A LITERATURE REVIEW OF THE EFFECTS OF AIRCRAFT DISTURBANCES ON SEABIRDS, SHOREBIRDS AND MARINE MAMMALS

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INTRODUCTION

This report reviews literature on the effects of aircraft disturbances on seabirds, shorebirds and marine mammals in order to provide background information for an assessment of current overflight regulations in Gulf of the Farallones National Marine Sanctuary. There are numerous studies that have investigated the effects of aircrafts on birds; therefore, in order to narrow down the scope of this review, I focus on studies that examine seabird and shorebird species that occur on the California coast. In addition, species that occur elsewhere in the world and that are closely related and behaviorally similar to those found in California were considered (i.e. same genus and nesting, feeding and roosting behaviors). This report also provides a preliminary review of literature on aircraft disturbances to marine mammals, with a focus on pinnipeds and cetaceans that are found on the California coast.

AIRCRAFT DISTURBANCES TO SEABIRDS AND SHOREBIRDS

Aircraft disturbance can be defined as any aircraft activity that changes the behavior or physiology of a bird. Behavioral changes range from the lowest detectable response of head turning to the more extreme response of flushing, while physiological changes can be detected as changes in heart rate. Disturbance from aircraft overflights are potentially harmful to seabirds and shorebirds due to reduced reproductive success, increased predation, increased energy expenditure, reduced habitat use and reduced food intake. Studies often examine the behavioral responses of birds to overflights; however, it is difficult to determine the broader impacts to the population, especially for lower levels of behavioral change. Many factors can influence the response of birds, including the type of aircraft, the magnitude and frequency of the disturbance, the bird species, habituation and timing. Although the study findings reviewed herein are specific to the species and conditions that were examined, this previous research can provide a better understanding of the factors that are important to consider as the Sanctuary assesses its overflight regulations.

TYPES OF REACTIONS

Birds can exhibit a range of reactions to aircraft disturbances. Behavioral changes can include 1) scanning and alert behaviors, such head turning, neck extension, body re-orientation and tension; 2) agitated behavior, such as increased calling, head bobbing, restless pacing and wing-flapping; 3) protective or escape behaviors, such as crouching, and flying, running, diving, or swimming away (Brown 1990; Kempf and Hüppop 1998). Although birds may sometimes not show outward behavioral changes to disturbances, they may still experience stress, which can be manifested physiologically as increased heart rates (e.g. Wilson et al 1991). It is not known whether chronic stress from overflights is harmful to animals, but several national wildlife refuge managers have suspected that stress from overflights make waterfowl more susceptible to disease (Gladwin et al. 1987, USFWS 1993 in NPS 1995).

TYPES OF AIRCRAFT

Aircraft disturbances from different types of aircrafts may elicit different responses in birds. Helicopters have been widely viewed as the most disturbing type of aircraft for birds (Drewitt 1999). For California Common Murre colonies at Castle-Hurricane, Rojek et al. (2007) found that the proportion of recorded helicopter overflights that caused disturbance (83%) was greater than that of fixed wing aircraft overflights (57%). These differences in response were partly attributed to the low-altitude capabilities of helicopters, which makes it more likely that a disturbance would occur. At the same time, on average, helicopters tended to disturb at higher altitudes than fixed aircraft. This may be due to the louder engines and rotor vibration of the helicopters (Rojek et al. 2007). In the Dutch Wadden Sea, helicopters disturbed roosting oystercatchers, Bar-Tailed Godwits and curlews more often and over longer distances than military jets (Visser 1986 as cited in Smit & Visser 1993). Visser (1986) found that a helicopter at <1500 m (4,920 ft) caused a greater proportion of flocks to take flight than a jet at <1200 m (3,940 ft). In the German Wadden Sea, Heinen (1986) reported that roosting shorebirds were disturbed in 100% of potentially disturbing helicopter overflights, which was more often than jets (84%), small civil aircraft (56%) and motor gliders (50%) (as cited in Smit & Visser 1993). In the MacKenzie Valley and North Slope of Alaska, it was found that the incubating behavior of Glaucous Gulls and Arctic Terns were affected more by helicopters than fixed wing aircraft, but even more so by human presence (Gunn and Livingston 1974 as cited in NPS 1995).

However, birds are not consistently affected by helicopters more than other types of disturbance. Kushlan (1979) compared the use of helicopters and fixed wing planes for conducting wading bird censuses in Florida and showed that for overflights at 60 m (200 ft) and 120 m (390 ft), helicopters caused the same or less amount of disturbance to Great Egrets, Snowy Egrets and Louisiana Herons than fixed wing planes in 11 out of 12 comparisons. In South Africa, a helicopter was used to spray rotenone in a lake, such that it flew for 5 hours at 15-20 m above the lake (Williams 2007). Although the waterbirds, which included Great White Pelicans and White-breasted Cormorants, demonstrated escape behavior by moving out of the path of the helicopter, the level of disturbance was less than that observed for a known predator, an African Fish Eagle, that flew overhead and for humans that were collecting dead fish on the shore. In Scotland, Dunnet (1977) studied the effects of helicopters and small fixed wing airplanes on a mixed colony of incubating and brooding seabirds, consisting of guillemots, kittiwakes, Herring gulls, fulmars, shags, razorbills and puffins. The guillemots and kittiwakes did not show any significant flight responses to the planes flying 100 m (330 ft) above the cliff where the birds were nesting (Dunnet 1977). It was thought that these birds may have become habituated to these overflights.

Findings on the effects of jets are also variable. In the Dutch Wadden Sea, Koolhaas et al. (1993) compared the numbers and behaviors of Red Knots in the presence and absence of low flying jet fighters at 50 m (160 ft). The authors found that there were fewer knots present on the days with jet overflights and that the birds were also more restless and less approachable by humans. However, they also observed that “light tourist airplanes” caused a more severe response in the knots than the jet fighters. Black et al. (1984) found that low flying F-16 jets at <150 meters (500ft) above ground level did not have any effect on colony establishment or the size of wading bird colonies, consisting of Cattle Egrets, Double-crested Cormorants, Great Blue Herons, Great Egrets and White Ibises.

Jets also have the capability of flying at supersonic speeds, which create sonic booms. The effects of sonic booms have also been found to be variable. For example, sonic booms have led to non-productivity limiting alert reactions in seabirds (Schreiber and Schreiber 1980 as cited in Black et al. 1984), but have also been associated with a mass hatching failure in Sooty Terns in the Dry Tortugas Islands (Austin 1970 as cited in NPS 1995).

Few studies have investigated the effects of ultralight aircrafts, and no studies could be found related to seabirds. Smit and Visser (1993) suggested that ultralights may be very disturbing due to the low altitudes at which these aircraft fly and the noise that they generate. In the Netherlands, the numbers of Bewick’s Swans roosting and foraging close to an ultralight air strip dropped dramatically from 1,400-4,300 in 1986-1988 to just a few birds in 1989 after the air strip had been used only for one year (in Smit & Visser 1993). On the other hand, a study on the effects of ultralights on Pink-footed geese observed that the birds were able to habituate quickly to the ultralights that were landing and taking off 250 m (820 ft) from their feeding area. Furthermore, it was found that the Pink-footed geese, lapwings, curlews and golden plovers showed no disturbance when ultralights were >300 m (1000 ft), and that disturbance was first observed around 500 feet (Evans 1994 as cited in Drewitt 1999). There is also evidence that a small brood of black-tailed godwits and curlews died out in Hesse, Germany due to ultralight activities (in Kempf and Hüppop 1998)

No studies on the effects of paragliding or hang gliding on seabirds or shorebirds could be found, though hang gliders have been identified as a source of disturbance to western snowy plovers (USFWS 1995 in Lafferty 2001). Acosta et al. (2009) also reported a motorized hang glider that flushed 20 Brandt's cormorants on Alcatraz Island. As for motor gliders, a study in the Wadden sea found that these aircrafts had a stronger effect on breeding and resting birds than powered planes (in Kempf and Hüppop 1998).

NOISE LEVEL

Aircraft noises can be measured based on their sound pressure level and frequencies. Sound pressure levels are often measured with the logarithmic decibel (dB) scale relative to a reference value. The following studies measure noise level using the decibel scale weighted with an A-weighting filter (dBA), which is based on the sensitivity of the human ear to different frequencies. Therefore, they may not reflect the noise sensitivity of birds (NPS 1995).

Brown (1990) conducted an experiment to measure the effect of noise on nesting Crested Terns in Australia using acoustic stimuli that simulated the sound of an overflying floatplane. The different sound treatments had peak noise levels that ranged from 65-95 dBA, and simulated a plane flying over at altitudes from 75-300 m (250-980 ft). The background level noise from ocean wave action was 55-65 dBA and noise from bird call activity was 60-75 dBA. The author measured multiple levels of response: 1) scanning, 2) alert, 3) avoidance, and 4) escape behaviors for these sound treatments. The majority of birds showed scanning behavior for all treatment levels, even just above the background noise level. Alert behavior had a strong positive relationship with increasing noise level, while avoidance and escape behaviors were mostly exhibited at the higher noise levels (>85 dBA). Brown (2001) also conducted a similar noise experiment, except the sounds simulated a helicopter landing, pausing and taking off. Even though the peak noise levels of the sound treatments were the same in the two experiments, the noise of the helicopter caused greater avoidance and escape behaviors than the noise of the fixed wing in the earlier experiment. It was suggested that these differences could be attributed to differences in frequency and the temporal aspects of the helicopter noise. In addition, Brown (2001) tested the effects of visual stimuli and found that they were not as important as the acoustic stimuli in generating behavioral responses.

Breeding gull colonies have been observed close to airports, and it had been thought that they do not experience any negative effects from aircraft noise (Busnel 1978 as cited in Burger 1981). However, Burger (1981) showed that a herring gull colony that was located close to the Kennedy International Airport was disturbed particularly by the high noise levels from landing supersonic planes (Concordes). To measure disturbance, the author counted the number of gulls that flew up in response to different noise conditions at the airport. The average noise levels were 77 dBA for ambient noise, 91.8 dBA for subsonic jet noise, and 108.2 dBA for noise from supersonic planes. The gulls did not react significantly to the noise from subsonic planes, but did react significantly to supersonic planes, such that there were twelve times as many birds that flew up than under normal conditions. These bird flights led to fights between birds returning to their nests, which in turn caused eggs to be broken. The differences in responses to the planes may also be due to other factors in addition to noise level. The author noted that the sound characteristics of supersonic planes are different and that they can cause vibrations when flying directly overhead. Furthermore, the supersonic planes land once daily whereas subsonic jets land every 2-3 minutes. Therefore, it is possible that the frequency of exposure to supersonic planes may not have allowed gulls to habituate to the noise.

In Minnesota, a study was conducted to investigate the effects of an airport expansion on nearby nesting Black-crowned Night Herons, Great Blue Herons and Great Egrets (Grubb 1979). A single engine propeller aircraft was flown over the heron rookery at 490-2,620 m (150-800 ft). The calculated noise levels corresponding to these flight altitudes ranged from 61-88 dBA, and were 9 dBA greater than calculated existing maximum aircraft noise levels and 20 dBA greater than measured ambient noise levels. No reactions were observed in the birds in response to these test overflights, although the author did not specify what behaviors he was examining.

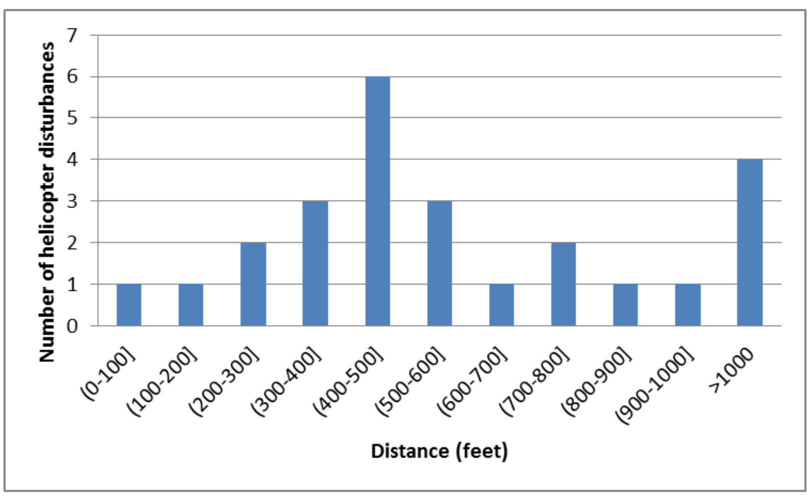
Jehl and Cooper (1980) studied the effects of sonic booms to seabirds on the Channel Islands and found that sonic booms disturbed birds less than humans at roost sites and helicopters (as cited in Manci et al. 1988). However, louder booms (80-89 dBA SEL) were more disturbing than softer booms (72-79 dBA SEL). They also conducted noise disturbance tests using shotgun blasts and explosives and observed that birds flew away from their nests without knocking their eggs out and then returned within 30 seconds. Another experiment at the Channel Islands used a carbide pest control cannon to simulate sonic booms (Stewart 1982 as cited in Manci et al. 1988). Most birds within 100 m (330 ft) of the cannon flushed and returned within 2-10 minutes.

Schreiber and Schreiber (1980) investigated the effects of sonic booms on nesting gulls and cormorants and found that the effects of the sonic booms were minimal compared to humans walking into the colony (in Drewitt 1999). In contrast, sonic booms have also been associated with a mass nesting failure of Sooty Terns in the Dry Tortugas Islands in 1969, where 98% of the tern population failed to reproduce. The authors did not have evidence showing that sonic booms caused physical damage to eggs, though it was thought that the booms disturbed the incubating rhythm and caused nest desertion (Austin 1970 cited in Manci 1988). A colony of Brown Noddies, however, was able to breed successfully. It is suggested that eggs are known to be resistant to sonic booms (cited in Burger 1981).

DISTANCE

Altitude and lateral distance determine the noise level and the visual size of overflying aircraft and are important factors that affect the responses of birds. The distances at which aircraft will disturb birds can depend on the type of aircraft. For example, as mentioned earlier, helicopters have been found to cause disturbance in shorebirds at higher altitudes than jets (Visser 1986). Rojek et al. (2007) found that on average, flushing of Common Murres at Castle-Hurricane seemed to occur at higher altitudes for helicopters (229 m/750 ft) than fixed wing planes (193m/630 ft), although the difference was not significant. Head bobbing occurred at similar altitudes for helicopters and fixed wing planes (232 m/761 ft and 233 m/764 ft on average, respectively). The average altitude at which fixed wing planes did not cause a response was 246 m (800 ft). Unexpectedly, the average altitude at which helicopters did not elicit a response was 205 m (670 ft), which is lower than the average helicopter flushing altitude. However, Rojek et al. did not address this finding in the discussion of their study.

In this report, distance information was compiled from reports on the restoration of Common Murres colonies in Central California from 1999-2011, which were prepared for the Apex Houston Trustee Council. This information is likely only a subset of the data on disturbance distances that have been recorded. The absolute distance was calculated when both the altitude above sea level (ASL) and lateral distance were provided for a given aircraft disturbance. Below is a graph representing the different distances at which 25 helicopter disturbances caused flushing of Common Murres in various colonies in Central California.



The number of helicopter disturbances that caused Common Murres to flush at different distances from the colony.

Many of the disturbances (6 out of 25) occurred due to helicopters that were 120-150 m (400-500 ft) away. There were also four disturbances that were caused by helicopters more than 1000 feet away. Two of the helicopters in this category were in fact at lower altitudes (120m/400 ft), but also had a lateral distance component. These results might suggest altitudes at which the birds might be particularly sensitive, but might also be a consequence of the flight patterns of pilots.

The table below is a summary of studies on seabirds and shorebirds that have disturbance and distance information.

Bird species	Aircraft type	Distance	Effect	Paper
Common Murres	Helicopters and Fixed wing	a) Helicopter at 15-366 m (50-1,200 ft) and Fixed Wing at 183-213 m (600-700 ft) b) Helicopter at 15-457 m (50-1500 ft) and FW at 152-426 m (150-1400 ft) c) Helicopter at 122-305 m (400-1000 ft) and FW at 91-305 m (300-1000 ft)	a) Flush b) Head-bob c) No response	Rojek et al. 2007
Common Murres, Kittiwakes	Helicopter and Fixed wing	150 m (500 ft) ASL, 100 m (330ft) above cliff	No significant effect on Murres and Kittiwakes	Dunnet 1977
Brunnnich's guillemots, kittiwakes	Helicopter	a) 500-6,000 m (1,640-19,670 ft) b) <2,000 m (6,560 ft)	a) Non-breeding birds left colony at these distances b) Non-breeding birds always disturbed	Fjeld et al. 1988
Glaucous gull, Arctic Tern	Helicopter and Fixed wing	150-300 m (500-1,000 ft)	Flushing from nest, disrupt nest behavior	Gollop et al. 1974 (cited in NPS 1995)
Great Egret, Snowy Egret, Louisiana Heron	Helicopter and Fixed wing	60 and 120m (200 and 390 ft)	90% of birds did not respond or looked up. Flushed birds return within 5 min	Kushlan 1979
Gannets	Light aircraft	200 m (660 ft)	Entire colony scattered for 1 hour, >2,000 gannets lost eggs or chicks to predation	Zonfrillo 1993
Shorebirds (includes Curlews, Red Shank and Bar-tailed Godwits)	Small aircraft	a) >300 m (980 ft) b) 150-300 m (490-980 ft) c) >300 m (980 ft)	a) 8% disturbed b) 66% disturbed c) 70% disturbed	Heinen 1986 (cited in Smit & Visser 1993)
Shorebirds (unknown)	Small aircraft	a) 150 m (500 ft) b) 300 m (1,000 ft)	a) Always disturbance b) disturbance within 1,000 m (3,280 ft) radius	Baptist & Meininger 1984 (in Smit & Visser 1993)
Shorebirds (unknown)	Small aircraft	1,000 m (3,280 ft)	Disturbance	Werkgroep Waddenzee 1975 (in Smit & Visser 1993)
Curlews, golden plovers (among others)	Ultralight	a) >300m (1000 ft) b) 150 m (500 ft)	a) No disturbance b) First signs of disturbance	Evans 1994 (in Drewitt 1999)
Shorebirds (includes Curlews and Oystercatchers)	Small aircraft	a) 360 m (1,180 ft) b) double pass at 450 and 360 m (1,480 and 1,180 ft)	a) Birds returned to same numbers after 10 min b) 67% of oystercatchers and 87% of curlews returned after 45 min	Glimmerveen and Went 1984 (in Smit & Visser 1993)
Oystercatcher, Bar-tailed Godwit, Curlew	Military jet and Helicopter	a) Jet at <1,200 m (3,940 ft) b) Helicopter at <250 m (820 ft) c) Helicopter at <1,500 m (4,920 ft)	In all cases, oystercatchers were most tolerant of overflights. a) 5-16% of flocks disturbed b) 27-52% of flocks disturbed c)73-86% of flock disturbed	Visser 1986 (cited in Smit & Visser 1993)
Shorebirds (unknown)	Military jet	<100 m (330 ft)	Generally did not respond. Looked up, stopped foraging for a few seconds, short flights of 10-30 seconds	Smit and Visser 1985 (cited in Smit & Visser 1993
Sooty Terns and Common Noddies	Seaplane	landing and departure within 400 m (1,310 ft)	Flushing, more likely when plane taking off	Hicks, King and Chaloupka 1987 (cited in GBRMPA 1997)
Waterbirds (includes small percentage of Grebes, Cormorants, Herons, Gulls)	Helicopters and Fixed wings	80-450 m (260-1,480 ft)	Minimum disturbance altitude was 450 m (1,480 ft) for the helicopter and 300 m (980 ft) for the fixed wing planes	Komenda-Zehnder et al. 2003

The results from these studies show that there is not a consistent distance at which birds will react to overflights and that disturbance distance likely depends on multiple factors. Other literature on disturbance distances has shown that birds may be more sensitive in undisturbed regions, when they are in high concentrations, when moutling or when breeding in colonies (in Komenda-Zehnder et al. 2003). In addition to these studies, there have been anecdotal observations on the effects of aircraft activities on seabirds and shorebirds. On Alcatraz Island, Saenz et al. (2006) observed that Brandt's Cormorants were flushed from nests by aircraft within 500 m (1,640 ft) every season. In the Great Barrier Reef (GBR), Crested and Bridled Terns and Common Noddies that breed within several tens of meters from an airstrip did appear not to be negatively impacted by aircraft, besides occasional bird strikes. Also in the GBR, helicopters that landed within meters of breeding noddies and shearwaters also did not appear to have an effect. However, in more remote areas of the GBR, it was observed that breeding seabirds flew from their nests even before the approach of an aircraft could be detected by humans (GBRMPA 1997). In the Netherlands, helicopters flying at 100-300 m (330-980 ft) altitude at a frequency of 2-3 per hour did not appear to have strong effects on foraging and roosting waders (Smit and Visser 1993).

Another factor that can affect bird responses is the speed of the aircraft. For example, in an experiment comparing the effects of different types of aircraft on waterbirds, the slower fixed wing plane had a significantly stronger effect than the faster plane (Komenda-Zehnder et al. 2003). Smit & Visser (1993) found that an overflight of a slow speed jet was more disturbing to shorebirds than the more frequent overflights of high-speed military jets, though the difference may also be a result of a lack of habituation.

HABITUATION AND FACILITATION

The extent to which birds may be disturbed by aircraft may depend on their ability to habituate to aircrafts. Birds may "learn" that a stimulus does not pose a danger after repeated exposure and as a result, may not display any substantial signs of behavior change. The ability to habituate may be a function of the frequency of aircraft overflights and the species of bird. As described earlier, Burger (1981) found that herring gulls nesting near an airport did not react significantly to subsonic aircraft noise, and Dunnet (1977) observed no effect of helicopters and fixed wing airplanes on kittiwakes and guillemots. These results were attributed to habituation from frequent exposure to overflights; the herring gulls in Burger's study experienced noise from subsonic planes that landed every 2-3 minutes, while in Dunnet's study, the cliffs on which kittiwakes and guillemots were nesting were on the regular route of helicopters flying from an airport to offshore rigs and platforms.

Birds that are not subject to frequent aircraft overflights may exhibit stronger reactions in response to a disturbance. In addition, birds may also be sensitive to aircraft that are "unusual" or that fly with unpredictable curves (Smit and Visser 1993, Boer et al. 1970). Olsson and Gabrielsen (1990) studied the effects of test helicopter overflights on a remote colony of Brunnich's guillemots in Svalbard, a Norwegian archipelago in the Arctic Ocean. They compared their results with those of an earlier study by Fjeld et al. (1988) that investigated disturbance in a less remote colony of Brunnich's guillemots, also in Svalbard. The authors found that it took the birds 20 minutes to return after a disturbance, compared to the 5-10 minute return time in the Fjeld et al. study. The authors did not find any evidence of habituation in the remote colony over the course of the study and hypothesized that the colony in the Fjeld et al. study was more habituated to helicopter overflights.

Nisbet (2000) has proposed disturbing waterbirds "frequently, regularly and predictably" in order to promote habituation to human disturbance (not aircraft specifically) and to minimize adverse effects. This author has based this on his and others' observations of birds that are tolerant of humans, and on his opinion that few studies have convincingly shown evidence of adverse effects. However, the appearance of habituation or tolerance does not necessarily indicate the absence of adverse effects. For example, although Smit and Visser (1993) did not observe strong effects of frequent helicopter overflights on foraging and roosting waders, they suggested that birds may be forced to move to less disturbed areas or temporarily leave the area. Furthermore, birds that do not show external stress may still experience physiological stress, manifested as changes in heart rate. The consequences of these physiological changes are not well understood enough to dismiss their potential effects.

In contrast to habituation, birds may become more sensitive to low levels of disturbance following other disturbances (Smit & Visser 1993). This cumulative effect is known as facilitation. As described previously, Red Knots were more restless and less approachable by humans following jet overflights (Koolhaas et al. 1993). In Germany, jet overflights seemed to have stronger effects on shorebirds when wind surfers were previously in the area (Kusters & von Raden 1986 in Smit & Visser 1993). In the Netherlands, after a disturbance by an "unusual" aircraft, shorebirds displayed panic reactions with overflying herons and gulls, even though under normal conditions, these birds would have much smaller effects (Smit unpublished).

SPECIES & FLOCK SIZE

The studies that have been described thus far demonstrate variations in the responses of different bird species to aircraft disturbance. Another example is a study by Heinen (1986), where Curlews and Redshanks in the German Wadden Sea were found to react more than Bar-tailed Godwits. However, there may not be consistent trends for the relative responsiveness of different species. In the Netherlands, Visser (1986) found that oystercatchers were more tolerant of aircraft disturbance compared to bar-tailed godwits and curlews, while Glimmerveen & Went (1984) found that it took longer for oystercatchers to resume normal behavior than it did for curlews.

The tendency for birds to take flight in response to a disturbance may depend on the flock size. Burger & Galli (1987) observed that a high proportion of gulls flew in response to disturbance (not just aircraft) when there were more birds present. Smit & Visser (1993) also mentioned that several studies have shown that larger flocks are easily disturbed. It is suggested that this may be due to larger flocks having a greater chance of containing particularly sensitive individuals. However, in Olsson & Gabrielsen (1990) did not find that stress increased with a larger colony.

BREEDING PRODUCTIVITY

Aircraft disturbance can impact breeding productivity, by interfering with courtship, initial nesting activities, and parental attendance. Flushing especially can cause damage to eggs, and expose eggs and chicks to predation and unfavorable temperatures. Rojek et al. (2007) suggest that aircraft disturbances are one of the many impacts that is slowing the recovery of the breeding population size and breeding success at the Castle-Hurricane Colony Complex in 1997-1999. Zonfrillo (1993) described two major incidents of losses of eggs and chicks resulting from overflights at an island off of Scotland. In the first incident, a Hercules transport aircraft that flew over at least eight times flushed an entire gannet colony. The birds were dispersed for about an hour and approximately 2,000 or more eggs and chicks were lost to predation by gulls. In the second incident, a passing light aircraft caused 123 young auks to panic, fall from their ledges and die. In Burger's study of herring gulls, she found that gulls nesting in denser areas of the colony had a lower mean clutch size during incubation than bird pairs that were in more isolated areas (Burger 1981). In these denser areas, gulls that returned to their nests following disturbances from supersonic planes engaged in prolonged fights, which caused eggs to break. Several U.S. wildlife refuges have also documented gulls, cormorants and murres kicking eggs from nests when flushed, causing eggs to be lost, broken or eaten. Pelicans have also abandoned nests from chronic disturbance from overflights (USFWS 1993 cited in NPS 1995). In Alaska and Canada, Gunn and Livingston found lower hatching and fledging success, higher nest abandonment and premature disappearance of nestlings in their study on disturbances to waterfowl, seabirds and terrestrial breeding birds (Gunn & Livingston 1974 in Manci et al. 1988).

The breeding status of birds may influence the responsiveness of birds to aircraft disturbances. Non-breeding birds may be more likely to fly away due to a disturbance, whereas breeding birds may not leave their nests in order to protect their eggs or chicks. Both Fjeld et al. (1988) and Olsson & Gabrielsen (1990) found a difference in behavior between breeding and non-breeding Brunnich's guillemots, where flight responses were observed mostly in non-breeders. Rojek et al. (2007) also found that most of the California Common Murres that flushed during the breeding season were roosting at the periphery of the colony or were mates of incubating birds. Dunnet (1977) did not see any effects of aircrafts on incubating and brooding kittiwakes, and observed that a few "second adults" took flight, although, this may also be a result of habituation.

Birds may also be more likely to take flight early in the breeding season as fewer investments have been made by adults. Therefore, overflights earlier in the season could cause more losses of offspring. California Common murres showed a greater proportion of flushing events before the peak of the egg-laying (Rojek et al. 2007). Olsson & Gabrielsen (1990) also attributed the weak responses of the breeding Brunnich's guillemots to the fact that the study was conducted at the end of the breeding season when most of the birds have chicks. In British Columbia, Bunnell et al. (1981) found that aircraft disturbances early in the incubation period of White Pelicans caused the birds to trample eggs, thus reducing the clutch size of the pelicans and increasing egg mortality by 88% compared to normal conditions. Disturbances of pelicans later in the incubation period did not have a significant effect on clutch size.

FOOD INTAKE & ENERGY EXPENDITURE

Disturbances can reduce the feeding activity of birds, either by causing changes in their behavior or by deterring birds from their preferred feeding sites. Studies specifically related to the effects of aircraft disturbances on feeding seabirds and shorebirds could not be found, though there are a number of studies on geese. For example, Davis & Wiseley (1974) conducted experimental overflights on staging Snow Geese in Alaska at two hour intervals; the fixed wing plane caused an 8.5% reduction in feeding, which corresponded to a 20.4% decrease in energy reserves for the juvenile geese. Disturbances that affect food intake can impact the time and energy budget of birds. In order to make up for the lost feeding time, birds may have feed at different times of the day, in riskier conditions or at the expense of other activities. Reduced feeding could also hinder the ability of birds to build up fat reserves for migration and breeding (Kempf and Hüppop 1998).

Escape behaviors in response to disturbances may cause increases in energy expenditure. The amount of energy that is used in flight depends on the species. For species that fly a lot, the metabolic rate may be only three times the base metabolic rate, whereas the metabolic rate for species that are poor flyers may increase to 20 times the base metabolic rate. However, even increased heart rates that result from disturbance can cause changes in metabolic rate. Without physical activity, the heart rate can increase by fifteen-fold and energy consumption can triple (Kempf and Hüppop 1998).

AIRCRAFT DISTURBANCES TO MARINE MAMMALS

PINNIPEDS

Another potential concern regarding aircraft disturbance is its effect on pinnipeds in Gulf of the Farallones National Marine Sanctuary. These disturbances may interrupt haulout activities, such as resting, mating, molting, giving birth and nursing pups. During a flushing event, there is also a potential risk of pups getting stampeded or the separation of mothers and pups. For example, in one incident, disturbance from low-flying aircraft may have caused the death of more than 200 harbor seal pups on Tugidak Island, Alaska (Johnson 1977 as cited in Suryan & Harvey 1999).

In a harbor seal monitoring study in Point Reyes from 2002-2006, aircrafts caused 3-11% of disturbances (alertness or flushing) each year (NPS 2006). In 2006, 7% of disturbances were caused by aircrafts, compared to 21% by humans, 13% by non-motor boats and 11% by motorboats. The authors noted that there was a decrease in aircraft disturbances in 2006 compared to 2005 and that this was related to a decline in disturbances from ultralights. This suggests that ultralights may be a particularly disturbing type of aircraft. An older study that was conducted in Bolinas Lagoon in 1984 found that aircrafts, in this case helicopters, only accounted for 0.7% of disturbances to harbor seals on Kent Island (Allen et al. 1984). However, the camera that was used to monitor the seals did not record the cause in 40% of the disturbances.

Kucey (2005) studied human disturbances to hauled out Steller sea lions in Alaska and British Columbia, and her results showed that the sea lions exhibited the weakest response to aircrafts compared to other sources of disturbance (birds, sea lions, humans, boats and unknown); aircrafts had the lowest percentage of disturbance events that caused sea lions to leave the haul out (33%) and had the lowest percentage of sea lions leaving haulouts in response to disturbance (<5%).

Human disturbances to harbor seals has also been studied in the Wadden Sea (Osinga et al. 2012), and it was found that in 200 cases of potentially disturbing aircraft activities, 8 events caused seals entered the water. Out of 330 seals, on average, 12 seals fled into the water and 5 became alert. The authors mentioned that aircrafts at lower altitudes appeared to cause more disturbances, and that aerial surveys by a small aircraft at 300 m (980 ft) only caused alert behavior. However, the study had very little specific information on disturbance distances.

The disturbance distance found in Osinga et al.'s study on harbor seals contrasts with a previous study on aircraft disturbances to ringed seals in the Arctic. Born et al. (1999) compared the escape responses of the ringed seals to a fixed-wing twin-engine aircraft and a helicopter, both flying at 150 m (490 ft), and demonstrated that seals responded more strongly to the helicopter. Forty nine percent of seals escaped in response to helicopters, while 6% of seals escaped in response to the fixed-wing plane. The helicopter also caused disturbance from a greater distance, where the maximum disturbance distance was about 1,250 m (4,100 ft) for the helicopter and 600 m (1,970 ft) for the fixed-wing plane. The authors identified that sound was an important factor causing these responses, and that other factors, such as the weather, the molting stage, and visual detection, may also have had an influence.

CETACEANS

Cetaceans may be disturbed by noise from aircrafts and by the sight of or shadow from aircrafts (Richardson & Würsig 1997, Luksenburg & Parsons 2009). The effect of noise, in general, is of particular concern for cetaceans as they are highly dependent on sound for communication, navigation and echolocation. Aircraft overflights can elicit behavioral changes such as sudden dives or turns, tail and flipper slaps, breaching, and group formations (Richardson & Würsig 1997, Smultea et al. 2007). More subtle responses involve changes in surfacing and respiration patterns (Richardson & Würsig 1997).

The strength of a response may vary depending on factors such as the disturbance distance, species, activity of the animal and water depth. Würsig et al. (1998) examined the responses of different cetaceans to aerial surveys from a fixed-wing airplane in the Gulf of Mexico. The plane flew at 229 m (750 ft) ASL and at a minimum lateral distance of 305 m (1,000 ft). The authors found that some species reacted more strongly to the airplane than others. For species found in California coastal waters, bottlenose dolphins reacted in 28% of the sightings, and Risso's dolphins in 16% of sightings. In general, it was observed that the animals were more sensitive to disturbance when they were "milling" and "resting." Other studies on cetaceans have found a stronger response to aircraft noise in small groups or individuals, in mothers with calves, in shallow waters, when resting and when aircraft flew at low altitudes (Luksenburg & Parsons 2009).

Measuring the exposure of cetaceans to aircraft noise can be difficult due to the transition of sound from air to water and due to the angle at which the sound enters the water as most sound is reflected at angles greater than 13 degrees from the vertical (Richardson et al. 1995 as cited in Nowacek et al. 2007). Furthermore, different species may have different frequency sensitivities to sound. Malme et al. (1984) performed experiments on migrating grey whales by exposing them to repeated playbacks of helicopter noise (as cited in Perry 1998). Three simulated passes per minute caused minor avoidance reactions in 50% of whales. The received sound pressure level was 120 dB re 1uPa; however, the playback excluded the strong low frequency component of helicopter noise.

It is thought that helicopters cause more responses from cetaceans than fixed-wing planes (Richardson et al. 1995 as cited in Luksenburg & Parsons 2009). For example, Patenaude et al. (2002) compared the responses of bowhead and beluga whales to a helicopter and a fixed-wing plane. Measurements showed that the helicopter was noisier than the twin otter, although it has been critiqued by Nowacek et al. (2007) that Patenaude et al. did not properly model sound pressure levels received by the whales. Both whales responded more frequently to the helicopter than to the fixed-wing plane. In terms of the disturbance distance, for the helicopter, most of the reactions by bowheads and belugas occurred when the helicopter was at ≤150 m (490 ft) ASL and ≤ 250 m (820 ft) horizontally. For the fixed-wing aircraft, most of the reactions occurred at ≤182 m (600 ft) ASL and ≤250 m (820 ft) horizontally.

CONCLUSION

This report has given an overview of the effects of aircraft disturbances on seabirds, shorebirds and marine mammals, and has identified the factors that can influence these effects. Although aircraft disturbances can potentially have negative impacts to these animals, the findings of this review suggest that the impacts to populations as a whole are often unknown. General trends from these studies show that aircrafts that fly at lower altitudes elicit stronger responses, and that helicopters tend to be more disturbing than fixed-wing planes. Ultralights are an emerging issue for the Sanctuary, but for which there has been little research. Other areas that should be investigated further are the effects of drones, model aircrafts and hang gliders/paragliders.

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