Available online at www.sciencedirect.com
SCIENCE DIRECT®

Biological Conservation 125 (2005) 309–322

BIOLOGICAL CONSERVATION

www.elsevier.com/locate/biocon

Aircraft operations near concentrations of birds in Antarctica: The development of practical guidelines

Colin M. Harris *

Environmental Research and Assessment, 5 The Footpath, Grantchester, Cambridgeshire CB3 9NE, United Kingdom

Received 30 March 2005
Available online 24 May 2005

Abstract

Aircraft operations have the potential to disturb and to impact negatively on bird life. A gradient of increasing behavioural response is evident in birds when exposed to increasing aircraft stimulus. The most major disturbance is likely to lead to impacts on the health, breeding performance and survival of individual birds, and perhaps bird colonies. A process of revision to policies on aircraft operations contained in management plans for a number of specially protected areas in Antarctica by the United Kingdom, accompanied by consultations made within the scientific community through the Scientific Committee on Antarctic Research (SCAR) and with operational interests through the Council of Managers of National Antarctic Programmes (COMNAP) resulted in new guidelines being adopted by the Antarctic Treaty Consultative Parties in June 2004. The principal recommendations of the guidelines are that bird colonies should not be overflown below 2000 ft (~610 m) above ground level and landings within 1/2 nautical mile (~930 m) of bird colonies should be avoided wherever possible. These guidelines are less stringent and less specific than those that were recommended by the SCAR specialist group on birds, and represent a compromise to accommodate operational needs. While the adoption of clear and consistent guidelines for the operation of aircraft in Antarctica is welcome in that this provides practical advice that is likely to reduce incidences of close aircraft/bird encounters, there remains insufficient knowledge of the interactions between aircraft and birds in Antarctica, and the consequent impacts on individual birds and on bird populations. It is important, therefore, that the guidelines adopted are considered interim, and should be kept under scrutiny with revisions made as new and improved research results appear.

Keywords: Birds; Penguin; Behaviour; Aircraft; Overflight; Disturbance; Impact; Indicator; Guidelines; Separation distance; Antarctica

1. Introduction

Aircraft provide vital support to modern Antarctic operations and their use is widespread and increasing. In the remote and sometimes hostile environment of Antarctica, aircraft often provide the most practical means of access to sites. Both fixed-wing aircraft and helicopters are used, the former often being ski-equipped for landings on snow/ice because there are few permanent hard-rock runways in the Antarctic region. The two most common types of fixed-wing aircraft used in the region are the Lockheed Martin C-130 'Hercules' transport (4-engined turboprop of about 30 m length and 40 m wingspan, with a cruising speed of 550–650 km/h (USAF, 2001)), and the DeHavilland Twin Otter (twin engine turboprop of about 15 m length and 20 m wingspan, with a cruising speed of 274 km/h). A variety of both single- and twin-engined helicopters are deployed (e.g., Aerospatiale, Bell, Hughes, Sikorsky, and Westland models).

In terms of total biomass, the most abundant birds in the Antarctic are the penguins (Knox, 1994), all flightless, of which eight species comprising approximately 28 million pairs breed in Antarctica and on the sub-Antarctic islands (Woehler, 1993). The most populous birds,

* Tel.: +44 1223 841 880; fax: +44 870 705 2705.
E-mail address: c.harris@era.gs.

0006-3207/$ - see front matter
doi:10.1016/j.biocon.2005.04.002

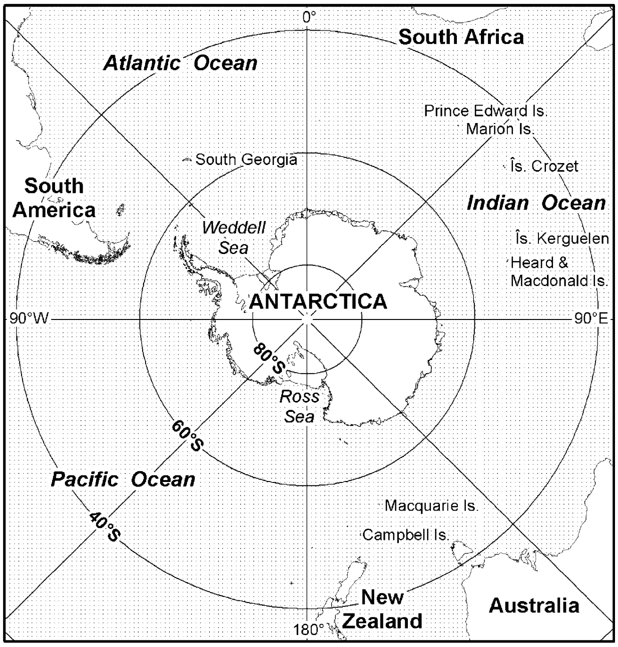

Fig. 1. Antarctica and the main sub-Antarctic islands.

however, are believed to be petrels (Stonehouse, 1985), with 24 species breeding in the Antarctic region (Hansom and Gordon, 1998). Reliable data on numbers are scarce for most petrel species in Antarctica, owing to the inaccessibility of breeding sites and the difficulties of conducting counts (Croxall et al., 1995; Patterson et al., in press).

More than 99.6% of conterminous Antarctica (Fig. 1) is covered by permanent ice (Fox and Cooper, 1994), so the amount of ice-free ground on which birds can breed is comparatively limited. Much of the ice-free land is concentrated near the coast and on off-shore islands. Being the most accessible, these places are also a focus of human activity, including for the operation of stations, conduct of science, and for tourism. Almost all aircraft operations in Antarctica occur in the summer months of October–March, which coincides with the breeding period of most Antarctic birds. Consequently, aircraft operations in Antarctica are frequently carried out near concentrations of breeding birds.

Concerns were expressed over the potential impacts of aircraft on Antarctic wildlife when approximately 7000 king penguins (*Aptenodytes patagonicus*), mostly chicks, died by asphyxiation when a stampede occurred on Macquarie Island on or around 30 May 1990 (Rounsevell and Binns, 1991; Cooper et al., 1994). The deaths occurred when large numbers of fleeing birds piled up on each other against a natural barrier at one edge of the colony. The stampede itself was not witnessed and the dead birds, piled up to 10 deep, were discovered around 10–12 days after the event. Coincidentally, an overflight by a C-130 Hercules aircraft had occurred on 30 May 1990 approximately one nautical mile out to sea from the colony at 250 m elevation. While subsequent inquiries could not definitively attribute the cause of the stampede to the overflight, it was concluded that 'a major sustained disturbance' was the most probable explanation. In the absence of any other known disturbance of such magnitude, it was concluded that the approach of the large aircraft at low altitude was the most likely factor (Rounsevell and Binns, 1991).

More recently, there has been a need to develop more explicit and practical guidelines for air access to Antarctic Specially Protected Areas (ASPAs) in management plans to meet the requirements of Annex V to the Protocol on Environmental Protection to the Antarctic Treaty (Madrid Protocol), which was agreed in 1991 and came into force on 24 May 2002. Previous management plans often lacked clear and consistent guidance for aircraft operations close to concentrations of birds. As far as possible, it is desirable that guidelines adopted are consistent across all protected areas, especially where the same species are present: confusion may result from different heights or distances being adopted at different breeding locations. This is particularly important in the context of Antarctica where there is a wide range of national operators, each following their accepted national procedures.

It is also important that any guidelines adopted are simple enough to be understood and applied easily by a wide range of operators from numerous countries, working in many different parts of the Antarctic. Yet achieving this is deceptively complex, and factors that might contribute to decisions on the 'appropriate' distance an aircraft may approach concentrations of birds are wide-ranging. For example, they include the variable interaction among the aircraft (the source), the birds (the receptor), the ambient environment (spatial context) and the timing, duration and frequency of exposure (temporal context) (Table 1). Moreover, the significance of disturbance, at any level, is ultimately a value judgement shaped by human tolerances and perceptions, which vary across people, cultures and over time. In view of the potential complexity, there is a need for guidelines that are simple enough to be applied practically, and yet are robust enough to ensure effective protection under a wide range of scenarios.

2. History of guidelines for aircraft use in Antarctica

No universal standards exist for the protection of wildlife from sound or other stressors associated with overflights (Efroymson et al., 2000: 52). Nevertheless, the US Federal Aviation Administration has established 610 m (2000 ft) above ground level (AGL) as the requested minimum altitude for aircraft flying in airspace over lands administered by the US National Park Service, Fish and Wildlife Service and Bureau of Land

Table 1
Factors influencing the interaction of aircraft and birds and the potential magnitude of impact

Source (aircraft)	Spatial and temporal context	Receptor (birds)
Type – fixed wing, rotor, non-motorised	Terrestrial, marine, or air	Species – sensitivity, flight capability
Engines/rotors – number, type, size	Surface – boulder, sand/gravel, ice, snow, water	Behaviour – response instinct (fight or flee), stress threshold, flight and movement patterns, flocking, time budget for different forms of activity, propensity to habituation
Shape/colour – size, wingspan, orientation	Terrain – rugged, slope, open, enclosed (echo)	Exposure history – 'experience'
Proximity – vertical, horizontal, and slant distance	Weather – clear, cloud, rain, snow, wind (speed and direction)	Energy budget changes
Form of action – ascending, descending, cruising, turning, accelerating, decelerating	Visibility – terrain, weather, time of day	Age
Direction of movement – approaching, departing, oblique	Predators – proximity, numbers, disposition	Stage of reproductive cycle
Speed – air, ground	Humans – proximity, numbers, activities	Colony numbers and density
Sound – frequency (kHz) and magnitude	Exposure – duration, frequency	Population abundance/rarity
Vibration	Timing – day, season, year	

Management in recognition of wildlife values (Dewey and Mead, 2000).

Various guidelines for the operation of aircraft near bird populations have been adopted for use within Antarctica. The first formal recommendations are found in the Agreed Measures on the Conservation of Fauna and Flora, adopted in 1964 by Antarctic Treaty Consultative Parties (ATCPs) through Antarctic Treaty Consultative Meeting (ATCM) Recommendation III-8. Article VII of the Agreed Measures prohibited activities likely to cause harmful interference with native fauna, such as 'flying helicopters or other aircraft in a manner which would unnecessarily disturb bird and seal concentrations, or landing close to such concentrations (e.g., within 200 m)' (Heap, 1994).

Formal steps were taken in 1963 by the New Zealand and United States national Antarctic programmes to restrict helicopter operations and other disturbance to birds by visitors at Cape Royds, Ross Island, where numbers of breeding Adélie penguins (*Pygoscelis adeliae*) had declined to almost half of their pre-1956 levels (Stonehouse, 1965; Thomson, 1977). Overflight of the colony was prohibited, and restrictions were placed on the number of visitors and their activities. The helicopter landing site was moved from within 70 m to about 250 m from the colony. Following these measures, the colony increased to its former size (Fig. 2), although strict cause and effect has not been established. Changes in colony size at Cape Royds since 1968 have reflected those in colonies throughout the region, and have been attributed to regional patterns of seasonal sea ice formation and duration rather than aircraft disturbance (Taylor et al., 1990; Martin, 1991; Wilson et al., 2001).

The ATCPs adopted management plans for three protected areas in 1992 with various restrictions on helicopter access (ASPA No. 101, Taylor Rookery, Mac. Robertson Land; ASPA No. 102, Rookery Islands, Mac. Robertson Land; and ASPA No. 103, Ardery and Odbert Islands, Budd Coast). At ASPA No. 101 it is recommended that helicopters should land on sea-ice (when conditions allow) at least 500 m from the emperor penguin (*Aptenodytes forsteri*) colony which breeds on a

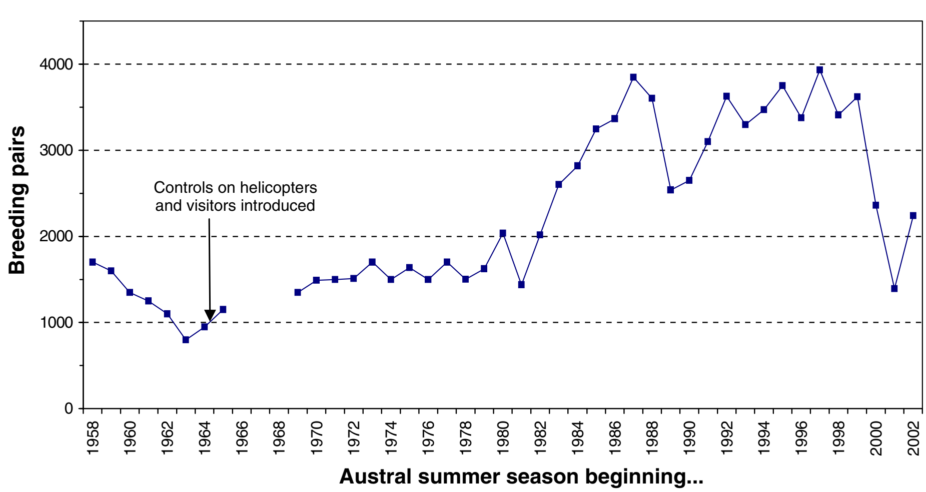

Fig. 2. Adélie penguin *Pygoscelis adeliae* population Cape Royds 1958/59-2002/03.

small island. Overflight of the colony is completely prohibited. When sea-ice is unsuitable for landings, helicopters may land on the island within 400 m of the colony at a site obscured from view of the birds by a headland. At ASPA No. 102, where the island on which landings are made is small, it is permissible to land a helicopter within 500 m of the colony 'only if it can be demonstrated that disturbance will be minimal'. Overflight is allowed for essential scientific purposes, for which it is prohibited to fly below altitudes of 500 m. At ASPA No. 103 the site identified as most suitable for helicopter landing on Ardery Island is less than 100 m from one of the breeding colonies of petrel, although it is stipulated that helicopter movements should be kept to a minimum during the breeding season of 1 November–1 April.

The Antarctic Flight Information Manual (AFIM) (SCALOP, 1995–2005) contains a number of restrictions on aircraft operations close to bird colonies. The most comprehensive and stringent guidelines are those issued by Australia, which note that it is an offence under Australian law to "fly an aircraft in such a manner as to disturb a concentration (20+) of wildlife unless authorised by a permit" (SCALOP, 1995–2005: AUS45). Australia has also issued guidelines governing the use of helicopters (included in AFIM 2005), discouraging pilots from overflying wildlife at any altitude, and more specifically prohibiting, without a permit, operation of single-engine helicopters and fixed-wing aircraft within 2500 ft (about 750 m), or a twin-engine helicopter within 5000 ft (about 1500 m), horizontally or vertically of wildlife. At Dumont D'Urville Station (managed by France), flights are prohibited below 250 m AMSL over bird colonies (SCALOP, 1995: DUMONT-3), while at Signy Station (managed by the United Kingdom) it is required that all 'low' overflights be avoided owing to the presence of bird and seal colonies, although 'low' is not defined. Many countries do not provide specific guidance on flying heights over bird colonies in the AFIM, with some suggesting that pilots 'contact the control tower' for information on any local flying restrictions.

ATCPs adopted in 2003 a revised management plan for Beaufort Island (ASPA No. 105), the site of breeding colonies of 46,000 pairs of Adélie and approximately 1300 emperor penguins. The management plan prohibits overflight of bird breeding areas lower than 750 m unless it is required for essential scientific or management purposes, when transient overflight (such as may be required for aerial census of the colonies) may be allowed down to a minimum altitude of 300 m. The areas within which these restrictions apply are shown on maps and extend at a minimum 250 m in horizontal distance from the borders of the breeding sites.

Three Nordic Antarctic programmes (Finland, Norway and Sweden) have agreed detailed environmental guidelines for the operation of aircraft in Antarctica (Modig et al., 1999). The guidelines share similarities to those adopted by Australia, and are divided into provisions for general application and those relating to specific sites. Guidelines for general application cover aircraft operations close to concentrations of wildlife (including birds, seals and whales), lakes, vegetation and station areas. Those for specific sites include stations and protected areas close to Nordic stations.

In summary and insofar as they relate to birds, the Nordic general guidelines provide that:

- aircraft should not fly or land within 2000 m vertically or horizontally from concentrations of birds or seals, where a 'concentration' is defined as 20 or more animals;
- if aircraft need to be used closer to such concentrations, then it is recommended this should be done outside of the sensitive breeding seasons for the species likely to be affected;
- flights should be postponed if conditions are such that the minimum separations cannot be maintained;
- aircraft should adopt a flight path as low to the horizon as possible; and
- landings should always be made downwind of wildlife concentrations to minimise disturbance from noise, dust and fumes.

In 2004, the ATCPs adopted a revised management plan for Svarthamaren (ASPA No. 142), Dronning Maud Land, which is protected because it contains the largest sea-bird colony on the Antarctic continent and a large proportion of the world population of Antarctic petrels (*Thalassoica antarctica*). All overflight and landings within the protected area are prohibited, although the recommended helicopter landing site – outside of the protected area boundary – lies within 350 m of the north-eastern breeding area of the birds.

In the sub-Antarctic islands, a variety of guidelines for aircraft operations have been adopted. In New Zealand's sub-Antarctic islands, helicopter use is controlled by permits specifying landing sites, overflight and approach paths on a case by case basis (NZ Department of Lands and Survey, 1983, 1984; NZ Department of Conservation, personal communication, 2001). Specifically, helicopter landings are prohibited except when necessary for scientific, emergency or other approved purposes, provided all precautions are taken against endangering or unduly disturbing plant and animal life. As a condition of all landings, low level flying within 200 m (assumed both horizontally and vertically) of any bird or seal colony during the breeding season is given as a mimimum (DoC, 1998). At Australia's Heard Island, helicopters must operate in a manner that minimises impacts on wildlife and in accordance with the guidelines in force by the Australian Antarctic Division (Australian Antarctic Division, 1995, 2002) and similar requirements apply at Macquarie Island

Nature Reserve (Australian Department of Parks, Wildlife and Heritage, 1991).

In relation to South African air operations on sub-Antarctic islands, Cooper et al. (1994) recommended that fixed-wing aircraft should normally avoid overflight below 1000 m vertically and 5000 m horizontally, reducing to 500 m vertically for passes required for essential air drops, and reducing further to an unspecified height for the drop itself. It was also recommended that helicopters avoid flying 'at low altitudes in the vicinity of, or approach or land within 500 m of king penguin breeding colonies' (Cooper et al., 1994: 281). On Gough Island, helicopter landings may only be undertaken for scientific or management purposes and must not cause 'excessive disturbance to seals and birds', and landings are not allowed within 200 m of breeding seals and penguins (Cooper and Ryan, 1993: 29). Helicopter overflight of seals and breeding penguins is to be 'kept to a minimum', although specific distance restrictions are not given.

The environmental management plan for South Georgia (McIntosh and Walton, 2000) sets out regulations on the use of helicopters. Overflight and landings are prohibited at all king penguin (*Aptenodytes patagonicus*) colonies at all times; at all albatross colonies during the breeding season; on beaches with elephant seals during the breeding season; and at certain designated fur seal breeding beaches. It is intended to develop specific flight path and approach procedures for regularly visited sites. Flight routes along the coast are set at a minimum horizontal distance of 1000 m, and at a minimum altitude of 1000 m above land in those areas where overflight is permitted (McIntosh and Walton, 2000: 63).

The Protocol on Environmental Protection to the Antarctic Treaty (Madrid Protocol), on the other hand, does not provide specific guidelines on minimum distances for the operation of aircraft near concentrations of birds or seals in Antarctica. Instead, the Madrid Protocol stipulates that flying or landing helicopters or other aircraft in a manner that 'disturbs concentrations' of birds and seals constitutes 'harmful interference', which is prohibited except in accordance with a permit. What constitutes 'disturbance' or a 'concentration' are not defined. Table 2 summarises examples of existing guidelines for aircraft use in the Antarctic and sub-Antarctic environment.

3. Experimental evidence on the effects of aircraft operations on Antarctic birds

Outside of Antarctica, numerous studies have been conducted on the effects of low-altitude overflight on wildlife, covering a wide range of species and aircraft types (Efroymson et al., 2000:56–62). Such studies have allowed a Lowest Observed Adverse Effects Level (LOAEL) threshold to be identified for some species, although the authors point out that consensus on what level of effect is considered 'significant' remains elusive (Efroymson et al., 2000: 51). Criteria used to judge an 'adverse effect' has often been whether birds take flight. This criteria is probably the easiest to observe, although it is not necessarily a consistent or reliable indicator of the level of stress suffered by birds. Undetected adverse effects may occur prior to the flight threshold being reached, such as changes in stress levels and bioenergetics, or in reproductive behaviour. Incubating birds are instinctively reluctant to abandon eggs or chicks, and may suffer higher stress levels before taking flight than would otherwise be the case. Moreover, different criteria are clearly needed to judge 'adverse effect' levels for flightless birds.

Reviewing a variety of studies of the effects of overflight on species of raptor, Efroymson et al. (2000) noted that at least 18 different LOAEL distances have been identified where 'taking flight' was used as the indicator of 'adverse effect', ranging from 30 to 1600 m from the overflight. Although this distance range seems wide, 90% of the LOAELs occurred closer than 340 m to overflights. This suggests that if overflights near raptors were required to be >340 m from the birds, then in 90% of cases no adverse effects should be observed, at least in terms of birds taking flight. Similar studies and comparisons have been made for waterfowl, with a general trend that LOAELs occur in these birds much further from the source. Waterfowl commonly took flight at distances of more than 1 km from an overflight, and in some cases 15 km or more (Efroymson et al., 2000: 52). Efroymson et al. (2000) were careful to emphasise that none of the LOAELs identified are direct measures of the impacts of overflight on species abundance or production.

Fjeld et al. (1988) found that in some instances Brünnich's guillemots (*Uria lomvia*) were prompted to take flight from their cliff habitat in Svalbard when a helicopter operated six kilometres away. However, their experiments showed that the flight reactions of birds were strongly influenced by whether the birds were breeders, and both by the position of the aircraft and the direction in which it was travelling in relation to the colony. Flight responses were principally by non-breeders, particularly when the aircraft made a direct approach to the colony from in front of, and at about the same height as, the cliff. Significantly more birds took flight as helicopter noise increased. Mexican spotted owls (*Strix occidentalis lucida*), on the other hand, were only likely to take flight when aircraft approached closer than 105 m (Delaney et al., 1999). In common with Brünnich's guillemots, breeders were less likely to take flight in response to helicopter disturbance than non-breeders. In both cases a gradient of more agitated behavioural responses could be identified as aircraft disturbance intensified.

These studies illustrate the species-specific nature of bird responses to aircraft stimuli, and emphasise the

Table 2
Examples of guidelines adopted for aircraft operations in the Antarctic/sub-Antarctic

Year	Originator	Location	Aircraft type	Number of engines	Minimum distance (m)	
					Vertical	Horizontal
1963	US/NZ	Cape Royds	Helicopter	Ns	ns	250
1964	Treaty Parties	Antarctica – agreed measures	Helicopter	Ns	200	200
1983	New Zealand	Campbell Island	Helicopter	Ns	200	200
1984	New Zealand	Snares Island	Helicopter	ns	OP[a]	ns
1991	Treaty Parties	Antarctica – Environmental protocol	All	All	ns	ns
1992	Treaty Parties	Taylor Rookery (ASPA-101)	Helicopter	ns	OP	500 (350[b])
1992	Treaty Parties	Rookery Islands (ASPA-102)	Helicopter	ns	500	<500[c]
1992	Treaty Parties	Ardery and Odbert Islands (ASPA-103)	Helicopter	ns	500	<500[d]
1993	South Africa	Gough Island	Helicopter	ns	ns	200[e]
1994	South Africa	Sub-Antarctic Islands	Fixed-wing	All	1000[f]	5000
1995	Australia (AFIM)	Antarctica	All	All	200	200
1995	Australia (AFIM)	Antarctica (additional guidelines)	Helicopter	1	500	1000
			Helicopter	2	1000	1000
1995	Australia	Heard Island and Macquarie Island	Helicopter	1	500	1000
			Helicopter	2	1000	1000
1995	France (AFIM)	Dumont D'Urville	All	All	250	ns
1995	UK (AFIM)	Signy Island	All	All	'low' OP	ns
1997	Treaty Parties	Beaufort Island (ASPA-105)	Helicopter	1 or 2	750	250
			Fixed-wing	All	300	250
1999	Treaty Parties	Svarthamaren (ASPA-142)	Helicopter	1 or 2	OP	500 (350[g])
1999	Finland, Norway, Sweden	Antarctica (recent published guidelines)	All	All	2000	2000[h]
2000	UK	South Georgia	Helicopter	1 or 2	OP[i]	1000
2000	Australia	Antarctica (recent published guidelines)	Helicopter	1	750	750
			Helicopter	2	1500	1500
2002	US	Antarctica[j]	Helicopter	1	750	750
			Helicopter	2	1000	1000
			Fixed-wing	1–2	450	450
			Fixed-wing	4	1000	1000
2002	Germany	Antarctica[k]	Helicopter	2	1000	1000
			Fixed-wing	2	450	450
2002	IAATO[l] (Quark Expeditions)	Antarctica	Helicopter	1 or 2	OP	750/1500[m]

Key: OP – overflight prohibited, ns – not specified.
[a] Prohibited within the Oct–Apr breeding season, otherwise allowed for essential purposes.
[b] Distance of recommended landing site from traditional breeding area of emperor penguins.
[c] Provided it can be demonstrated disturbance will be minimal.
[d] Can land less than 500 m from colony provided it can be demonstrated disturbance will be minimal, but all overflight must be no less than a horizontal distance of 500 m from the colony. Preferred landing site on Ardery Island <100 m from petrel colony.
[e] Refers to landings, with distances for overflight not specified.
[f] Reducing to 500 m vertical and 2000 m horizontal for air drop passes, and less for the drop itself (recommendations by Cooper et al., 1994; applying at Marion Island).
[g] The text of the management plan recommends landings at least 500 m from the boundary, although the designated helicopter landing site is shown on the plan map as 350 m from the boundary and bird breeding areas.
[h] When aircraft are to be used closer than the minimum stipulated, this should be outside of the breeding/weaning period (Modig et al., 1999).
[i] Prohibited over all king penguin breeding colonies at all times; specific other areas prohibited at breeding times; 1000 m vertical limit over areas where overflight is permitted.
[j] The US used the interim guidelines proposed in IP-39 (United Kingdom, 2001) to guide access policies in revised management plans for protected areas.
[k] Germany followed the interim guidelines proposed in IP-39 (United Kingdom, 2001) as they are applicable to their operations.
[l] International Association of Antarctica Tour Operators. Guidelines in use supplied by Quark Expeditions.
[m] Helicopters must not fly <750 m in altitude laterally to each side of wildlife concentrations, and helicopter landing sites must be >1500 m from concentrations. The term 'concentration' is not defined in the guidelines.

difficulties in transferring results from one context to another to guide aircraft operations, especially one as different as Antarctica. There have been few experimental studies to measure the effects of aircraft operations on Antarctic birds. Observations have been reported for only a few species: Adélie penguins (e.g., Stonehouse, 1963, 1965; Ainley et al., 1983; Culik et al., 1990; Taylor et al., 1990; Wilson et al., 1991; Giese, 1996), king penguins (Rounsevell and Binns, 1991; Cooper et al., 1994) and emperor penguins (Kooyman and Mullins, 1990; Regel and Pütz, 1997; Giese and Riddle, 1999) (Table 3).

A number of studies have examined the effects of human disturbance on Antarctic penguins (e.g., Wilson et al., 1989, 1990; Nimon and Stonehouse, 1995; Giese,

Table 3
Distance at which 'disturbance' was apparent in Antarctic birds in experimental flight observations

Study	Aircraft Type, No. of engines	Species	Distance at which 'disturbance' was observed					
			Vertical (m)			Horizontal (m)		
			Behavioural response[a]			Behavioural response[a]		
			Minor	Moderate	Major	Minor	Moderate	Major
Helicopter								
Sladen and Leresche (1970)	Bell LH-34, 2	*Pygoscelis adeliae*	914	457	300	N	N	183
Taylor et al. (1990)	ns	*Pygoscelis adeliae*	610	N	N	N	N	N
Culik et al. (1990)[b]	Sea King, 2	*Pygoscelis adeliae*	N	N	50	<1500	N	200–1500[d]
Wilson et al., 1991	Super Puma AS332, 2	*Pygoscelis adeliae*	50 m constant[c]			600–1500[d]	ns	400–1250[d]
Cooper et al., 1994	Super Puma AS332, 2	*Aptenodytes patagonicus*	ns			500	N	N
Giese et al., 1999	Sikorsky S-76, 2	*Aptenodytes forsteri*	1000 m constant[c]			Mostly minor; distances ns		
Stone and Shears (personal communication, 2003)	Westland Lynx, 2	*Aptenodytes patagonicus*	1768	N	N	ns	N	N
Fixed-wing								
Wilson et al., 1991	Twin Otter DHC-6, 2	*Pygoscelis adeliae*	80 m constant[c]			1000–600[d]	500	N
Kooyman and Mullins, 1990	Hercules C-130, 4	*Pygoscelis adeliae*	1500	N	N	N	N	N
Wilson et al. 1991	Hercules C-130, 4	*Pygoscelis adeliae*	50 m constant[c]			1100–2500[d]	500–2300	350
Cooper et al., 1994	Hercules C-130, 4	*Aptenodytes patagonicus*	100–300 m[c]			ns	ns	<500
Cooper et al., 1994	Hercules C-130, 4	*Diomedea exulans*	'low level', presumed overhead			N	N	N

Key: *A* – *Aptenodytes*, N – Response at this level not observed, ns – not specified.
[a] The strengths of behavioural response recorded in the different studies are not directly comparable, and this classification into 'Minor', 'Moderate' and 'Major' is intended as a general guide. *Minor* is taken as the distance at which birds first showed visible reactions (e.g., neck craning, wing-flapping), *Moderate* where a large proportion of birds (30–70%) began more vigorous displays or moving away, while *Major* is where more than 70% of birds began moving away, or many began running or panicked. For specific explanations of the reactions of the birds the reader is referred to the papers referenced.
[b] This study focused on measuring heart rates, not behaviour with distance: only behavioural observations are included here.
[c] The reaction of the birds was noted for constant flying heights, with varying horizontal distance: the reactions are therefore presented only in horizontal distance columns.
[d] Where two distances are given, the first refers to the approach distance at which disturbance was observed to cause this reaction, while the second figure is that at which the reaction ceased as the aircraft receded.

1998; Fraser and Patterson, 1997; Nimon, 1997; Cobley et al., 2000), although only a few have made controlled observations or measurements of the effects of aircraft (Sladen and Leresche, 1970; Taylor et al., 1990; Culik et al., 1990; Giese and Riddle, 1999; Stone and Shears, personal communication, 2003). Several studies have considered human impact on other species, such as skuas (*Catharacta* sp.) (Hemmings, 1990; Young, 1990) and southern giant petrels (*Macronectes giganteus*) (Chupin, 1997), although these were not specifically concerned with the effects of aircraft. The latter study attributed poor breeding performance among southern giant petrels on Fildes Peninsula, King George Island, to low aircraft overflight (in some instances less than 50 m), helicopter activity and other direct human disturbance on the ground. At the same locality, Pfeiffer et al. (2003) measured levels of an excreted glucocorticoid hormone in skuas as an indicator of stress that might be arising from nearby aircraft operations. Although non-breeding birds were observed to take flight when aircraft flew nearby (less than approximately 200 m), hormone levels did not indicate a change in stress in either non-breeders or breeders, although results are preliminary and further work is planned (Pfeiffer, personal communication, 2003).

Sladen and Leresche (1970) observed the behaviour of Adélie penguins in response to an LH-34 US Navy helicopter operating at various altitudes with a ground speed of around 40 knots at Cape Crozier, Ross Island. In summary, they observed that when this aircraft operated at altitudes of less than about 500 m over the birds, disturbance to their behaviour became 'moderate' or 'great', which was classified on the basis of the percentage of birds exhibiting reactions such as displays or moving from their territories. These authors recommended that a minimum altitude for overflight of Adélie penguins by a helicopter should be 610 m (2000 ft), although they acknowledged that even at this altitude there was still some disturbance evident. They also noted that overflights using fixed-wing aircraft (such as a Twin Otter) at the same elevation generally caused less disturbance, although controlled observations of fixed-wing aircraft were not undertaken.

Taylor et al. (1990) also made observations of the effects of aircraft passes over Adélie penguin colonies during preparations for a regular aerial census programme of colonies in the Ross Sea region. These authors reported findings similar to Sladen and Leresche (1970) in relation to helicopter movements. They also observed overpasses by C-130 Hercules fixed-wing aircraft, and did not detect visible signs of disturbance when flying above 300 m (984 ft) over the birds. Detection of signs of disturbance more subtle than running may have been difficult, however, because observations were made from the aircraft and not on the ground.

Culik et al. (1990) reported that helicopters approaching within 300–400 m of an Adélie penguin colony caused noticeable behavioural responses among the birds, such as running away from the aircraft. Late in the breeding season helicopter activity as distant as 1500 m caused 'panic runs' and 'escape reactions', even in areas where helicopters had not approached closer than 400 m (p. 181). In addition to behavioural observations, heart-rate levels in a number of Adélie penguins were monitored. When subjected to a helicopter operating within 20 m, the heart rate of one adult bird was elevated to the highest recorded, although, perhaps because of the small sample size, there was no statistical difference between the rate observed as compared with those measured when incubating adult birds stood without any aircraft stimulus, as they might a few times an hour (Culik et al., 1990: 197). Techniques employed to measure heart rates in response to aircraft stimulus in this study involved human handling of birds that were later used in the observation, which some authors suggest could skew results (Nimon and Stonehouse, 1995; Nimon, 1997).

The behaviour of Adélie penguins in response to aircraft has also been observed when the birds were commuting between nests and the sea (Wilson et al., 1991). A graded form of response was observed as aircraft approached, with birds first "stopping any locomotory movement, then moving directly away, initially walking, then running, and finally tobogganning." (p. 365). Much stronger and more prolonged responses were provoked by a Hercules C-130 aircraft than a Twin Otter. Initial reactions were first noted when both aircraft were approximately 1000 m distant, but while only about half of the birds moved away in the case of the Twin Otter when it approached to within 500 m, all did so when the Hercules was at the same distance. The Hercules provoked 75% of birds to toboggan away when it passed within 350 m, while only about 10% tobogganed when the Twin Otter was at the same distance. Furthermore, bird responses were observed to return to normal after the Twin Otter had retreated to 600 m distance, while this did not occur until the Hercules was 2300 m away. In the case of an overflight by a Super Puma helicopter, the distance at which reactions were first noted was only 600 m, with behaviour returning to normal after the aircraft had retreated to 1500 m.

Wilson et al. (1991) also observed the heart rates of adult Adélie penguins on nests with chicks in response to a helicopter operating to within 25 m. The heart rate rose from a mean resting value of 83.4 beats per minute (bpm) to a maximum value of 286 bpm, although birds did not move from their nests and outward behavioural responses were limited to head movements. Heart rates increased as helicopter–penguin distance decreased, although were shown to decrease again with increasing exposure time. Observations were also made of the numbers of birds present in defined sub-colonies during exposure to helicopter overflights: the total number of active nests declined by 8% over three days, implying some chick mortality was attributable to aircraft operations. Exact chick mortality was difficult to determine, however, since it remained unknown how many of those nests would have deserted without the aircraft stimulus.

Giese and Riddle (1999) observed creching emperor penguin chicks when they were exposed to two overflights by a Sikorsky S-76 twin-engine helicopter at 1000 m. They reported that all chicks became more vigilant when approached by the helicopter (at an air speed 60 knots), and almost 70% either walked or ran, generally less than 10 m, toward other chicks. Most displayed flipper-flapping, which was seldom displayed in the absence of the aircraft. Although the effects were found to be transitory, the authors suggested the results supported the "introduction of a more conservative guideline of 1500 m (5000 ft) minimum overflight altitude for helicopter operations around breeding localities of this species" (p. 366).

Stone and Shears (personal communication, 2003) carried out a series of controlled observations of king penguins (*Aptenodytes patagonicus*) exposed to overflights by a twin-engine Westland Lynx helicopter at Antarctic Bay, South Georgia. Seventeen overflights of a colony were conducted at elevations ranging from 1768 m down to 230 m over an 8-day period between 10 and 20 December 2000, with the highest overflights taking place at the start of the experimental period. Their results showed that all birds in the colony exhibited a significant increase in behavioural patterns classified as 'stressed' during overflights. The increase in 'stressed' behaviour was in part explained by the greater number of birds moving about in the colony as a result of aircraft presence, precipitating more aggressive territorial encounters between penguins. There was a higher probability that birds would display 'stressed' behaviour during the early overflights in the experimental period, despite the fact that these were at higher altitudes, suggesting that to some degree the birds became habituated to the aircraft. Nonetheless, adult non-incubating birds were more likely to display stressed behaviour as overflight altitudes reduced, although there was no similar increase in stressed behaviour evident in incubating birds. Contrary to expectation, no significant relationship was found between helicopter noise levels and the proportion of adult birds displaying stressed behaviour.

This led the authors to suggest that the visual presence of aircraft may affect bird stress levels to a greater degree than noise, perhaps because the birds associate aircraft with natural aerial predators.

A range of behavioural responses by penguins to aircraft stimuli were identified in some of the above studies (Sladen and Leresche, 1970; Kooyman and Mullins, 1990; Wilson et al., 1991; Giese and Riddle, 1999; Stone and Shears, personal communication, 2003). While all differ in the precise method of classification, there is general agreement that more active and aggressive forms of response are elicited by higher levels of disturbance. In general, aircraft detection is initially indicated by changes to the level of alertness displayed by birds, such as by an increase in head movements. With increasing stimulus, the usual patterns of calling, displays, stances or movements of the birds tend to change: calling may cease or increase; walking birds may stop; stationary birds may start to walk; sitting birds may stand up; and wing-flapping and other displays may also increase. Further increase in the stimulus tends to result in a greater proportion of birds actively engaging in these responses, and higher proportions walking or starting to run. At the highest levels of stimulus observed in these studies, a high proportion of birds either walk, run, or 'toboggan' (where penguins use their wings and feet to propel themselves over snow/ice surfaces on their stomachs) away at speed, ultimately in panic. Such responses may result in increased egg or chick predation, and injury or death of birds could occur either directly or indirectly in some circumstances (Cooper et al., 1994).

Observations made of the distance at which 'disturbance' was apparent in birds as a result of aircraft are summarised from the above Antarctic studies in Table 3. Where possible, the immediate behavioural responses provoked by aircraft operating at certain distances have been classified according to whether they could be considered minor, moderate or major. Because of the different methods and behavioural classifications used in the various studies, this comparison in Table 3 is intended as no more than a guide.

In an attempt to improve the comparability of such classifications, Fig. 3 proposes a 'Disturbance Scale' that relates commonly observed behavioural responses and/or overall outcomes to the likely relative magnitude of impact. The scale combines two categories of impacts arising from disturbance: immediate behavioural responses, and longer-term population outcomes, the latter being considered the 'ultimate criterion of detrimental change in a species' (Nimon and Stonehouse, 1995, p. 422). More minor responses or outcomes are expected at the 'Detection' end of the scale. At the other, population decline, deterioration in health, injury or death are considered as 'major' outcomes of disturbance. Interpretation of the magnitude of impact will also be influenced by spatial and temporal aspects such as the numbers, or proportion, of birds affected, and the duration for which detectable impact remains. Care must be exercised when translating the strength of behavioural responses into levels of 'stress', especially if comparing birds of different species and breeding stage.

It is important to note that outcomes such as declines in population, in reproductive performance or in health may not be demonstrated in specific behavioural responses, and can be difficult to attribute to impact source. Many species experience wide natural fluctuations in these variables, and it can prove difficult to separate natural from human-induced change. More research is needed to develop reliable indicators in these areas.

4. Discussion: the need for interim guidelines

Aircraft are operating, and will continue to operate, in proximity to concentrations of birds in Antarctica, and pilots would benefit from access to clear and consistent guidelines on acceptable – perhaps precautionary – approaches to the operation of their aircraft in these contexts. Pilots are usually keen to minimise the environmental impacts of their operations, although often lack the expert guidance needed to enable this to be

Disturbance Scale	Detection	Distraction Disquiet	Discomfort	Distress	Decline Damage Disease	Death
Behavioural Response / Outcome	Source of disturbance perceived but minimal reaction eg. head turning	Change to usual patterns of calling / displays / stances	Active vigilance, more vigorous displays, some birds (<50%) walking / taking flight	Panic reactions, aggressive defence / attack, many birds walking / taking flight (>50%) , or >5% running	Deterioration in health or reproductive performance, physical injury, population decline	Mortality: Direct – eg. collision with source Indirect – eg. increased predation, starvation
Likely Magnitude of Impact		Minor		Moderate		Major

Fig. 3. Disturbance scale and likely impact magnitude – the "D-scale".

achieved. However, guidelines also need to be practical, as over-precautionary approaches have the potential to be unreasonably restrictive on air operations, and could severely curtail flight operations or compromise margins of safety.

The variety of species, aircraft, spatial and temporal contexts, and methodologies employed in the studies reviewed in this paper highlights the difficulty of developing generic guidelines for the use of aircraft close to birds. Indeed, these difficulties have led some to the view that it is "impossible ... to generate generic tolerance distances which are useful" (Hill et al. 1997). The weaknesses of generalising on the basis of research to date are recognised, and the on-going need for site-specific environmental assessments clearly remains. However, the alternatives of proceeding with a range of inconsistent guidelines in the multinational context of Antarctica, or of rejecting all guidelines and insisting that every flight be assessed on its own specific merits, may be even less useful.

Most research has shown that reactions to aircraft disturbance by birds of a given species and breeding status are usually more minor with greater distance from, and/or time since, the stimulus. The studies reviewed by Efroymson et al. (2000) illustrate that, given the development of suitable criteria and a sufficient number of controlled studies, it should be possible to develop general guidelines for aircraft operations based on probable outcomes, at least for application to certain species. In the case of Antarctica, the situation is perhaps relatively more manageable than in many other parts of the world because fewer species are present.

In relation to disturbance to penguins, Nimon and Stonehouse (1995) were confident that human behaviour guidelines appropriate to varying factors such as group size, species and breeding stage could be developed, given better understanding of the interactions between humans and penguins in terms of:

(a) what stimulus aspects of human behaviour affect penguins;
(b) the changes in behaviour and physiology induced in penguins in the short and long terms; and
(c) the contextual variables which modify penguin reaction.
(d) Even the few studies that have been conducted to date examining the effects of aircraft on birds in Antarctica have shed considerable light in these areas.

The urgent need for more empirical data on which to base guidelines for air operations in the Antarctic is acknowledged, but in the interim there remains an immediate need for practical guidelines that can be followed, and other aids such as overflight awareness maps, that can assist pilots, aircrew and management to make better informed judgements about the likely effects of their operations before they are carried out.

In relation to protected areas, specific procedures for site access, including air access, need to be written into the management plans required by Annex V to the Madrid Protocol. Development of air access policies for these sites cannot wait until the research required to determine definitive effects thresholds is completed. Policies are being developed on minimum flying distances, both horizontally and vertically, and in relation to selection of suitable landing sites. There has emerged a range of recommended distances, some of which differ for the same species at different sites although without any clear basis for the variation. An agreed set of interim guidelines would assist formulation of management plans, leading to greater consistency where appropriate, and enable more practical implementation by pilots in the field. If departure from guidelines is necessary for a specific site or circumstance, at least the rationale for that variation can be made more explicit.

Discussions with a number of Antarctic ornithologists throughout the process of preparing draft management plans suggested that a scientific consensus on minimum distances might be possible for the purpose of interim guidelines. Table 4 presents a summary of suggested minimum heights and distances developed after consultation with ornithologists reviewing a number of draft protected area management plans. Table 4 incorporates recommendations made by the Scientific Committee on Antarctic Research (SCAR) Bird Biology Subgroup, which supported the need for interim guidelines on air operations close to concentrations of birds in Antarctica after consideration of an earlier version (Harris, 2000) at SCAR, 2000 (Tokyo) (SCAR, 2000).

At this stage the recommendations do not differentiate between species, since a clear scientific basis to do so is not yet available, although perhaps this is desirable and will eventually be possible when sufficient research has been completed. Questions may arise over what distances would be appropriate for sites where there are

Table 4
Minimum horizontal and vertical separation distances for aircraft operations close to concentrations of birds in Antarctica as recommended by the SCAR Bird Biology Subgroup (from SCAR, 2000)

Aircraft type	Number of engines	Minimum distance			
		Vertical (above ground)[a]		Horizontal	
		Feet	Metres	Feet	Metres
Helicopter	1	2461	750	2461	750
Helicopter	2	3281	1000	3281	1000
Fixed-wing	1 or 2	1476	450	1476	450
Fixed-wing	4	3281	1000	3281	1000

[a] Heights are above the ground on which birds are present, not mean sea level.

multi-species assemblages, although guidance could be set according to the needs of the most sensitive species present. As recommended minimums, however, there is nothing to prevent countries and/or operators from adopting more rigorous standards should they so choose.

It should be recognised that there may be circumstances in which it might actually be desirable to exceed guidelines, which by their nature are for general application. For example, it may be necessary for research itself examining the impacts of aircraft operations on birds. Aerial operations deemed essential for some greater benefit might be assigned priority over impacts accruing to a locally resident bird colony. In such cases, site- and event-specific environmental impact assessment is required, and the criteria offered in Fig. 3 may be a useful aid to distinguish the significance of impacts from minor and immediate behavioural responses to more serious long-term impacts on survival. It is important to note that because of the complexity of particular circumstances, and also the present rudimentary state of our knowledge of the impacts that may result from aircraft operations on birds, the proposals are intended as *guidance*, and not as strict regulations.

The interim guidelines proposed in Table 4 were submitted for further consideration to the XXV ATCM (United Kingdom, 2002). Additional practical measures related to the location and timing of aircraft operations were also suggested for pilot consideration (Table 5), with the aim of heightening awareness of potential causes of pressure on birdlife that could otherwise be avoided. These recommendations were based primarily on guidelines developed by the Australian Antarctic Division (2002) and the Nordic Antarctic programmes (Modig et al., 1999).

These proposals were referred by the ATCPs to the international Council of Managers of National Antarctic Programs (COMNAP) for consideration against practical issues of operational management. COMNAP is a forum in which information and expertise on Antarctic logistics and operations is shared among national operators. COMNAP (2004) reported its conclusions to the XXVII ATCM, and these formed the basis of the interim guidelines for aircraft operations close to concentrations of birds in Antarctica adopted by the ATCPs (2004). The adopted guidelines recommended that penguin, albatross and other bird colonies should not be over flown below 2000 ft (~610 m) Above Ground Level, except when operationally necessary for scientific purposes, and landings within 1/2 nautical mile (~930 m) of bird colonies should be avoided wherever possible. Other guidelines adopted are similar to those presented in Table 5.

The guidelines adopted by the ATCPs are less complex and also less stringent than those recommended by the SCAR Bird Biology Subgroup (Table 4), illustrating a difficulty that sometimes arises over the need to balance scientific recommendations against practical operational needs. COMNAP (personal communication, 2004) explained that the guidelines submitted to the ATCM took biological advice into account, but needed to balance this against the range of site access required by all scientists in Antarctica. COMNAP noted the relatively few empirical studies on interactions

Table 5
Suggested additional guidance to pilots operating aircraft close to concentrations of birds in Antarctica (after Australian Antarctic Division, 2002; Modig et al., 1999)

Location of aircraft operations

- Where practical, avoid overflying concentrations of birds
- Concentrations of birds are most likely to be found in coastal areas. When operating in coastal areas, keep above the minimum vertical and horizontal separation distances given in these guidelines where possible
- Minimise the time spent overflying coastal areas. If practical, cross the coast at 90° rather than flying along the coastline
- Aircraft landings should be as far away as practical from concentrations of birds. Do not land within the horizontal separation distances given in these guidelines, except in emergency situations or in accordance with a permit issued by an appropriate national authority
- Where practical, landings near to concentrations of birds should be downwind and/or behind a prominent physical barrier (e.g., hill) to minimise disturbance
- Avoid Antarctic Specially Protected Areas (ASPAs), unless authorised by a permit issued by an appropriate national authority to overfly and/or land. For many ASPAs there are specific controls on aircraft operations, which are set out in the relevant Management Plans
- Follow aircraft flight heights, preferred flight paths and approach paths contained in the Antarctic Flight Information Manual (AFIM), in station aircraft operation manuals and on relevant charts and maps
- Avoid steep banking turns in flight as this significantly increases the amount of noise generated

Timing of aircraft operations

- Most Antarctic birds breed at coastal locations between October and April. When planning aircraft operations near bird concentrations, consider undertaking flights outside of the main breeding season
- Where aircraft operations are necessary close to concentrations of birds, then the duration of flights should be the minimum necessary
- To minimise bird strikes, especially in coastal areas, avoid flying after dark between October and April. Prions and petrels are active at night when breeding, and are attracted by lights
- Aircraft operations should be delayed or cancelled if weather conditions (e.g., cloud base, winds) are such that the suggested minimum vertical and horizontal separation distances given in these guidelines cannot be maintained

between aircraft and wildlife that have been undertaken in the Antarctic and that guidelines need to be workable for, and acceptable to, a wide range of countries operating throughout the region. Thus, while less stringent than recommended by biologists, the guidelines were considered a reasonable compromise between the best available scientific evidence and anticipated operational needs.

Given the paucity of scientific studies, the recommendations of SCAR Bird Biology Subgroup were of necessity based on the personal experience of those biological specialists consulted and their 'professional judgement'. However, the lack of scientific data itself led operations specialists considering the guidelines within COMNAP to question the basis of the SCAR recommendations, themselves exercising 'professional judgement' from the perspective of the need to maintain practical aircraft operations in a highly demanding environment. At the political level, decisions within the Antarctic Treaty System require consensus among all ATCPs, which can result in outcomes that are only acceptable to the least willing party. All groups considering the guidelines have stressed the need for taking a precautionary approach, a requirement written into the Madrid Protocol. However, the fundamental problem remains – what should be considered 'precautionary' when quantitative scientific data are so lacking as to provide no definitive guidance? Unfortunately, this situation requires that we proceed on the basis of opinion, judgement, and even conjecture until the requisite science is undertaken.

Agreement of guidelines does not replace the need for specific on-site assessments and for judgements on variations to be made in particular circumstances. Moreover, the problem itself remains complex because of the large number of variables that need to be taken into account. For example, aircraft of equivalent size and engine capacity can differ markedly in their noise profiles, and even if operating to the same guidelines in similar situations could produce very different reactions by various bird species. On the other hand, it would be impractical to develop workable guidelines that covered every aircraft in every possible situation. Aircrew and passengers should remain attentive to signs of disturbance at all times with a view to adjusting operational procedures when required.

It is important to emphasise that substantially more research is required to provide a robust scientific basis for guidelines of this nature, as might be desired in the longer term. As such the guidelines adopted must be kept under review and developed further as more experience is gained, and as new information and research results appear. Nevertheless, even interim guidelines should assist site-specific assessments and help to make the basis of flight policies more clear and consistent. Despite their acknowledged weaknesses and limitations, it is to be hoped that the guidelines will help to avoid disturbance, especially of the magnitude reported by Rounsevell and Binns (1991). The guidance adopted may be useful as a model to assist development of guidelines tailored for the use of aircraft close to other forms of wildlife in Antarctica, and perhaps in other parts of the world.

Acknowledgement

The author acknowledges comments received from the UK Antarctic Protected Areas Project Steering Committee (M. Richardson, N. Gilbert, D. Walton, J. Shears), the SCAR Bird Biology Subcommittee (J. Cooper, J. van Franeker, Y. le Maho, E. Woehler), and COMNAP (A. Guichard, Executive Secretary). Individually, thanks are due to the following: K. Barton, I. Boyd, J. Cooper, J. Croxall, R. Stone, P. Trathan, and P. Wilson. Data on numbers of Adélie penguins at Cape Royds were kindly supplied by K. Barton and P. Wilson. Updates on current national and industry practice were kindly provided by J. Cooper (South Africa), W. Dinter (Germany), A. Fairbanks (USA), D. Landau (IAATO), B. Njåstad (Norway), W. Stambach (Quark Expeditions), E. Waterhouse (New Zealand), and E. Woehler (Australia). Valuable comments from the referees were greatly appreciated. Funding from the Government of the British Antarctic Territory for the preparation of this paper is very gratefully acknowledged.

References

Ainley, D.G., LeResche, R.E., Sladen, W.J.L., 1983. Breeding Biology of the Adélie Penguin. University of California Press, Berkeley.

ATCPs (Antarctic Treaty Consultative Parties), 2004. Resolution 2 (2004): Guidelines for the operation of aircraft near concentrations of birds in Antarctica. Final Report of the XXVII Antarctic Treaty Consultative Meeting, Cape Town, South Africa, 24 May– 4 June 2004.

Australian Antarctic Division, 1995. Heard Island Wilderness Reserve Management Plan. Australian Antarctic Division, Kingston.

Australian Antarctic Division, 2002. Flight Paths for Helicopter Operations in Australian Antarctic Territory. Australian Antarctic Division, Kingston.

Australian Department of Parks, Wildlife and Heritage, 1991. Macquarie Island Nature Reserve Management Plan. Department of Parks, Wildlife and Heritage, Hobart.

Culik, B., Adelung, D., Woakes, A.J., 1990. The effect of disturbance on the heart rate and behaviour of Adélie penguins (*Pygoscelis adeliae*) during the breeding season. In: Kerry, K.R., Hempel, G. (Eds.), Antarctic Ecosystems: Ecological Change and Conservation. Springer-Verlag, Berlin, pp. 177–182.

Chupin, I., 1997. Human impact and breeding success in Southern Giant Petrel Macronectes giganteus on King George Island (South Shetland Islands). Korean Journal of Polar Research 8 (1, 2), 113–116.

COMNAP (Council of Manager of National Antarctic Programs), 2004. Working Paper on guidelines for the operation of aircraft near concentrations of birds in Antarctica. Working Paper WP-010, XXVII Antarctic Treaty Consultative Meeting, Cape Town, South Africa, 24 May– 4 June 2004.

Cooper, J., Ryan, P.G., 1993. Management Plan for the Gough Island Wildlife Reserve. Edinburgh, Tristan de Cunha.

Cooper, J., Avenant, N.L., Lafite, P.W., 1994. Airdrops and king penguins: a potential conservation problem at sub-Antarctic Marion Island. Polar Record 30 (175), 277–282.

Croxall, J.P., Steele, W.K, McInnes, S.J., Prince, P.A, 1995. Breeding distribution of the Snow Petrel Pagodroma nivea. Marine Ornithology 23 (2), 69–99.

Davison, W., Shears, J.R., Roderick, H. Downie, 2000. The impact of tourists on gentoo penguins at Port Lockroy, Antarctic Peninsula. In: Howard-Williams, C., Broady, P. (Eds.), Antarctic Ecosystems: Models for Wider Ecological Understanding. New Zealand Natural Sciences, Canterbury University, Christchurch, New Zealand, pp. 319–323.

Delaney, D.K., Grubb, T.G., Beier, P., Pater, L.L., Hildegard Reiser, M., 1999. Effects of helicopter noise of Mexican Spotted Owls. Journal of Wildlife Management 63 (1), 60–76.

Dewey, R., Mead, D., 2000. Unfriendly Skies: the threat of military overflights to National Wildlife Refuges. Available from: <http://www.defenders.org/pbs-us00.html>.

DoC (Department of Conservation), 1998. Subantarctic Conservation Management Strategy. Department of Conservation, Wellington, New Zealand.

Efroymson, R.A., Rose, W.H., Nemeth, S., Suter II, G.W. 2000. Ecological risk assessment framework for low-altitude overflights by fixed-wing and rotary-wing military aircraft. Report ORNL/TM-2000/289. Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Fjeld, P.E., Gabrielsen, G.W., Ørbæk, J.B., 1988. Noise from helicopters and its effect on a colony of Brünnich's Guillemots (*Uria lomvia*) on Svalbrad. Norsk Polarinstitutt, Rapportserie 41, 115–153.

Fox, A.J., Cooper, A.P.R., 1994. Measured properties of the Antarctic ice sheet derived from the SCAR Antarctic digital database. Polar Record 30 (174), 201–206.

Fraser, W.R., Patterson, D.L., 1997. Human disturbance and long-term changes in Adélie penguin populations: a natural experiment at Palmer Station, Antarctic Peninsula. In: Battaglia, B., Valencia, J., Walton, D.W.H. (Eds.), Antarctic Communities: Species, Structure and Survival. Cambridge University Press, Cambridge, pp. 445–452.

Giese, M., 1996. Effects of human activity on Adélie penguin Pygoscelis adeliae breeding success. Biological Conservation 75, 157–164.

Giese, M., 1998. Guidelines for people approaching breeding groups of Adélie penguins (*Pygoscelis adeliae*). Polar Record 34 (191), 287–292.

Giese, M., 1999. Eco-tourism and seabirds: Antarctica as a case study. World Birdwatch March 22.1, 12–15.

Giese, M., Riddle, M., 1999. Disturbance of emperor penguin Aptenodytes forsteri chicks by helicopters. Polar Biology 22, 366–371.

Hansom, J.D., Gordon, J.E., 1998. Antarctic Environments and Resources. Addison Wesley Longman, New York.

Harris, C.M., 2000. Guidelines for the operation of aircraft near concentrations of birds. Unpublished Discussion Paper for the SCAR Working Group on Biology Bird Biology Subcommittee, 3–6 July 2000, Tokyo, Japan.

Heap, J. (Ed.), 1994. Handbook of the Antarctic Treaty System, eighth ed. US Department of State, Washington.

Hemmings, A.D., 1990. Human impacts and ecological constrains on skuas. In: Kerry, K.R., Hempel, G. (Eds.), Antarctic Ecosystems: Ecological Change and Conservation. Springer-Verlag, Berlin, pp. 225–230.

Hill, D., Hockin, D., Price, D., Tucker, G., Morris, R., Treweek, J., 1997. Bird disturbance: improving the quality and utility of disturbance research. Journal of Applied Ecology 34, 275–288.

Knox, G.A., 1994. The Biology of the Southern Ocean. Cambridge University Press, Cambridge.

Kooyman, G.L., Mullins, J.L., 1990. Ross Sea Emperor Penguin breeding populations estimated by aerial photography. In: Kerry, K.R., Hempel, G. (Eds.), Antarctic Ecosystems: Ecological Change and Conservation. Springer-Verlag, Berlin.

Martin, L., 1991. Cumulative environmental change: case study of Cape Royds, Antarctica. Unpublished M.Sc. thesis, University of Auckland.

McIntosh, E., Walton, D.W.H., 2000. Environmental Management Plan for South Georgia. British Antarctic Survey, Cambridge.

Modig, A., Njåstad, B., Sandler, H., 1999. Helicopter and aircraft operations in Antarctica: environmental guidelines. Finnish Marine Research Institute, Finnish Ministry of the Environment, Norwegian Polar Institute, and the Swedish Polar Research Secretariat.

Nimon, A.J., 1997. Gentoo penguin (*Pygoscelis papua*) responses to tourist and other disturbances in Antarctica. Unpublished PhD thesis, University of Cambridge.

Nimon, A.J., Stonehouse, B., 1995. Penguin responses to humans in Antarctica: some issues and problems in determining disturbance caused by visitors. In: Dann, P., Norman, I., Reilly, P. (Eds.), The Penguins: Ecology and Management. Surrey Beatty, Chipping Norton, NSW, pp. 420–439.

NZ Department of Lands and Survey, 1983. Management Plan for the Campbell Islands Nature Reserve. Management Plan Series No. NR13. Department of Lands and Survey, Wellington.

NZ Department of Lands and Survey, 1984. Management Plan for the Snares Islands Nature Reserve. Management Plan Series No. NR9. Department of Lands and Survey, Wellington.

Patterson, D.L., Woehler, E.J., Croxall, J.P., Cooper, J., Poncet, S., Fraser, W.R. Breeding distribution and population status of the Northern Giant Petrel Macronectes halli and the Southern Giant Petrel Macronectes giganteus. Marine Ornithology (in press).

Pfeiffer, S., Möstl, E., Kuchar-Schulz, A., Peter, H.-U., 2003. Effects of disturbance on two Antarctic seabird species – analysis of faecal hormones. In: Abstract, Proceedings of the 4th Conference of the European Ornithologist's Union, 16–21 August 2003 (Chemnitz, Germany), Die Vogelwarte, vol. 42, No. 1–2, pp. 162–163.

Regel, J., Pütz, K., 1997. Effect of human disturbance on body temperature and energy expenditure in penguins. Polar Biology 18, 246–253.

Rounsevell, D., Binns, D., 1991. Mass deaths of King Penguins (*Aptenodytes patagonicus*) at Lusitania Bay, Macquarie Island. Aurora 10 (4), 8–10.

SCALOP (Standing Committee on Antarctic Logistics and Operations), 1995–2005. Antarctic Flight Information Manual. Second Edition 1995 with updates through to January 2005. Council of Managers of National Antarctic Programs, Hobart.

SCAR (Scientific Committee on Antarctic Research), 2000. Working Group on Biology Bird Biology Subcommittee, Minutes of Meeting, 3–6 July 2000, Tokyo, Japan. Marine Ornithology 28, 191–201.

Sladen, W.J.L., Leresche, R.E., 1970. New and developing techniques in Antarctic ornithology. In: Holdgate, W.M. (Ed.), Antarctic Ecology, vol. 1. Academic Press, London, pp. 585–596.

Stonehouse, B., 1963. Observations on Adélie penguins (*Pygoscelis adeliae*) at Cape Royds, Antarctica. In: Proceedings of the XIIIth International Ornithological Congress, pp. 766–779.

Stonehouse, B., 1965. Counting Antarctic animals. New Scientist (July 29), 273–276.

Stonehouse, B., 1985. Penguins. In: Bonner, W.N., Walton, D.H.W. (Eds.), Key Environments: Antarctica. Pergamon Press, Oxford, pp. 266–292.

Taylor, R.H., Wilson, P.R., Thomas, B.W., 1990. Status and trends of Adélie penguin populations in the Ross Sea region. Polar Record 26 (159), 293–304.

Thomson, R.B., 1977. Effects of human disturbance on an Adélie penguin rookery and measures of control. In: Llano, G.A. (Ed.), Adaptations within Antarctic Ecosystems. Proceedings of the Third SCAR Symposium on Antarctic Biology. Smithsonian Institution, Washington, DC, pp. 1177–1180.

United Kingdom, 2001. Review of guidelines for the operation of aircraft near concentrations of birds in Antarctica. Information Paper IP-039, CEP IV, XXIV ATCM St Petersburg, Russia, 9–13 July 2001.

United Kingdom, 2002. Proposed Guidelines for the operation of aircraft near concentrations of birds. Working Paper WP-026, CEP V, XXV ATCM, Warsaw, Poland, 10–16 September 2002.

USAF (United States Air Force), 2001. US Air Force Fact Sheet July 2001. Available from: <http://www.af.mil/news/factsheets/C_130_Hercules.html>.

Wilson, K.-J., Taylor, R.H., Barton, K.J., 1990. The impact of man on Adélie penguins at Cape Hallett, Antarctica. In: Kerry, K.R., Hempel, G. (Eds.), Antarctic Ecosystems: Ecological Change and Conservation. Springer-Verlag, Berlin, pp. 183–190.

Wilson, P.R., Ainley, D.G., Nur, N., Jacobs, S.S., Barton, K.J., Ballard, G., Comiso, J.C., 2001. Adélie penguin population change in the Pacific sector of Antarctica: relation to sea-ice extent and the Antarctic Circumpolar Current. Marine Ecology Progress Series 213, 301–309.

Wilson, R.P., Coria, N.R., Spairani, H.J., Adelung, D., Culik, B., 1989. Human-induced behaviour in Adélie penguins *Pygoscelis adeliae*. Polar Biology 10, 77–80.

Wilson, R.P., Culik, B., Danfeld, R., Adelung, D., 1991. People in Antarctica – how much do Adélie penguins *Pygoscelis adeliae* care? Polar Biology 11, 363–370.

Woehler, E.J., 1993. The Distribution and Abundance of Antarctic and Subantarctic Penguins. SCAR, Cambridge.

Young, E.C., 1990. Long-term stability and human impact in Antarctic Skuas and Adélie penguins. In: Kerry, K.R., Hempel, G. (Eds.), Antarctic Ecosystems: Ecological Change and Conservation. Springer-Verlag, Berlin, pp. 231–236.