world airline aircraft fleet “, and South and Central America 6.8%, compared with 43.7% and 23.7% in the USA and Western Europe respectively (Mackinnon 2001). Therefore, the construction of new airport infrastructure in, for example, Africa and South America, to cater to an expansion in civil aviation is likely to have considerable local ecological effects.

2.2 GENERAL AVIATION

General aviation includes light aircraft, many of which are powered by a single piston engine. It is estimated that there are approximately 339,000 of these aircraft in service, 65% of which are in the USA (Mackinnon 2001). Although light aircraft are the most numerous in civil aviation, they fly for an average of only 135 hours per year (Mackinnon 2001). As mentioned previously light aircraft were used in aerial spraying and more recently in the destruction of “crops” which are used in the manufacture of drugs.

2.3 MILITARY AVIATION

Although the use of aircraft for military purposes has been the major force in the ‘evolution’ of aviation generally, less information is available about the number of aircraft and their operations. Remarkable military aircraft include the SR-71B Blackbird which travels at Mach 3 and exceptionally high altitudes; the eight engined B 52 bomber which is still in service following its launch in 1955, and the stealth bombers Lockheed F-117 Nighthawk and the Northrop B-2 which are effectively invisible to radar surveillance (Grant 2004). Military aviation also includes a variety of helicopters and, increasingly, unmanned reconnaissance aircraft. In addition a vast arsenal of missiles and “smart bombs” have been designed for use in combat.

As with commercial aviation, the air forces of the world require large air bases although these usually lack ancillary infrastructure such as hotels and car parking facilities. However, air forces need large safe areas in which to practice bombing and other military manoeuvres.

2.4 OTHER FORMS OF AVIATION

2.4.1 Rocketry and space travel

Following the launch of Sputnik 1 in October 1957, manned space flights were successfully completed in the USSR and the US, in 1961, only 58 years after the Wright brothers’ pioneering achievement in North Carolina. The Apollo mission to the moon was launched on July 171969 and the landing took place on July 20th. Thereafter space travel has involved the construction of the MIR space station, the Space Shuttle and missions like the Galileo space probe to Jupiter. This was launched in October 1989, arriving six years later in July 1995 (Grant 2004).

2.4.2 Helicopters

Helicopters were flown in Germany in the mid-1930s but were not widely used until after the Second World War. Again there is extensive use of rotary winged aircraft in both military and civil aviation. There are about 33,000 helicopters being used in civil aviation (based on Mackinnon 2001). Helicopters generally fly at low altitudes, and at relatively low speeds. However, this type of aircraft which uses either piston or turboshift engines, requires relatively little supporting infrastructure, unlike almost all other forms of aviation.
2.4.3 Powered hang gliding and the microlight
Hang gliding and paragliding have now become popular sports. In the 1970s powered hang gliders known as microlights were developed, attaching piston engines to a ‘pivoting wing’ (Grant 2004). These very small aircraft fly at low altitudes and low speeds.

2.4.4 Gliders
The use of gliders was developed in Germany in the 1920s (Grant 2004). However, although gliders are still widely flown, the sport does not appear to have attracted large numbers of participants. Gliders generally have to be towed into flight by a light aircraft, but once operating on their own they are relatively noiseless.

3. The ecological effects of air transport
Aviation is likely to have three major ecological effects. First as a polluter of the air, included in which would be the release of the gases which are believed to be responsible for climate change. The scale of this effect will be at both the global and regional level e.g. 72% of all transatlantic air traffic between Europe and North and Central America passes over Ireland (data from the Irish Aviation Authority). This environmental impact is addressed in Chapter 15.

The second ecological impact is noise pollution. This occurs at the regional to local level. For example, the noise from transatlantic aircraft descending in the early morning towards destinations in Britain is clearly audible over the southern counties of Ireland. Likewise, aircraft noise will be obvious in the approach and climb-out zones of most international airports. And finally, airports themselves are generally noisy places (e.g. Burger 1983).

The noise impacts of aviation are controversial as they lead to very negative responses from the public and extensive measures are now being taken to reduce this problem. However, noise and other stimuli produced by the aircraft, are also believed to impact on wildlife (e.g. Kelly et al. 2001; Frid & Dill 2002; Komenda-Zehnder & Bruderer 2002; Pepper et al. 2003), though the responses of birds in particular are proving difficult to resolve (Kelly et al. 2000; Kelly et al. 2001; Komenda-Zehnder et al. 2003).

Finally, the third major ecological impact occurs at the level of the airfield. This involves the impact of a) the installation of major infrastructural requirements for aviation in the jet age and b) habitat management to reduce the impact to aviation of collisions with wildlife, mainly birds and mammals. Infrastructural requirements for jet and turbo jet aircraft include long concreted runways, wider taxiways, extensive apron space and aircraft parking areas, Instrument Landing Systems (ILS), approach lighting, control and watch towers etc. The new Airbus A380, for example, has a wingspan of 79.8m, and airports endeavouring to receive this aircraft may have to modify existing runways, taxiways and the apron to achieve appropriate stand sizes.

Mammals, birds and reptiles may collide with aircraft causing what is now termed a wildlife strike. This ‘strike’ may be sufficiently severe to cause the destruction of the aircraft with the loss of life of all of those on board (e.g. Blokpoel 1976; CAA 1998; Mackinnon 2001; Thorpe 2003; Cleary et al. 2004). Most wildlife strikes do not have such catastrophic results but nevertheless may reduce the safety margins of flying. Bird strikes are expensive, causing losses of US$1.5 billion per annum (Allan 2002). Therefore, measures must be taken on airfields to prevent or reduce the risk of wildlife strikes. These measures include, albeit rarely, the direct killing of species which pose the most serious risk (e.g. Dolbeer et al. 2003), the drainage of wetlands, and the chemical removal of weeds and invertebrates (e.g. earthworms and insects) which attract hazardous birds and mammals. In addition, airfield grasslands are
managed to minimise the build up of flocks of species like starlings (*Sturnus vulgaris*), and gulls (*Larus* sp) (CAA 1998; Mackinnon 2001). Finally, a variety of noise emitting devices including shell crackers fired from a pyrotechnic launcher/Very Pistol and re-broadcast distress calls are used to scare or haze birds and mammals from the airfield (e.g. Blokpoel 1976; CAA 1998).

### 3.1 THE NON-LETHAL EFFECTS OF AIRCRAFT ON WILDLIFE

Non-lethal disturbance of animals by aircraft is an important issue and a source of conflict between the various aviation interests and wildlife conservation bodies (Frid & Dill 2002). This problem has received considerable attention in recent years, and a protocol on how it should be measured, and its effects assessed, is emerging (Efroymson *et al.* 2000; Efroymson *et al.* 2001; Efroymson & Suter 2001; Komenda-Zehnder & Bruderer 2002; Frid & Dill 2002; Frid 2003; Rees *et al.* 2005). Aircraft may cause animals to flee in panic and these behaviours in turn may affect fitness because they are costs in terms of energy expended, energy lost through a reduction in foraging time, decreased time allocated to parental care, increased time allocated to vigilance, and desertion of preferred feeding grounds, territories, and home ranges (e.g. Gill *et al.* 1996; Hill *et al.* 1997; Gill & Sutherland 2000; Frid & Dill 2002; Frid 2003). However, difficulties remain in overcoming the effects of confounding variables—even where experimental protocols have been carefully prepared (e.g. Komenda-Zehnder *et al.* 2003; Frid, 2003; Rees *et al.* 2005). Thus, while most researchers believe that the noise emitted by the aircraft is the primary source of the disturbance (Efroymson *et al.* 2001; Efroymson & Suter 2001; Pepper *et al.* 2003), others argue forcefully that it is the looming visual stimulus that is the main cause of the panic responses (Frid & Dill 2002). However several studies have also shown that noise looms and sounds that move towards a subject have greater “biological salience than those that move away” (Hall & Moore 2003).

Other studies have mentioned the importance of habitat, location and time of year in explaining the variation in response to sources of human disturbance (e.g. Delaney *et al.* 1999; Frid 2003; Rees *et al.* 2005; Laurson *et al.* 2005). It is also known that there are inter-specific (e.g. Smit & Visser 1993; Pepper *et al.* 2003) and age differences (e.g. Rees *et al.* 2005) in the magnitude of the response to aircraft.

In addition, there is evidence that birds and mammals may habituate to aircraft, particularly if the angle of approach is not direct, and both vertical and horizontal distances are sufficiently large to reduce the probability of a perceived immediate threat (e.g. Conomy *et al.* 1998; Delaney *et al.* 1999; Komenda-Zehnder *et al.* 2003; Pepper *et al.* 2003; Frid 2003). However, Robinson and Pollitt (2002) noted that waterbirds were less likely to habituate to infrequently occurring disturbances. This important observation, echoing those of Burger (1981), has clear implications for the interpretation of results of field experiments where the aircraft-related disturbance is relatively novel in the environment of the studied species.

There is a consensus that helicopters are a greater disturbance to birds and mammals than fixed wing aircraft (e.g. Smit & Visser 1993; Stock 1993; Komenda-Zehnder & Bruderer 2002; Komenda-Zehnder *et al.* 2003).

### 3.2 NON-LETHAL INTERACTION BETWEEN AIRCRAFT AND ANIMALS AT AIRPORTS

Airports may be a focal point where intense interactions will take place among birds, mammals and aircraft. Some will, as mentioned, involve collisions with aircraft, but these potentially damaging events are relatively rare (generally between 2 and 6 per 10,000 aircraft movements; Kelly & Bolger in prep) given the large number of birds that commute through
the at-risk air space. This raises the question – do birds avoid aircraft, and if so, which cue or cues stimulate the avoidance response?

Kelly et al. (1999) showed that at Dublin Airport, Ireland, 88% of birds flying towards the active runway performed obvious avoidance manoeuvres. These were described and classified. Four bird species actively avoided aircraft namely the rook (Corvus frugilegus), black headed gull (Larus ridibundus), woodpigeon (Columba palumbus) and lapwing (Vanellus vanellus). Both the rook and woodpigeon are residents at Dublin Airport, but the black headed gull and lapwing are migrants and winter visitors.

Subsequent research by Kelly et al. (2001) focused on the avoidance behaviour of the rook. Two categories of aircraft are now identified namely those belonging to either Chapter 2 or ‘Chapter 3’. ‘Chapter 2’-type aircraft (examples include the Boeing 707, 727 and 737 series 200) are much noisier than those in the ‘Chapter 3’ category (examples of which include the Boeing 737 series 300-800, the Airbus series A300 to A340 and the British Aerospace 146) (Anon 1993). In the study the repertoire of avoidance behaviours shown by the rook to the different categories was analysed. The results showed that significantly fewer rooks responded to the Bae-146, a well-known ‘Chapter 3’ type aircraft, than to the B737-200, a distinctly more noisy ‘Chapter 2’-type aircraft. This suggests that noise may be an important cue for the rooks. However, size differences between these two aircraft may account for the observed pattern of response. The Bae-146 (length 26.3m, height 8.6m and span 26.34m) is shorter and narrower than the B737-200 (length 30.5m, height 11.3m and span 28.4m), but it is questionable whether this contrast in dimensions is sufficient to explain the statistically significant \( P < 0.01 \) difference in the response of the rook. Tomlinson et al. (1991) found that birds showed a more marked physiological response to larger aircraft; but others, including Smit and Visser (1993), Koolhaas et al. (1993), Davidson and Rothwell (1993), Conomy et al. (1998), and Ward et al. (1999), have shown that the disturbance caused by aircraft is inversely proportional to their size with, for example, microlights causing the most severe effects.

The results of Tomlinson et al. (1991) suggest that there is a hierarchy in the stimuli to which the birds respond, where visual stimuli elicit the most significant response followed, in order, by a combination of both visual and auditory stimuli and finally purely auditory stimuli. It is clear that, while noise is potentially an important cue for rooks, it was not possible in the Kelly et al. (2001) study to resolve the confounding effect of the visual stimulus. Kempf and Huppop (1996) refer to this difficulty and state “the noise of aircraft can scarcely be assessed separately from its optical appearance”. Further investigations are therefore necessary to establish the relative importance of aircraft noise in the avoidance behaviour of the rook and other bird species found at airports. This may be important as the noisier ‘Chapter 2’ type aircraft are to be completely phased out from European airports by December 2005.

To summarise, aircraft are a disturbance, sometimes of considerable proportions, to birds and mammals, but research into this problem continues to be hampered by our inability to quantify the relative importance of the noise, versus the visual, stimulus. Birds are well known to respond to multi-component i.e. aural and visual, signals in, for example, their courtship behaviour (Kelly et al. 2000). It is likely, therefore, that their responses to aircraft will prove to be both behaviourally and neurologically complex. However, a greater understanding of the basis of their responses, including the role of learning and habituation, is important, as recreational and military aviation increases in the wilderness of the USA and Canada (see Mackinnon 2001). Paragliding appears to be an increasing problem in Europe (Schnidrig-Petriq & Ingold 2001; Enggst-Dublin & Ingold 2003).

3.3 REDUCTION OF THE NEGATIVE IMPACT OF NON-LETHAL AVIATION

It is generally recommended that over-flying of important conservation areas for birds, marine and terrestrial mammals should be reduced to a minimum. Guidelines proposed by the
government of the United Kingdom recommend minimum horizontal and vertical distance of 750m for single engined helicopters, but 1000m for those with twin engines operating close to concentrations of birds in Antarctica. The minimum distances for fixed-winged aircraft with 1 to 2 engines is 450m whereas it is 1000m for those with 4 engines. Raptor species showed no response to aircraft flying at a distance greater than 500m, and Komenda-Zehnder et al. (2003) suggest that a minimum altitude of 600m AGL should be sufficient to prevent major disturbances of waterbirds on lakes in Switzerland. Finally, Efroymson et al. (2001) and Efroymson and Suter (2001) recommend that “slant distances” be used to estimate the exposure of wildlife to “stresors” emitted by low flying aircraft. However, this method requires the measurements of angles in the field, which appear to be difficult to obtain (Frid & Dill 2002; Frid 2003).

3.4 MILITARY AVIATION AND AERIAL BOMBING CAMPAIGNS

The ecological effects of war have not, for obvious reasons, attracted much detailed study. The bombing of Guernica on April 26 1937 proved to be a portent of the mass destruction of civilian human life in the Second World War up to and including the dropping of the atom bombs on Hiroshima and Nagasaki in 1945. But, even in early January 1940, this scale of devastation appeared a somewhat unlikely eventuality. In the House of Commons when the Secretary of State for Air, Sir Kingsley Wood was pressed to bomb the Black Forest to destroy German timber supplies “the little man replied outraged”: “Are you aware it is private property? Why you will be asking me to bomb Essen next!” (Collier 1980).

W.G. Sebald’s (2003) book “On the Natural History of Destruction” (a title borrowed from Lord Solly Zuckerman) contains a remarkable but shocking essay entitled “Air War and Literature” which describes the consequences of the Allied bombing campaign against cities in the Reich. On page 35 he quotes Hans Erich Nossack who observed that “Rats and flies ruled the city. The rats bold and fat, frolicked in the streets, but even more disgusting were the flies, huge and iridescent green”.

Orians and Pfeiffer (1970) remark that tigers benefited from the Vietnam War and apparently consumed “large numbers of battle casualties”. They speculated that the tiger population had “increased much as the wolf population in Poland increased in World War II”.

Orians and Pfeiffer (1970), also describe the impact of B-52 bombing raids and particularly the number of craters that were created by the payload, which they estimate to have been 2,600,000 in 1968 alone. Some of these would become fishponds, but others the breeding ground for mosquitoes. Defoliation (notoriously by “Agent Orange”) was one of the main aerial warfare strategies carried out by the USA in Vietnam (See Chapter 15). As this impacted on the mangrove swamps, Orians and Pfeiffer (1970), considered that fish-eating birds including the grey heron (Ardea cinerea) were fewer than expected. However, Fitter (1945) noted that during the London Blitz the great heronry at Walthamstow was hardly affected by “a hail of bombs that fell on all sides of it” and in fact “there was an increase of three occupied nests in 1941 compared to 1940”. Fitter (1945) also shows that while the black redstart (Phoenicurus ochrurus) did breed on bombsites, it had been increasing in the London area before the war. However, Holllom (1975) argues that its “establishment” in areas outside Middlesex and Sussex including the midlands followed “ bomb damage of 1940-41”.

Fitter (1945) summarises the effects on plant communities resulting from the blitz. Most of the work was undertaken and published by Salisbury (1943). One curious finding was that the London rocket (Sisymbrium irio) was not part of the re-colonising plant community after the Blitz, even though it apparently flourished following the Great Fire of 1666.
Rhodes (1986) is one of many who described the devastation caused by the atomic bombs in Japan in 1945, and while no ecological data is presented it must be presumed that most, if not all life, was extinguished within the area of the blast.

4. The wildlife hazard problem

The first human fatality caused by a bird strike occurred in 1912 “when a gull became entangled in the exposed control cables in an aircraft” (Blokpoel 1976). This accident occurred at Long Beach California, and the person killed was Cal Rogers who “had been the first person to fly across America” (Thorpe 2003). Bird hazards to aircraft became a much more serious problem with the arrival of jet propulsion; the greater speed of jet aircraft results in much more severe impact damage resulting from collisions with birds (e.g. Blokpoel 1976; Mackinnon 2001). In addition, jet engines can “ingest” birds and this, albeit rarely, may cause the aircraft to crash (e.g. Blokpoel 1976; CAA 1998; Mackinnon 2001; Sodhi 2002; Thorpe 2003; Cleary et al. 2004).

In an authoritative review, Thorpe (2003) showed that 231 people have been killed in 42 wildlife-related fatal civil aviation accidents. Overall, a total of 80 civil aircraft have been destroyed by collisions with birds. In addition, at least 141 people have been killed as a result of bird strikes to military aircraft (Richardson & West 2000). People on the ground have been killed in bird strike-related fatal accidents involving both civil and military aircraft (Thorpe 2003; Richardson & West 2000). A collision between a mammal and an aircraft has caused one human fatality in the USA (Cleary et al. 2004).

Wildlife strikes are responsible for significant additional (i.e. non-fatal) damage and costs, to both civil and military aircraft (see Allan 2002; Cleary et al. 2004).

The response of the aviation industry to these hazards has been to implement a wide range of control measures to reduce the overall risk and costs of wildlife strikes (e.g. CAA 1998; Mackinnon 2001; Cleary et al. 2004). Managing wildlife hazards is generally confined to the airfield and therefore the effects are mostly local (though see Rees et al. 2005) but necessary planning restrictions to ensure air safety may exert an influence on a wider scale (see Section 5).

4.1 ECOLOGICAL EFFECTS OF AIR TRANSPORT: NUMBERS OF ANIMAL FATALITIES

Most animals that collide with an aircraft are killed. Therefore an increase in mortality is the main impact of air transport on the population dynamics of animals. Culling of hazardous species may also occur on or off the airfield and would therefore constitute an additional source of mortality.

For mortality to exert a negative effect on a population i.e. to cause it to decline, it must be additive, i.e. in excess of natural mortality (Newton 1998). This can be compared with compensatory mortality i.e. where increased losses are “compensated” for by enhanced survival and reproductive success (Newton 1998). It is of interest to know therefore, if the mortality caused by bird and other wildlife strikes is additive, and whether it may, as a consequence, cause the decline of the affected species. It is also relevant to compare aircraft strike induced losses with other anthropogenic sources of collision related mortality. While authorities may disagree over the definition of a bird strike (e.g. Brown et al. 2001), the consequences of differences in interpretation are unlikely to have major implications in calculating the effects on the population dynamics of most, but not all, species (i.e. those in which the bird strikes cause additive mortality). A more substantial problem is the non-reporting of bird strikes. It is suggested that as few as 15-20 per cent are reported (Burger
1985; Linnell et al. 1996, 1999; Barras & Dolbeer 2000; Brown et al. 2001; Cleary et al. 2004). Therefore in calculating the total number of birds and mammals killed by civil aircraft it is necessary to make the appropriate transformations. We have assumed, for the data set compiled by Cleary et al. (2004) for the USA, the most comprehensive of its kind in the World, that only 20 per cent of strikes are reported. It is obvious however; that air strikes involving deer are much more likely to be documented than collisions with small animals such as voles, bats and swallows. Therefore, any analysis at this stage is necessarily preliminary, crude and possibly in some cases (e.g. large birds and mammals) an overestimate.

Table 1. Estimates of the numbers of birds killed in collisions with man-made structures. Erickson et al. (2001) Percival (2005) Cleary et al. (2004) (Data on mammals and reptiles Cleary et al. 2004)

| Collision with:          | Birds (range) | Mammals | Reptiles |
|-------------------------|---------------|---------|----------|
| Motor vehicles          | 60-80 million | Not available | Not available |
| Buildings               | 98-980 million | Not available | Not available |
| Power lines             | 10,000 to 174 million | Not available | Not available |
| Communication towers    | 4-50 million | Not available | Not available |
| Wind turbines (civil)   | 10,000-40,000 | Not available | Not available |
| Aircraft (civil)        | 15-30,000***  | 364 | 20 |

*** The data from Cleary et al. (2004) refers to the 1990-2003 interval. Therefore the totals for each group were divided by 14 to give an annual average, and then this figure was multiplied by 4, to account for unreported strikes. The range in the number of birds killed by aircraft is based on an average of 1 and 2 respectively, killed per strike.

It is obvious from Table 1, that even when the very major problems of compiling such data, and their obvious limitations, are taken into account (Erickson et al. 2001; Percival 2005) collisions with manmade structures are a major source of mortality in birds. However, aviation appears to be responsible for the least amount of birds (and probably mammals and reptiles) being killed in this way. It is unlikely that the level of recorded mortality will prove additive and therefore of conservation concern. While the number of large birds being struck by civil aviation in the USA is increasing, and is itself an expanding threat to air safety (Dolbeer & Eschenfelder 2003), the reason is that their populations are recovering from previous declines. So, while large birds generally have high annual survival rates, and are therefore particularly vulnerable to the effects of additive mortality, there is no evidence as yet that the number of bird strikes to these species poses a threat to their population viability. Most bird strikes involve just one individual being killed, and with improving standards of management the overall losses (per collision) are likely to decrease (Kelly et al. 1996).

Culling birds, even when this is designed to improve air safety, is controversial for both ethical and scientific reasons. There is a long history of opposition to the deliberate killing of animals (e.g. Thomas 1983) which precedes the so-called “Bambi effect” (Cartmill 1993), and an increasing number of airports are employing non-lethal methods for reducing wildlife hazards. Some are using dogs, particularly border collies (e.g. Patterson 2000), and others falcons, to scare off birds from the airfield.

However, culling is also being implemented particularly at John F Kennedy Airport in New York. Here gulls are shot as they approach and over-fly the airfield. In total 72,063 gulls were shot between 1991 and 2002 (Dolbeer et al. 2003) This procedure has led to a marked and statistically significant reduction in the number of bird strikes caused by gulls (mainly the Laughing Gull Larus atricilla) and a 58 per cent reduction in the size of the adjacent gull
colony. The numbers of gulls over-flying the airfield has decreased by 14-26 per cent. Nevertheless, Brown et al. (2001) recommend alternative procedures including the relocation of the gull colony. The laysan and black-footed albatrosses posed a problem for air operations on Midway Island. These are a species which would normally have an annual adult survival rate of up to 95 per cent. Some 30,000 had to be killed on the island to ensure air safety, but the actions attracted a lot of publicity and the effects in terms of the viability of the population (900,000 individuals in 1994-1995) were apparently relatively small (Blokpoel 1976; Whittow 1993; Dolbeer et al. 1996).

4.2 SPECIES KILLED BY AIRCRAFT

4.2.1 Birds
The species of bird involved in a collision with an aircraft is often not expertly established. Consequently it is not possible to provide a definitive list of species that have been killed as a result of bird strikes. However, lists are provided by, among others, Blokpoel (1976), Mackinnon (2001) for Canada; Cleary et al. (2004), Rochard and Horton (1980) for the UK, and Owino et al. (2004) for Kenya. It is probable that species from most avian orders have been struck. Damaging bird strikes are caused by species that are heavy (>100 g) and that form flocks (e.g. the starling). Thorpe (2003) showed that ingestion of gulls into jet engines was the major cause of fatal bird strikes whereas windscreen penetration by large raptors, including vultures, resulted in the loss of most light aircraft and helicopters.

4.2.2 Mammals
The only systematically collected data on mammal strikes that has been published, to our knowledge, is that of Cleary et al. (2004). Of the 1272 mammals struck in the USA between 1990 and 2003, 96 (8%) were bats, 88 (7%) were hares and rabbits, 74 (6%) were rodents, 312 were carnivores (24.5%), 643 (51%) were artiodactyls. Of these 574 (42% of all mammal strikes) involved the white tailed deer (Odocoileus virginianus) reflecting the remarkable abundance of this species (Cote et al. 2004). The white tailed deer was the species involved in the only fatal mammal collision with a civil aircraft between 1990 and 2003 in the United States (Cleary et al. 2004).

4.2.3 Reptiles
Cleary et al. (2004), list 67 records of reptiles being struck by civil aircraft in the United States between 1990 and 2003. Fifty of these (75%) involved turtles of 6 species. In two cases the strikes had a negative effect on the flight. More serious however, were 12 strikes involving the American alligator, three (25 %) of which had a negative effect on the flight.

4.2.4 Introduced animals
Although the relevant data does not appear to have been collated, there is evidence that some introduced bird, mammal and reptile species may become a serious hazard to aviation. For example in Great Britain, the Canada goose (Branta canadinensis) population has increased exponentially and is posing a serious threat to air safety (Allan et al. 1995). In the Netherlands, the Egyptian goose (Alopochen aegyptiacus) population has also increased dramatically and has been found at times at Schipol Airport (Schipol Group 2000). The European starling is a problem in the United States where it was involved in the worst bird strike to have been recorded, at Logan Airport in Boston, in October 1960, when 62 people died. In the United States, the introduced rock or feral or racing pigeon (Columba livia var domestica), was
involved in at least 983 bird strikes between 1990 and 2003, and 245 (25%) of these caused some damage to the aircraft (Cleary et al. 2004). In Holland, some intending passengers release their pets including cats, raccoons and mink on the outskirts of Schipol Airport (Schipol Group 2000). The main threat these animals pose is that while hunting, they disturb flocks of birds, and therefore have to be trapped or culled (Schipol Group 2000).

Finally, the introduced green iguana has become a problem in Puerto Rico (Quinones & Engeman, 2004). This 1.5-2m lizard has become well established in and around Luis Munoz International Airport, where hundreds of iguanas invade the area of the runway to breed. Determined attempts to exclude these reptiles from the aircraft manoeuvring areas, included the construction of a 300m three strand electric fence. But “rather than being repelled by the electric charges”, “the iguanas charged straight forward through the fences”! (Quinones & Engeman 2004). In the end a 30cm high chicken wire fence led to a reduction in the “intrusions” by the iguanas. Cleary et al. (2004) mention five green iguana strikes of which three caused some damage to the aircraft involved.

5. Airports in the environment

The vast majority of discussions surrounding the impact of aviation on the environment centres on noise and atmospheric pollution. What is less often considered is the direct impact of the airport and surrounding infrastructure on the nearby environment in terms of land take and the control that needs to be applied to developments on and around the airport that may impact upon flight safety. As well as controlling the most obviously hazardous developments, such as buildings that may obstruct the approach paths of aircraft or interfere with radio communications, aviation regulators are required to control the hazards posed to aircraft by collisions with wildlife, especially birds (birdstrikes). Birdstrikes are conservatively estimated to cost the world civil aviation industry US$1.2 billion per year (Allan 2002). They have also resulted in the loss of 80 civil aircraft and 231 lives (Thorpe 2003). In order to control this risk the International Civil Aviation Authority (ICAO) introduced a new standard for controlling bird-attracting sites near airports in November 2003. The standard states inter alia that:

Garbage disposal dumps or any such other source attracting bird activity on or in the vicinity of an aerodrome shall be eliminated or their establishment prevented unless an appropriate aeronautical study indicates that they are unlikely to create conditions conducive to a bird hazard problem.

In small densely populated countries, such as the United Kingdom, the rigorous application of this standard could have profound effects on the environment. ICAO defines a distance of 13km around aerodromes as the radius within which the presence of birds may be considered a hazard. The UK Civil Aviation Authority has interpreted ‘in the vicinity of an aerodrome’ to mean the ICAO 13km circle. If all UK licensed civil airports implemented this standard, and the Ministry of Defence were to do the same at its military airfields, then approximately 40% of the land surface of England would be subject to these controls. There is clearly scope for conflict between flight safety requirements and national and local commitments to nature conservation and biodiversity enhancement. Similarly, local and national regulations concerning planning and economic development may conflict with flight safety. For example, the need to extract minerals such as sand and gravel for construction work frequently leaves large voids, which have often been landscaped to form wetlands for biodiversity benefits and/or recreational use for local communities. Such sites often attract hazardous birds and pose significant problems to the aviation industry (CAA 1998). The fact that many aerodromes are sited on large areas of flat ground such as river floodplains, which often also have rich deposits of sand and gravel further complicates the situation.
The projected growth of civil aviation, which will result in the need for more and larger airport facilities at least over the medium term future, combined with increasing pressure for sustainable economic growth that takes due account of environmental issues such as biodiversity and climate change, means that increasing attention will be paid to the impact of aviation on the environment. Whilst issues such as noise and pollution are closely monitored, the other impacts of airports on the environment are less well understood and very poorly measured. The following sections attempt to describe some of these impacts and to estimate, where possible, their effects on the environment.

5.1 DIRECT IMPACT OF AIRPORT INFRASTRUCTURE

There are around 13,860 airports with paved runway surfaces in the world plus a large number of smaller facilities without paved surfaces (CIA 2002). Airports vary considerably in size depending both on the length, number and alignment of the runways, and on the quantity of ancillary infrastructure that surrounds them. An airport with a single runway and one or two terminal buildings may have a relatively low land take compared to an airport with two or three runways set at different angles to allow aircraft to take-off and land into the wind. Where land-take is not a major constraint, airports may be constructed with numerous long runways and multiple terminal facilities. Like runway length, the passenger throughput of an airport is also not a good guide to the physical size of the facility. Former military airfields converted to civil use may be very large, but with relatively low passenger numbers, whilst purpose built civil airports can accommodate large passenger throughputs with relatively small airfields. Although the length of the runways at airports is documented and information on passenger and flight numbers can be obtained, it is impossible to make an accurate determination of the land take of airports around the world. Notwithstanding this, the actual land take of airports is relatively small compared to other forms of transport. Civil and military airports combined constitute around 1% of the total transportation land-coverage in the EU (European Environment Agency 2001). A study in Germany estimated that air travel utilised 0.4ha of land per 1,000,000 passenger miles compared to 2.6ha for rail travel (UK Commission For Integrated Transport 2001).

5.2 IMPACT OF ANCILLARY STRUCTURES

As with the size of the airport itself, estimating the impact of the ancillary structures such as hotels, car parks, road and rail links, office and industrial buildings etc. associated with an airport is difficult. It is often unclear which buildings are linked directly with the airport and which would be in that location anyway. Some data are available on car parking as a component of airport size (see Table 2), but this does not include car parks associated with other buildings around the airport.

| Table 2. The total area and area of car parking at 3 major UK airports. Numbers from Whitelegg (1994) |
|---------------------------------------------------------------|
|                  | Total site area (Ha) | Car park land take (Ha)             |
| Heathrow          | 1197                 | 58.19                             |
| Gatwick           | 759                  | 68.57                             |
| Stansted          | 975                  | 57.6                              |
5.3 ECOSYSTEM MANAGEMENT FOR AIR SAFETY

The majority of aerodromes around the world operate some form of programme to deter hazardous wildlife from the property. The techniques used can be broadly categorised as habitat management and bird deterrence. The techniques used vary depending upon the habitat on the airfield, the bird species involved and on the manpower and resources available to the aerodrome manager to carry them out.

5.3.1 Aerodrome habitat management

Birds exploit the habitat provided by aerodromes for a variety of reasons, but these can broadly be categorised as feeding, breeding and roosting opportunities. Different bird species have adaptations that permit them to exploit airports in different ways. Grassland feeders, such as gulls (Larus sp.), plovers (Vanellus sp.) starlings (Sturnus sp.) corvids (Corvus sp.) pigeons (Columba sp.) and egrets (Egretta sp.) are all able to exploit the vegetated areas between runways and taxiways as feeding sites, but all do so in slightly differing ways, some relying on soil surface invertebrates, some on subsoil invertebrates, others on plant species in the sward. The basic principle of aerodrome habitat management is either to remove the resources that the birds are exploiting, or to deny birds access to these resources. The choice of which resource to concentrate on can be a difficulty. For example, in Western Europe the practice of growing the grassed areas between the runways as dense monocultures with a sward height of 15-20cm is commonly employed to deter species such as Lapwing (Vanellus vanellius), Rook (Corvus frugilegus) and Gulls (Brough & Brigeman 1980, Mead & Carter 1973). The swards thus created provide a haven for voles (Microtus sp.), which in turn attract birds of prey such as Kestrels (Falco tinnunculus) and owls (Strigidae). The final choice of habitat management technique therefore depends on the ecology of the bird species that constitute the greatest risk at the airport concerned. As well as impacting directly on the wildlife that is deterred from using the airfield, wildlife management can have more general environmental impacts. The long grass swards described above require regular inputs of chemical fertilisers to maintain good grass growth and periodic application of selective herbicides to remove broad-leaved weeds. Insecticides and lumbricides may also occasionally be used to remove invertebrates from the sward that are attracting birds, but their use is not generally encouraged because of the impact on predatory invertebrates which can result in a superabundance of prey invertebrates that requires further chemical applications to correct (Allan 1990).

Risk assessment, followed by the formulation of an appropriate habitat management plan is now becoming increasingly common as part of safety management systems at civil airports (Allan et al. 2003). Whatever the techniques used, the outcome of most airport habitat management programmes is to minimise the resources available to hazardous bird species and to lower the diversity of the aerodrome as a habitat for birds, thus simplifying the task of deterring any birds that remain. Because this process is restricted to the aerodrome, it has relatively little impact on surrounding ecosystems, but the presence of the airport may act as an interruption to wildlife corridors. Some species of conservation concern can benefit from airfield habitat management. The Skylark (Alauda arvensis) thrives in the long grass swards used to deter other species from airfields. Its small size means that it poses little threat to aircraft, but precautionary landings following strikes with small birds may still result in significant financial losses (Allan 2002). In recent years, attempts have been made to develop habitat management techniques that remove the attraction offered by aerodromes to hazardous birds whilst retaining a diverse flora and fauna (Dekker 2003). If successful, this approach has the potential to provide significant ecological benefits, especially for plant and invertebrate species, but controlled scientific evaluations have yet to be completed.
5.3.2 Management of the surrounding area

The birdstrike reduction standards imposed by ICAO do not apply directly to airports, but are instead enacted by the various countries that are signatories to the Chicago Protocol. The methods by which birdstrike hazards that arise off the airfield are controlled are therefore highly variable. Some countries employ prohibitions on particular land uses, such as landfills, within a specified distance of an aerodrome, some require consultation on a case-by-case basis, while others have little or no effective control in place. The impact of planning controls on the environment is thus impossible to quantify, but it has the potential to be significant in densely populated countries with large numbers of aerodromes and a relatively small land area. In the UK, for example, every application for a new development within 13km of a licensed civil or military airport is assessed for its potential to attract birds. The civil airport manager or the Ministry of Defence is given the opportunity to object to the development on the grounds of flight safety. It is often possible to reach a compromise solution involving a re-design of problematic applications that satisfies both the developers and aviation interests, but where developments such as nature reserves or restoration of industrial sites to areas of amenity value for the local community are concerned, biodiversity benefits are often given a high profile in the applicant’s submission. Compromises to ensure flight safety will almost always result in a reduction in the biodiversity value of the site. For example, removal of wetlands to avoid attracting hazardous waterfowl can substantially reduce the habitat diversity on a site and diminish the botanical and invertebrate interest as well as affecting the aesthetics of the design. Experience has shown that if a compromise is to be reached, an early consultation with flight safety interests is vital (Jackson & Allan 2000). It is frequently difficult to persuade applicants to change designs that have been developed over a long period and at considerable cost, whereas offering a consultant the challenge of developing a biodiverse proposal that does not attract hazardous birds from the outset of the process can produce results that are acceptable to both sides. One possible solution is to develop sites that are targeted at particular species of conservation interest rather than at a general increase in biodiversity. If a site is designed with a particular non-hazardous species in mind then it is far easier to implement design changes or management plans specifically aimed at deterring hazardous wildlife providing that it does not adversely affect the species that the site was designed to protect.

Further to this, designing for habitat rather than particular species will often satisfy the needs of the conservation advocates. In addition, if a management plan is designed to promote or protect a particular species part of the challenge presented to the designer can be to establish a target of limited numbers.

5.3.3 Managing existing attractions

The control of risks arising from sites around airports that already exist is far more problematic. Aside from the conflicting demands of commitments of national and local regulators to biodiversity on the one hand and flight safety on the other, most countries lack any sort of legislative framework that allows airports or aviation regulators to compel landowners to manage flight safety risks that arise from wildlife on their property. In many instances it may be legally impossible to undertake actions to reduce numbers of a protected species or to degrade the habitat in order to discourage them from areas close to an airport where their presence causes a flight safety risk. In the EU 7% of RAMSAR sites have aviation infrastructure within 5km of their centre, and in the UK, 15% of special bird areas are within 5km of an airfield (UK Commission For Integrated Transport 2001). These areas have statutory legal protection and attempting to manage habitat or otherwise control hazardous
bird populations may meet with practical and legal difficulties that make effective risk management impossible. One such situation has occurred at JFK International Airport, New York where Laughing Gulls (*Larus atricilla*) nest in large numbers in the adjacent Jamaica Bay Wildlife Refuge. The Port Authority, which operates the airport was unable to reach an agreement with the US Fish and Wildlife Service, which manages the wildlife refuge, to permit them to prevent nesting by the gulls in an effort to relocate the colony. This has resulted in staff from a third government agency (the US Department of Agriculture) deploying staff along the airport boundary during the gull nesting season to shoot any Laughing Gull that flies over the airport. This has proved highly successful in reducing the number of birdstrikes with Laughing Gulls by 62%.

In some circumstances it may be possible to utilise other regulatory processes to enhance flight safety. For example, all landfill sites in the UK have their operating permits periodically renewed. The Environment Agency, which is responsible for this process, is now requiring bird control to be implemented at any landfill site within 13km of a licensed aerodrome if the aerodrome operator determines that there is a birdstrike risk arising from birds feeding at the landfill.

Where there is no conflict with biodiversity issues, the main problem in achieving wildlife management objectives off the aerodrome is often one of cost. Many landowners would be only too happy to have a colony of roof-nesting gulls removed or to have flocks of geese dispersed from their fields, but they are unwilling to bear the cost of something that they do not see as their problem.

5.4 SUMMARY OF ENVIRONMENTAL IMPACTS

The direct environmental impact of aerodromes on the environment as a result of land take and the need for wildlife management on the airport to preserve flight safety is localised and small compared to other forms of transportation. The cumulative impact of controlling developments close to aerodromes to prevent wildlife attractions may be significant over longer time periods, especially in those countries where there are high densities of population. Opportunities for biodiversity enhancement on aerodromes themselves are limited, but may be possible if new developments are carefully designed to deter hazardous birds and other wildlife. Outside the airport perimeter there is considerable scope for biodiversity enhancement providing that an imaginative approach is taken at an early stage in the design process.

6. Aviation and the transport of alien species

It is well known that all transport systems are capable of transferring alien species over great distances and facilitating their entry to new geographical areas (Pimental 2002; Kelly 2004). These introductions may be extremely damaging to the receiving ecological systems and have lead to the extinction of endemic species. Alien species often become pests of agriculture, horticulture and forestry, leading to huge economic losses. These in turn require the implementation of expensive control programmes some of which are themselves ecologically destructive (reviewed by Pimental et al. 2001).

Parasites especially viruses and other directly transmitted (i.e. person to person) micro-pathogens constitute a major threat to public health but also to economic stability. For example, the SARS virus epidemic which ran from March to July 2003, involved 8439 cases of which 812 died (9.6%) (Anon 2003). But the epidemic also cost “nearly” US$100 billion, and caused massive disruption to air travel, and tourism, particularly in China, Hong Kong and
Canada. (and almost forced the cancellation of Bird Strike 2003 in Toronto!) The Millennium Ecosystem Synthesis Report (2005) observes that “An event similar to the 1918 Spanish Flu pandemic, which is thought to have killed 20 to 40 million people worldwide could now result in over 100 million deaths in a single year. Such a catastrophic event, the possibility of which is being seriously considered by the epidemiological community, would lead to severe economic disruption and possibly even rapid collapse in a World economy dependent on fast global exchange of goods and services”. It is also likely that modern Health Services in the developed world would be unable to cope with such a crisis.

Aviation provides ideal opportunities for the rapid dissemination of a highly infectious pathogen to all the major cities of the world, within a very short time (Grais et al. 2003; Enserink 2004). While considerable attention is being given to an avian flu epidemic, other zoonotic diseases are also emerging (Kelly 2004). The Millennium Ecosystem Synthesis Report (2005) warns of the growing bush meat “economy” in Africa and Asia which is “harvesting species closely related to man from which could emerge a hitherto unknown pathogen”. This might enter a city (bush meat has often been confiscated by airport customs authorities) where there is little or no Herd Immunity, and if the pathogen is highly infectious i.e. has a high $R_0$ value and is highly pathogenic then a major epidemic would follow.

Aviation is also being associated with the spread of pathogens which have evolved resistance to various drugs (Witte 2004; Roper et al. 2004). It has been suggested by Roper et al. (2004), in the context of the intercontinental spread of Pyrimethamine-resistant malaria, that careful thought should be given to preventing the further import of resistant parasites, perhaps by screening and treatment of passengers travelling from southeast Asia or South America to Africa.

Imported malaria is now relatively common in Europe, with up to 7000 cases occurring every year. However, the great majority of these cases are due to people becoming infected while travelling – mostly in Africa. Imported malaria in most temperate regions is unlikely, at present, to be transmissible via local mosquitoes i.e. become autochthonous (Gratz et al. 2000; Snow 2000), although this does appear to have occurred in both Germany (Krug et al. 2001) and Italy (Romi et al. 2001) (see also Marchant et al. 1998 and Snow 2000).

Airport malaria, though not common or involving many cases, is regarded as being serious because of possible delays in diagnosis. Airport malaria is caused by the long distance transport (mostly from West Africa) of mosquito vectors – particularly species belonging to the *Anopheles gambiae* complex. These may escape from the aircraft after its arrival and bite people living nearby. These people may become infected with malaria, though this, at least initially, might not be considered in the differential diagnosis. Another, and more worrying, scenario is where the mosquitoes are in the luggage and get transported over greater distances from the airport (Reviewed by Gratz et al. 2000). This is known as baggage malaria and diagnosis may be compromised by the apparent ‘missing link’ with a transmitting organism. It is now widely recognised that special precautions need to be taken where aircraft have departed from tropical airfields, especially in West Africa where in some areas malaria is hyperendemic and mosquitoes are very abundant. The techniques which can be employed to ‘deinsect’ aircraft are outlined by Gratz et al. (2000).

Modern aviation has an obvious potential for the rapid dissemination of infectious disease agents. Since no two points on the globe are now more than 24 hours from each other, there are unprecedented risks of transferring pathogens from remote isolated disease foci to distant densely populated, cities. The efficiency and decreasing costs of international air travel inevitably increases the risks of a major pandemic, since the receiving urban populations may have no immunity to the novel pathogen(s). The severity of such disease outbreaks (particularly those caused deliberately in biological warfare) will depend on the $R_0$ values
associated with the pathogen, its incubation period and lethality (Ferguson et al. 2003; May et al. 2001; Antia et al. 2003).

In the case of directly transmitted pathogens – of which SARS would be an example -air transport poses the greatest transport-mediated risk as it enables the rapid, widespread and multiple initiation of “chain reaction” type infection processes following contact between infectious and susceptible hosts (see Ferguson et al. 2003).

In contrast, it appears that vector borne diseases, and particularly the vectors themselves, are more effectively transported via shipping. Mosquitoes are most likely to become established in a distant receiving environment if they are dispersed by ships as larvae and pupae rather than by air as adults (Lounibos 2002).

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