Assessing the potential impact of aircraft stimuli on wildlife in New Zealand’s Hauraki Gulf Marine Park

by

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Abstract:

The potential impact of human-generated noise on New Zealand wildlife has not been well-studied. This draft report tests the following null hypothesis: aircraft stimuli does not adversely impact wildlife in New Zealand's Hauraki Gulf Marine Park. The test methodology involved reviewing peer-reviewed scientific articles describing the effects of aircraft stimuli on wildlife, ecosystem components, and ecological processes. The scope of this enquiry is limited to behavioural and physiological responses of birds and marine mammals to aircraft overflights, colloquially, noise disturbance. Among study highlights:

- Avian behavioural responses to aircraft stimuli include flushing, scanning, agitation, escape actions, habituation and facilitation, breeding and productivity, foraging, predation risk, energy expenditure, vocal activity, and masking. Cumulative responses can influence species viability, abundance and richness, thereby impacting population, community and ecosystem structures.
- The list of avian physiological responses to noise disturbance includes increased heart rate, metabolism, blood sugar, respiration rate and depth, brain and heart blood flow, and oxygen consumption. Conversely, blood flow to the gut, gut motility and digestive secretion parameters have been shown to decrease.
- Behavioural and physiological responses to noise disturbance on marine mammals for this report remains a work in progress. However, similar to avian species, multiple references suggest that the impact of aircraft stimuli on marine mammals can interfere with communication activities vital to species fitness and survival.

Articles describing positive effects of noise on wildlife have yet to be found. Importantly, behavioural and physiological responses to noise disturbance regardless of species are not uniform. Factors such as species type, life stage, sex, location, proximity, source, and type of noise disturbance can influence the scope and breadth of responses. Also important, simply because responses are not observed doesn't mean they don't occur.

In conclusion, empirical and qualitative data gathered thus far suggests that the impact of human-generated noise on avian and marine mammals appears adverse and significantly more than minor. Therefore, the null hypothesis stated above should be rejected with a high degree of confidence.

1.0 Introduction

1.1 Project background

This report assesses the potential impact of aircraft stimuli on wildlife species found in New Zealand's Hauraki Gulf Marine Park, colloquially, the Gulf. Also subject to assessment is the potential impact on wildlife to related ecosystem components such as species population richness, habitats, biodiversity, and community structure.

The intended audience for this report includes anyone interested in understanding interactions and consequences of human-generated noise on wildlife and associated ecosystems in non-scientific language. Whenever possible, definitions for scientific or otherwise technical terms are defined. For important background context, introductions to key concepts and connections are discussed in Chapter 2.0. All of the information in this report is an open source for public consumption.

The need for this assessment stems from multiple policy mandates by New Zealand's Resource Management Act 2013 (RMA) (Fettermann et al., 2019) and Auckland Council regarding environmental information required for resource consents. For example:

- Sections 6 and 7 of Schedule 4 of the RMA articulates environmental and ecological information required in applications for a resource consent.
- Specifically, Section 7 part (c) describes the need for an assessment for consent if there is "*any effect on ecosystems, including effects on plants and animals and any physical disturbance of habitats in the vicinity*."
- In addition, Policy 11 from New Zealand's Coastal Policy Statement 2010 specifies protections for:
    - ✓ Indigenous biological diversity in the coastal environment. Such protections must (a) "*avoid adverse effects of activities*" and (b) "*avoid significant adverse effects, and avoid, remedy or mitigate other adverse activities*" in multiple contexts for indigenous biodiversity.
    - ✓ "Areas set aside for full or partial protection in indigenous biological diversity under other legislation." (Section (a) vi)
    - ✓ "Indigenous ecosystems and habitats that are only found in the coastal environment and are particularly vulnerable to modification, including

estuaries, lagoons, coastal wetlands, dunelands, intertidal zones, rocky reef systems, eelgrass and saltmarsh." (Section (b) iii.)

1.2 The Hauraki Gulf – then and now

The Hauraki Gulf was designated a marine park in 2000. Under the administration of New Zealand's Department of Conservation (DOC), the Gulf covers approximately 12,000 km^2 (4,633 miles^2) and surrounds 50 islands, approximately 25 of which are terrestrial nature reserves that complement 5 marine reserves (Figure 1). Wildlife inhabitants of the Gulf include birds, mammals, invertebrates, reptiles and amphibians, several of which are threatened or at risk (Funnell et al., 2023).

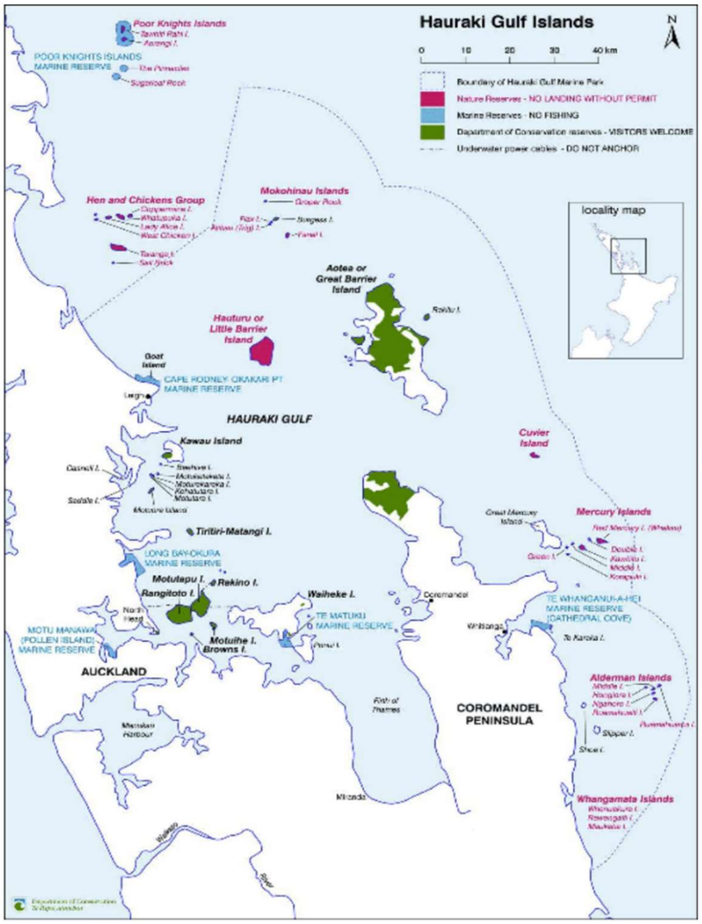

Figure 1.

Map illustrating boundaries and islands of the Hauraki Gulf Marine Park (DOC)

New Zealand's Hauraki Gulf Marine Park Act 2000 (HGMPA, 2021) describes the Hauraki Gulf as having "…a quality and diversity of biology and landscape that makes it outstanding within New Zealand. The islands of the Gulf are valued as the habitats of plants and animals, once common, now rare, and are often the only places in the world where these species exist naturally" (HGMPA, 2021). Appendix A provides a partial list of traits, classifications and conditions of wildlife endemic to the Hauraki Gulf Marine Park.

In 2011, New Zealand's Department of Conservation (DOC) published a literature review describing the impact of noise-related disturbance on recreationists and wildlife in the country's natural areas (Harbrow et al., 2011). Authors of the review suggested that "Chronic exposure to noise is rare for wildlife because of threat-avoidance mechanisms and because high levels of human-made noise are uncommon in natural areas."

Since 2011, much has been learned about the relationship between threat-avoidance mechanisms of wildlife and human-generated noise (Bejder et al., 2009b; Hoang, 2015). In barely over a decade ago, it may have been safe to assume that high levels of human-made noise are uncommon in natural areas. In some areas of New Zealand, such an assumption may still be safe. Since 2011, however, there has been an estimated 50- to 60-fold increase in helipad permits and an unregulated increase in recreational helicopter overflights to and from Waiheke Island, which is located within Gulf boundaries and hosts one of the Gulf's marine reserves and a scenic reserve.

Given recent advances in our knowledge of wildlife responses to human-generated noise and the exponential surge in aircraft overflights, this review examines the potential impact of aircraft stimuli on wildlife and related ecosystems found in the Hauraki Gulf Marine Park. Details of the methodology used for this review are described in Appendix A.

2.0 Concepts and connections

2.1 Introduction

A brief overview of fundamental principles in ecosystems and ecology provides context for the remaining topics in this section . Similarly, a basic understanding of non-human animal physiology reveals a world of sensory perception barely comprehensible compared to human perception. Finally, the concepts of *habituation* and *facilitation* are discussed as a possible confounding explanation for similarities or differences in behavioural responses by the same species to the same stimuli. (Feel free to skip this section if you are already familiar with these topics.)

2.2 An ecosystem primer

The next time you visit a beach, pick up a palm-sized mixture of seaweed, seagrass, driftwood, and other organic material that has washed ashore, collectively referenced as ‘wrack’. You will be holding an entire ecosystem. As much as 40% of invertebrates on the beach rely on wracks deposited by surf, tides, and storms for nutrition and, if lucky, protection from feeding shorebirds. Wracks provide fertilizer to plants already rooted on dunes and even help prevent dune erosion. In a way, wracks are an important bridge in the transition from marine to terrestrial ecosystems. In other words, wracks are multi-purpose: standalone ecosystems unto themselves, yet critical components to multiple surrounding ecosystems small and large.

Equilibrium is probably the single most important driver to healthy functioning ecosystems. At least three principles apply to ecosystem equilibrium. The first is scale. For example, a single coral colony can have its own ecosystem of fish, algae, eels, nutrients, and water currents. That ecosystem can be affected by activities of neighbouring coral ecosystems; fish go back and forth, eels chase food from one coral head to another, or an unsustainable abundance of species in one ecosystem may spill over to another. In larger scales, an entire bay, cove, or sand bar can have an ecosystem comprised of several smaller ecosystems. By extension, an entire lagoon can be a single ecosystem made up of several smaller systems. In turn, many lagoons make up oceans or seas, which all add up to Earth’s biosphere.

A second principle of ecosystems is that it takes much longer for ecosystems to recover or regain equilibrium after a disturbance than the duration of the disturbance itself. Much like the human body, an injury (disturbance) can take only seconds to occur, but recovery can last much longer and, unfortunately, can sometimes be permanent. While a forest can be cut down in a matter of days or weeks, restoration and recovery can take hundreds of years.

The third principle applies to all systems theory. No matter how small or large, we can expect that 99.99% of the time that a change to one component of a system will affect other system components. Equilibrium will be disturbed. The time it takes for equilibrium to be restored depends on rate of recovery (principle # 2), and the scale to which recovery occurs (principle # 1).

There is far more to understanding ecosystems and the role of ecology on system functions and health than the principles summarized above. The take-home message is that ecosystems are multi-dimensional and inextricably interdependent to a level of complexity we have yet to fully understand…and appreciate.

2.3 Sensory capacity of animals

The paragraphs in this section summarize a chapter in *Animal Physiology: Adaptation and environment*, Fifth edition, *Chapter 13, Information and senses (Schmidt-Nielsen, 1997)*. A key message of the chapter is that mechanisms of sensory perception vary among animal species, and that in some cases, sensory sensitivity challenges human imagination and understanding. Unless specified otherwise, all of the following can be cited as originating in (Schmidt-Nielsen, 1997).

Obtaining, assessing, and managing information about our surroundings influences feeding, breeding, predator avoidance and other behaviours for all animals. Specialized sensory organs deliver most of the information about our environment. Although not mutually exclusive, the range of stimuli in the animal world includes three main categories and associated sensory stimuli:

Category	Sample stimuli
Electromagnetic and thermal energy	▪ Light ▪ Infrared radiation ▪ Thermal (heat / cold) ▪ Electric ▪ Magnetic
Mechanical energy and force	▪ Sound and sonar ▪ Touch and vibration ▪ Pressure ▪ Gravity ▪ Inertia
Chemical agents	▪ Taste ▪ Smell ▪ Humidity

Table 1.

General categories and specific physical examples of associated stimuli

(Schmidt-Nielsen, 1997).

Regardless of the species involved, all sensory neurons translate stimuli into nerve impulses that are transmitted to the central nervous system. If the nerve is optic, the central nervous system perceives the stimuli as light. If the nerve is auditory, the central nervous system perceives the stimuli as sound. Intriguing is the fact that optic nerves and auditory nerves carry the same nerve impulses, each carrying action potential. Only the central nervous system identifies the original stimuli.

2.3.1 Electromagnetic

Electromagnetic sensitivity has been demonstrated in marine species such as stingrays, molluscs, salmon, salamanders, turtles, birds, hornets, honeybees and even some bacteria. Among birds, the European robin exhibits migration restlessness during Spring and Fall seasons. When placed in an indoor circular cage, specimens tend to move toward its typical migratory direction for that time of year. It has also been shown that when the horizontal component of a magnetic field is artificially deflected, the bird's orientation changes accordingly (Moore, 1977). This author concluded that magnetic disturbances may indirectly influence avian orientation systems, of potential significance because magnets – at least according to UK-based IMAMagnets.com – are used for helicopter propellers.

2.3.2 Mechanical

Information about the direction and distance of stimuli permits us to move toward or away from the source for a given situation, for example toward mating opportunities or away from threat of predation. Although vision provides most of the directional information, certain auditory mechanisms can be used for extremely precise information about distance and direction. Sound consists of regular compression waves transmissible in air, water, and solids, and for this reason, 'hearing' is not restricted to stimuli through air alone. Examples include extreme mechanical sensitivity to mandible vibration in certain reptiles and the lateral line of fish.

Echolocation describes a mechanism for detecting location and direction. Also referenced as animal sonar, echolocation has been well-developed in bats, whales, dolphins, vols, and birds found in the Hauraki Gulf. The sensitivity of this mechanism speaks for itself. For example,

- Owls can detect prey in total darkness with an error of less than 1° in vertical and horizontal planes.
- Bats, New Zealand's only native terrestrial mammal, whales, dolphins, shrews and a few birds rely on echolocation for directional information whether in dark airspaces or deep and murky waters.
- Dolphins use echolocation to target food. A dolphin can find a dead fish thrown into water so murky that the fish is not visible to the trainer within a matter of seconds. If a clear plastic panel is used to block its path, the dolphin can immediately find an opening and locate the fish (Norris et al., 1961).

Infrasound describes noise frequencies below human detection, e.g., <~20 Hz – 20 MHz. Sensitivity to infrasound may be important to bird species. For example:

- Certain species of pigeon can detect sounds as low as 0.05 Hz.
- The difference between what humans can hear and what homing pigeons can hear is 30-40 decibels, or a 1,000-10,000-fold difference in sound intensity.

- For birds, the maths of sound attenuation suggest that infrasound sources are detectable at hundreds or even thousands of kilometers from their source.
- An advantage of infrasound is that low frequencies suffer little attenuation in still air. To compound matters, it has been reported that nightly temperature inversions coupled with still air facilitates communications between some animals at ranges greater than 10 km (Garstang et al., 1995).

Senses other than hearing provide organisms with additional information. Typically referenced as mechanoreceptors, humans can sense texture, surface qualities and temperature. Other animals have developed mechanoreceptors to detect minute vibrations by insects and fish. For example:

- Spiders can detect vibrations from prey snared in a web.
- Schools of fish in the tens of thousands can perfectly coordinate changes in speed and direction based on vibrations sensed by mechanoreceptors in their lateral lines.

Another mechanical sense is hydrostatic pressure, which is relevant to animals carrying a volume of gas, such as the swim bladder of fish. However, even planktonic organisms with no bodies of air have demonstrated sensitivity to small changes in pressure (Enright, 1963). Pressure is significant to aircraft flight: For example:

- It is broadly accepted that airfoils generate lift when pressure decreases above the airfoil while pressure increases below the airflow.
- Given the airfoil nature of helicopter blades, lift is likely generated in proportion to increased air pressure. The extent to which increased pressure could potentially impact pressure-sensitive organisms requires additional study.

2.3.3 Chemical

Chemical stimuli are most commonly associated with foraging, reproduction and locating enemies, and is best developed in vertebrates and arthropods. Similar to humans, smell and taste stimuli in aquatic animals is closely related and, in some cases, indistinguishable. The sensitivity to chemo receptors in certain marine species is numbing.

The sensitivity to amino acids is demonstrated by the spiny lobster *Panulirus argus*, relatively familiar to New Zealand shorelines. Spiny lobsters have been shown to exhibit sensitivity to the amino acid taurine, important to metabolic processes (Fuzerry et al., 1978). This species also exhibits a sensitivity threshold for taurine of about 10^{-10} molar, a metric requiring 33 mg of this amino acid in an Olympic-sized swimming pool. To put numbers in perspective, an Olympic-size swimming pool holds ~2600 cubic meters of seawater. It is barely comprehensible that spiny lobsters can detect the addition of approximately 1/70th of a teaspoon of taurine in about 92 tons of sodium chloride and other salts in our hypothetical seawater swimming pool.

2.3.4 Summary

Animals cited in the chapter by Schmidt- Nielson ranged from insects, birds, reptiles, and mammals in primarily terrestrial environments, to lobsters, fish, and mammals in marine environments. Understanding the sensory capacity of animals is significant for several reasons. For example:

- Increased sensory sensitivity is particularly acute for acoustic dependencies on communication behaviours.
- Above all is a heightened awareness of differences in the scale and sensitivity to informational stimuli between humans and other life forms.
- Human frames of reference for terms like “noise” or “sound” are relatively limiting compared to the suite of sensory mechanisms that provide wildlife with information critical to survival.
- Sources of disturbance to wildlife need to include a broad range of sensory mechanisms well beyond simply “noise” or “sound”.

2.4 Habituation and facilitation

2.4.1 Introduction

Habituation and facilitation are terms applicable to just about every living organism. human and non-human species alike. In general, terms, habituation describes a process whereby organisms are believed to develop a greater tolerance to various stimuli over time.

Facilitation describes behaviours influenced by multiple (cumulative) stimuli that facilitate habituation. For example, any given species may exhibit a lingering restlessness to the presence of humans following a singular sonic boom or helicopter landing, or gradual tolerance over compounding incidents or episodes of respective booms or landings over time. Importantly, habituation and facilitation are not necessarily mutually exclusive. It is also important to accept that just because a behaviour is not observed does not mean an absence of effects(Hoang, 2015).

The subjective nature of habituation has fueled considerable debate in academic circles, primarily in terms of whether it is perceived as a positive, neutral, or negative condition regardless of species involved. The debate is further complicated by the number and type of factors involved such as species type, timing, and frequency of stimuli, availability of optional habitats, and life-stage.

2.4.2 Habituation and birds

A literature review by New Zealand’s Department of Conservation (DOC) on the impact of noise on recreationists and wildlife in New Zealand’s natural areas suggests that wildlife responses to noise-related disturbances reflect either tolerance or aversion/flight behaviours. The review offers a definition of habituation as “….the strength of a response to a stimulus over time after repeated exposure, where the consequences of the stimulus are neither adverse or beneficial” (Bejder et al., 2009a).

However, a closer read of the article by Bejder, Samuels et al. (2009) reveals a significant context for applying the term ‘habituation.” They suggest that terms such as ‘habituation’, ‘sensitization’, and ‘tolerance’ can represent a rather simplistic view of complex processes. They cite a description of such complexities by Gill et al. (2001 p. 226), which amounts to a decision tree (bullets added):

> “The decision of whether or not to move away from disturbed areas will be determined by factors such as:
>
> - the quality of the site currently being occupied,
> - the distance to and quality of the site currently being occupied,
> - the distance to and quality of other suitable habitats,
> - the relative risk of predation or density of competitors in different sites, and

- the investment that an individual has to make in a site (for example, in establishing a territory, gaining dominance status or acquiring information) (Gill & Sutherland, 2000)."

A major problem with labeling animal behaviour as 'habituated' is the general perception that it indicates that a particular disturbance has little or no affect, thereby concluding that animals are not adversely impacted. Or, perhaps more detrimental, 'habituation' can be interpreted as a desirable outcome, as when tourism operators strive to habituate certain animals so that they can be closely approached or handled (Nisbet, 2000).

Bejder, Samuels et al. (2000) urge caution for wildlife managers to conclude that animal habituation in response to human activities have neutral or benign consequences for wildlife when, in fact, the effects are detrimental. They point to research suggesting that existing harmful effects may go unrecognized, leading management strategies to call for no corrective measures, an easing of conservation, or even an increase in the [detrimental] activity (Griffin et al., 2007).

In much of the literature, the terms habituation and tolerance are often used interchangeably.

- In a section on tolerance in the DOC review (Harbrow et al., 2011), the authors conclude that human attempts to drive wildlife away from attractive sites (e.g., crops), do not succeed in the long run due to habituation (Bomford & O'brien, 1990; Marsh et al., 1991).

- Conceptually similar, other research attempts to discourage fur seals away from fishing nets using acoustical explosives have fallen short, in part attributable to habituation (Shaughnessy et al., 1981).

The extent to which birds are disturbed by aircraft may depend on their ability to habituate to aircraft noise(Hoang, 2015). Bird species and frequency of aircraft overflights also contributes to perceived habituation. For example:

- Herring Gulls nesting near an airport did not react to subsonic aircraft noise near an airport (Burger, 1981).

- Other researchers observed no effect of helicopters and fixed-wing aircraft on kittiwakes and guillemots (Dunnet, 1977).

- In these instances, *frequency* of overflights appears closely related to habituation.

- The Herring gulls in Burger's study were exposed to planes landing every 2-3 minutes at a nearby airport, while the Guillemots in Dunnet's study were nesting on cliffs under the regular route of helicopters flying from an airport to offshore oil rigs and platforms.

- Birds that are not subject to frequent aircraft overflights are known to exhibit stronger reactions to an aircraft disturbance (Hoang, 2015).

- The effect of helicopter and fixed-wing overflights on a remote colony of Brunnich's guillemots has been studied (Olsson & Gabrielsen, 1990). The authors compared their results with those of Fjeld et al. (1988), who studied a less remote colony of Brunnich's guillemots at the same archipelago as those observed in the Olsson study (Fjeld P. E. et al., 1988).

- Olsson et al. reported that birds took 20 minutes to return to their nests following the disturbance compared to 5-10 minutes it took birds to return after a disturbance in the Fjeld (1988) study. They further observed no evidence of habituation over the course of the study and hypothesized that the difference in responses was attributable to greater habituation to birds in the Fjeld et al. study.

As previously mentioned, the appearance of habituation and tolerance may not necessarily reflect the absence of adverse effects (Hoang, 2015). For example:

- No strong effects were observed during frequent helicopter overflights on foraging and roosting waders, suggesting that birds may be forced to move to different areas, or at least depart temporarily (Smit C. J. & Visser, 1993).

- Other research suggests that birds not exhibiting stress may be experiencing physiological stress such as elevated heart rate, and that consequences of physiological impacts are not understood well enough to dismiss their potential effects (Hoang, 2015).

- In addressing tolerance as a behavioural response in birds, a DOC literature review (2011) suggests that the absence of obvious behavioural responses by birds to disturbances does not necessarily mean there is no impact on an individual or population. For example,
  - Penguins are known to cease activity (at least initially), freeze or feign death in response to disturbance.
  - Other species have shown a dramatic spike in heart rates and other physiological responses without showing any outward changes in behaviour (Nimon & Stonehouse, 1995).

2.4.3 Facilitation

In contrast to habituation, the term *facilitation* refers to increased sensitivity of birds to low levels of overflight disturbance following other anthropogenic disturbances (Smit C. J. & Visser, 1993). For example:

- Red Knots were found to be more restless and less approachable by humans following jet overflights (Koolhaas et al., 1993).
- Jet overflights appeared to have a stronger effect on shorebirds when wind surfers were previously in the area (Smit C. J. & Visser, 1993).

2.4.4 Habituation and marine mammals (cetaceans and pinnipeds)

Additional research is required regarding habituation of marine mammals in response to aircraft overflights. A starting point for such enquiry will begin with a synthesis of a 238-page workshop publication by the International Society for Comparative Psychology titled *Considerations of the effects of noise on marine mammals and other animals* (Wright & Highfill, 2007).

Articles by Wright and Kucazaj (2007) titled *Noise related stress and marine mammals: An Introduction*, and by Wright et al. (2007) titled *Anthropogenic noise as stressor in* *animals: a multidisciplinary perspective*, provide a detailed review of the definition, application and alternative concepts surrounding the issue of habituation regardless of species.

2.4.5 Habituation and facilitation for wildlife (other than avian)

TBD

3.0 Factors capable of influencing wildlife responses to aircraft

3.1 Introduction

Several literature reviews have been published regarding the effect of noise on wildlife, some more applicable to New Zealand and the Hauraki Gulf Marine Park than others. However, each of the following literature review provided useful information for this report. In chronological order:

1. Effects of aircraft noise and sonic booms on domestic animals and wildlife: a literature review synthesis, by Manci et al., (2003)
2. *The Effect of Noise on Wildlife: A Literature Review*, by Autumn Lyn Radle, (2007)
3. *The effects of aircraft on cetaceans: implications for aerial whalewatching*, by Luksenburg and Parsons, (2009)[1]
4. *The Impact of Noise on Recreationists and Wildlife in New Zealand's Natural Areas: A Literature Review*, published by New Zealand's Department of Conservation (DOC), (2011)
5. *A Literature Reviews of Aircraft Disturbances on Seabirds, Shorebirds and Marine Mammals*, by Tinya Hoang, (2013)
6. *A Synthesis of two decades of research documenting the effects of noise on Wildlife*, by Shannon, et al., (2016)

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[1] Although not titled as a literature review, this article reviews articles on the effects of noise on cetaceans from 1995 to 2008.

Importantly, all reviews cited challenges inherent to conducting and interpreting research results on the impact of noise on wildlife (Harbrow et al., 2011; Hoang, 2015; Luksenburg & Parsons, 2009; Manci et al., 1988; Radle, 2007; Shannon et al., 2016). For example:

- Variables affecting observed results include differing sensitivities across taxa (Slabbekoorn, 2013), context, sex, and life history (Ellison et al., 2012) (Francis & Barber, 2013).

- Similar to other forms of environmental stimuli, noise has been shown to elicit compound behavioural and physiological responses, making pinpoint cause and effect relationships difficult (McLaughlin & Kunc, 2013).

- The impact of noise on wildlife is confounded by other environmental conditions or disturbances such as modified habitat, and visual disturbance in conjunction with audio stimuli, which can make interpretation of experimental reports difficult (Summers et al., 2011).

- Response variables are known to differ by time of day and year, an animal's physical condition, whether an animal is restrained or not, the animal's experience (exposure), or whether confounding physical conditions are in place, e.g., drought (Manci et al., 1988).

- Finally, the scale and extent of wildlife responses to noise is subject to variance in noise characteristics such as source, duration, frequency content and intensity (Francis & Barber, 2013), and short- versus long-term exposure on breeding success, mortality, population dynamics or overall fitness (Harbrow et al., 2011).

Note that additional reviews have been conducted for specific wildlife species, families or classes, and are cited herein separately. The point is that regardless of taxa, scientifically quantifying behaviour is difficult. However:

- Recent improvements in measurement technology, experimental design and cumulative complementary results have converged to overcome earlier experimental obstacles.

- The convergence of advanced methodologies is delivering results upon which scientists, resource management and policy can more safely and accurately assess the effects of noise exposure on wildlife (Shannon et al., 2016).

3.2 What are aircraft stimuli?

Types of aircraft, noise levels, distance from noise source, species and flock size represent factors capable of effecting behavioural and physiological responses of wildlife. Degree of species habituation is a major factor of influence to wildlife responses to stimuli. However, the complexities of habituation are examined separately at the end of Section 2.3.

3.3 Types of aircraft

Several types of aircraft elicit different responses in birds. However, helicopters have been widely viewed as the most disturbing (Drewitt, 1999):

- Among California Common Murre colonies (order charadriiforms), the proportion of helicopter overflights that caused disturbance (83%) was greater than fixed wing aircraft (57%) (Rokek et al., 2007). These authors suggest that such metrics are partially attributable to the low-altitude capabilities of helicopters, and that, on average, helicopters tend to disturb at higher altitudes than fixed-wing aircraft, perhaps due to louder engines and rotor vibration.

- In the Dutch Wadden Sea, helicopter noise disturbed roosting oystercatchers, Bar-tailed Godwits and curlews more frequently and over longer distances than military jets (Smit C.J. & Visser, 1985). Helicopters at <1500 m (4,920 feet) caused greater proportions of stocks to take flight than a jet at <1200 m (3,940 feet) (Visser, 1986).

- In the German Wadden Sea, roosting shorebirds were disturbed in 100% of potentially disturbing helicopter overflights, followed by jets (84%), small civil aircraft (56%) and motor-gliders (50%) as cited in Smit and Visser, 1993. In addition, the incubating behavior of Glaucous Gulls and Arctic Terns were more affected by helicopters versus fixed-wing aircraft, but even more so by human presence (Gunn & Livingston, 1974).

- A 1980s study of the impact military aircraft on animal disturbance revealed that humans at avian roosting sites and helicopters impacted seabirds more than sonic booms “(Jehl & Cooper, 1980).

- Brown (2001) reported that responses of bird colonies “to balloon overflights suggests that visual stimulus is likely to be an important component of aircraft noise disturbance” (Brown, 1990).

- Similarly, the literature review prepared by DOC appears to corroborate this assertion: “…wildlife may respond to the size, speed or sudden appearance of aircraft rather than only to the noise it creates” (Harbrow et al., 2011).

3.3.1 Noise levels

The topic of noise levels in the literature sometimes overlaps with behavioural responses.

- Aircraft noise can be measured based on sound pressure and frequencies (Hoang, 2015). Most studies measure noise levels using the decibel scale weighted with an A-weighting filter (dBA). This methodology is based on the noise sensitivity of the human ear, which, as we learned earlier, significantly differs from the noise sensitivity of wildlife (NPS, 1994).

- Brown (1990) measured the effect of acoustic stimuli of a float plane on Crested Terns in Australia at simulated altitudes from 75-300 m (250-980 feet). Peak noise levels ranged from 65-95 dBA. Background noise levels for ocean wave action was 55-65 dBA, and noise from bird call activity was 60-75 dBA. Dependent variables included:
    - Scanning
    - Alertness
    - Avoidance, and
    - Escape behaviors.

- Most birds exhibited scanning behavior at all treatment levels, even when above background noise levels. Alert behavior had a strong positive relationship with increasing noise levels. Avoidance and escape behaviours were observed at elevated noise levels (>85 dBA).

- The experimental methodology was repeated nearly a decade later, but this time with simulated helicopter noise during landing, pausing, and taking off. Although peak noise levels of sound treatments were the same, noise from the helicopter caused greater avoidance and escape behaviors than simulated noise from the fixed wing aircraft in the earlier experiment. Differences in bird behavior may be attributable to differences in frequency and temporal aspects of helicopter noise (Brown, 2001)

3.3.2 Distance from stimuli source

A table listing studies on sea birds and shore birds in terms of aircraft disturbance and distance is in Appendix C (Hoang, 2015). Results suggest that there is no consistent distance at which birds will react to overflights. Multiple factors may contribute to such findings. For example, disturbance differences indicate that birds may be more sensitive in undisturbed regions, when they are in high concentrations, or when they are molting or breeding (Komenda-Zehnder et al., 2003).

There appears to be a relationship between distance and disturbance that overlaps with habituation, described in *Section 2.4, Habituation and facilitation*. In addition to studies cited in Appendix C, there is anecdotal evidence that exemplifies variability in the impact of disturbance and distance. For example:

- In the Great Barrier Reef (GBR). Crested and Bridled Terns and Common Noddies breeding within tens of meters from an airstrip did not appear negatively impacted by aircraft despite occasional bird strikes.

- Also, in the GBR, helicopters landing meters of breeding noddies and shearwaters did not appear affected.

- Helicopters in the Netherlands at altitudes of 100-300 m (330-980 feet) at a frequency of 2-3 per hour did not appear to have a strong impact on foraging and roosting waders (Smit C.J. & Visser, 1985).

- Conversely, and to complicate matters, in more remote areas of the GBR, breeding seabirds flew from their nests before approaching aircraft could be detected by humans (GBRMPA, 1997).

3.3.3 Species and flock size

Avian response variables to noise have been shown to differ by species and flock size. For example:

- Curlews and Redshanks in the German Wadden Sea were found to be more reactive than Bar-tailed Godwits to aircraft disturbances (Heinen, 1986).

- In another study, oystercatchers were more tolerant of aircraft disturbance compared to Bar-tailed Godwits and curlews (Visser, 1986).

- Yet another study found that it took longer for oystercatchers to resume normal behavior than it did for curlews (Glimmerveen & Went, 1984) following an aircraft disturbance. Flock size may influence avian responses to aircraft overflights, but the literature reviewed thus far appears inconclusive. Smit and Visser (1993)[2] mentioned that several studies indicated that larger flocks are easily disturbed, perhaps because larger flocks have a greater chance of having particularly sensitive individuals.

- Conversely, Olsson and Gabrielsen (1990) did not find that stress responses increased in a larger colony.

3.4 Behavioural responses of birds

3.4.1 Introduction

Approximately two thirds of the scientific literature studying the impact of human-generated noise on wildlife between 1990 and 2013 focused on songbirds and

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[2] This is a comprehensive study involving multiple species and birds found in New Zealand subjected to multiple independent variables. Additional study of this paper is required and, as applicable, findings will be incorporated into this report.

marine mammals (Shannon et al., 2016). Their review of the literature suggests that responses of terrestrial wildlife to noise begins at noise levels of ~40 dBA. As a frame of reference, 40 dBA is comparable to noise levels in a library or other bird calls (Appendix D). Many peer-reviewed papers suggest a range or scope of behavioural responses to various stimuli regardless of species. For example:

- Frid and Dill, (2001) propose including vigilance, fleeing, habitat selection, mating displays and parental investment as potential behavioural areas of interest.

- A sampling of behavioural responses in a 1998-2002 review of noise effects on animals (and birds in particular) includes vigilance, head-turning, demographic and nesting success, ledge attendance, and levels of intensity for each (Kull & McGarrity, 2003).

- Still other researchers suggest that habituation(Ditmer et al., 2019), reproduction, and overall fitness are behavioural reponses(Kleist et al., 2018; Schroeder et al., 2012; Zwart et al., 2015).

- Still other authors suggest that behavioural responses include scanning and alert behaviors, such head turning, neck extension, body re-orientation and tension, agitated behavior, such as increased calling, head bobbing, restless pacing and wing-flapping, protective or escape behaviors, such as crouching, and flying, running, diving, or swimming away (Brown 1990; Kempf and Hüppop 1998) as cited by Hoang 2015.

Note: Given the scope of potential behavioural responses in current and future research, this section may be a nearly continual work in progress. The following section outlines key avian responses, which, unfortunately, is not all inclusive at time of writing.

3.4.2 Breeding and productivity

Aircraft noise has been shown to impact activities associated with a variety of species propagation activities across multiple bird species, including:

- Embryonic and post-natal development
- Courtship

    - Fertility
    - Nesting activities
    - Prey delivery
    - Population recovery, and
    - Parental attendance (Hoang, 2015).

- Research findings reveal significant impacts of human-generated noise on avian embryonic development regardless of noise source or species involved. Recent research helps illustrate this point:

    - ✓ Bird eggs and nesting babies exposed to moderate levels of anthropogenic traffic noise exhibit large and direct adverse impacts in terms of long-term development and fitness. Impacts include impaired nesting growth, shorter telomere length and reduced fitness as adults (Meillère et al., 2024).

    - ✓ So pervasive is the potential impact of anthropogenic noise on breeding birds that other researchers suggest reviewing the impacts of acoustic comfort for pregnant [human] mothers in hospital environments (Slabbekoorn, 2004).

    - ✓ Another research group found that exposing fertilized eggs to a 110 dB noise source resulted in a decrease in body weight, brain weight and size (Kesar, 2014).

    - ✓ Two studies by Mariette, et al., 2024, revealed that birds exposed to noise in pre- and postnatally conditions produced only half as many offspring compared to those not exposed to traffic noise. Note: “One month after the end of exposure, we measured the juveniles again and found that noise-exposed chicks were no longer smaller that their song-exposed siblings, but the impact on their physiology had worsened. And even a year later, once the birds were adults, the cellular impact of noise was still clearly visible” (Mariette, 2024).

    - ✓ Still other research on avian embryonic development showed that adult nesting attempts were reduced by traffic noise as a result of reduced embryo mortality in traffic noise treatment groups. The conclusion of this research was that “traffic noise may disproportionately affect chronically stressed [bird] individuals during reproduction” (Potvin & MacDougall-Shackleton, 2015).

- Disturbance from helicopters and fixed-winged aircraft is thought to be slowing the recovery of breeding populations and breeding success of Common murres (*Uria aalge*) at three locations in California (Rokek et al., 2007).

- The same authors found that helicopters tended to cause more disturbance than fixed-winged aircraft and at altitudes higher than those of planes.

- Prey delivery rates of Mexican Spotted Owls has been shown to decrease in response to disturbance stimuli from helicopters and chainsaws (Delaney et al., 1999).

- Far less invasive disturbance stimuli have been shown to impact breeding of European Oystercatchers. For example:

    - ✓ Parental European Oystercatchers decreased time incubating eggs, self-feeding and provisioning their young in response to people on foot (Verhulst et al., 2001).

The following summary abstract is from an article by Halfwerk, Bot et al. (2011) titled: *Low-frequency songs lose their potency in noisy urban conditions* (Halfwerk et al., 2011)

Avian fertility, mate selection and reproduction are of genetic and ecological importance. Interpersonal communication by acoustical signals is the mechanism critical to reproductive process. According to the authors, “Several bird species have been reported to increase song frequency by which they reduce the masking impact of spectrally overlapping noise”. Halfwerk, et al. suggest that increasing song frequency may be insufficient or whether there are hidden costs to reducing song frequency. For example, “Species may rely on low frequencies to attract and impress females, and the use of high frequencies may, therefore, come at the cost of reduced attractiveness."

The authors further studied the potential tradeoff between signal strength and signal detection of the great tit (Parus major). Results indicate "that the use of low-frequency songs by males is related to female fertility as well as sexual fidelity. The authors showed that urban noise conditions impair male-female communication, and that signal efficiency depends on song frequency in the presence of noise. The data further revealed a response advantage for high-frequency songs during sexual signaling in noisy conditions, whereas low-frequency songs are likely to be preferred.

These data are critical for our understanding of the impact of anthropogenic noise on wild-ranging birds because they provide evidence for low-frequency songs being linked to reduced reproductive success and adversely impacted noise-dependent signal efficiency.

3.4.3 Foraging

Behavioural ecologists have recently been applying economic models of antipredator behaviour to disturbance studies to better predict and understand observed responses. An article by Frid and Dill (2001) suggests that regardless of species investigated, predation and non-lethal disturbance stimuli create similar tradeoffs between avoiding perceived risk and other fitness-enhancing activities such as feeding, parental care, or mating.

- Prey have evolved antipredator responses to generalized threatening stimuli such as loud noises and rapidly approaching objects. "Thus, when encountering disturbance stimuli ranging from the dramatic low-flying helicopter to the quiet wildlife photographer, animal responses are likely to follow the same economic principles used by prey response to predators" (Frid & Dill, 2001).

- The New Zealand dotterel typically forages on molluscs, small crustaceans, crickets, and other insects present on the beach. When people were present, dotterel chicks spent less time foraging in littoral zones and more time in the supralittoral zones[3], and in general, less time feeding. Littoral zones are preferable foraging destinations compared to supralittoral zones, and that high levels of human disturbance may infer energetic constraints on dotterel chicks.

- The authors conclude that “fledgling success of chicks may be enhanced if human access to feeding areas adjacent to breeding sites is reduced during the chick-rearing phase of the breeding season (Lord et al., 1997).” (Of potential relevance, the Biodiversity Section of the Taranaki Regional Council estimates that the total population of New Zealand dotterels is currently about 1400, and are listed as ‘nationally vulnerable’).

- Although not specific to aircraft, two experiments were conducted to quantify the effects of human disturbance on foraging and parental care in European oystercatchers (*Haematopus ostralegus*).

    - In experiment one, oystercatcher pairs incubating a clutch were disturbed on their feeding territory on the mudflat. Disturbance significantly reduced the proportion of time that the clutch was incubated, but also the proportion of time that the pair spent foraging on the mud flat.

    - In experiment two, foraging oystercatcher pairs with chicks were disturbed by two observers at different distances from the edge of the salt marsh where the chicks resided. Total food collected was independent of disturbance, but a smaller proportion of the food collected was allocated to the chicks with increasing disturbance levels.

    - Both experiments demonstrate that human disturbance of foraging in breeding oystercatchers reduced the amount of parental care, and thus presumably reproductive success (Verhulst et al., 2001).

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[3] Also known as the splash zone or white zone. This is the area above the high-tide water level, typically the result of storm surges (https://biophysics.sbg.ac.at/rovigno/rovigno3.htm).

3.4.4 Predation risk

The concept of predation risk influences a broad spectrum of potential impacts at individual, population, and community levels. It has long been recognized that noise disturbance produces physiological responses that help animals survive in threatening or otherwise emergency conditions (Cannon, 1929).[4]

Physiological responses once labeled "fight or flight" are more recently cited as "active defense response", a process further delineated as either "active" or "passive" (Gabrielson & Smith, 1995). More recent research on disturbance has adopted the principle that human-induced non-lethal disturbance is equivalent to an animal's prey risk assessment (Frid & Dill, 2001).

Behavioural ecologists have applied economic models of animal antipredator behaviours to disturbance studies to better predict disturbance responses. Frid and Dill, 2002, define "disturbance" as "*a deviation in an animal's behavior from patterns occurring without human influences*." These authors have elaborated on the argument that disturbance stimuli ranging from low-flying helicopters to nature photographers can influence fitness and population dynamics via energetic and lost opportunities inherent to avoiding risk. Disturbance effects on behaviours such as vigilance, fleeing, habitat selection, mating displays, and parental investment affect animal populations and communities.

The result of disturbance stimuli has been shown to divert time and energy from feeding, parental care or mating displays, and activities related to fitness-enhancement (Steidl & Anthony, 2000) . In such instances, habituation or relocation may be options. However, animals may be unable to shift from disturbance stimuli habitats depending on the costs and benefits involved. The capacity for animals to relocate from disturbance stimuli habitats is constrained when alternative habitats are too far away or of lower quality for maintaining life sustaining activities. In such instances, the benefits of relocating do not outweigh the costs of remaining at sites high in disturbance stimuli (Gill et al., 2001). Assessing predation risk against resource

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[4] Physiological responses of animals to noise are detailed in Section 4.0 of this assessment.

availability initially appears to be an individual decision. However, variation in the scope and scale of responses can spill over to population dynamics and habitat quality expressed increased energetic costs associated with antipredator behaviour (Frid & Dill, 2001).

3.4.5 Energy expenditure

The previous section on predation risk overlaps with examples of energy expenditure in response to disturbance stimuli is compounded by other contextual factors. For example, in response to disturbances, woodchucks have been shown to decrease flight initiation distance the closer they are to their refuge burrow (Bonenfant & Kramer, 1996).

3.4.6 Vocal activity

Lines separating vocal activity, reproduction and breeding, masking and habituation can blur. However, if not for avian vocal activity, the other life sustaining behaviours would be moot. As such, avian vocalization plays a significant role in establishing territory, mate attraction, predation alarm, announcement and exchange of food, and maintaining social integration (Slabbekoorn, 2004). The impact of noise on birds spans the spectrum from the molecular level through behavioural, population and community levels of biological organization as a result of degraded sensory environments (Injaian et al., 2018) (Kleist et al., 2018). For example:

- Birds have been known to alter the frequency and timing of vocalizations to avoid masking, alter time spent singing, change the amplitude and structure of vocalizations, or increase song duration and rate to enhance vocal projection in noisy environments (Díaz et al., 2011; Lohr et al., 2003) (Mockford & Marshall, 2009).

- Changes in the rate and type of vocalization may affect energy budgets, while masking may hinder or hamper parent-offspring communication and male territory defense, thereby negatively impacting reproductive opportunities with consequences for species fitness (Schroeder et al., 2012; Zwart et al., 2015).

- Noise has been shown to affect avian community levels of biological organization (Clinton D. Francis et al., 2009). For example, species with high-frequency vocalizations tend to adjust vocalization frequency in response to low frequency noise, while species with low-frequency vocalizations tend to adjust the timing of vocalizations or depart the area to avoid interferences inherent to masking (Hu & Cardoso, 2010; Proppe et al., 2013). In particular, Proppe et al. 2013 demonstrated that human-generated noise decreases songbird diversity that may contribute to community homogenization and diversity.

- Additional research suggests that some avian species (Eurasian wrens) appear less impacted by noise exposure (Yang & Slabbekoorn, 2014), but the degree to which habituation influences such responses is unknown. However, similar species-specific [non]-responses may lead to indirect benefits that include decreased predator abundance in loud habitats (Clinton D. Francis et al., 2009). The cumulative responses can change community composition, diversity, and ultimately ecosystem functioning (C. Francis et al., 2012).

- A leading source of chronic anthropogenic noise pollution in relatively remote landscapes is air traffic (Buxton et al., 2017). Such conditions can have negative consequences for wildlife and respective habitats (Shannon et al., 2016). Protecting and managing avian acoustic sensory conditions is relevant to maintaining natural environments, particularly habitat availability and associated ecological functions (Dumyahn & Pijanowski, 2011).

- A recent paper by Vincelette et al. (2020) provides insight on the effect of aircraft traffic on avian vocal activity. The study attempted to demonstrate differences in vocal activity before, during and after aircraft overflights in areas with high and low rates of aircraft noise. This research team sought to understand the impact of aircraft traffic noise on the richness of avian vocal activity at two remote sites in Denali National Park (Alaska), where aircraft (jet, helicopter, and prop) were the only audible anthropogenic sources of noise. Both experimental sites had similar rates of jet noise, but one site had approximately 10 times the rate of propeller noise.
    - The bird community in the lower aircraft activity site showed increased vocalization richness after the aircraft had passed, while birds at the site with higher rates of aircraft activity did not demonstrate a response.

- Birds in the lower aircraft audibility were audible in 72.6% of samples, aircraft in 2.5% of samples, and birds in 2.2% of samples when aircraft noise was present. Birds in the high aircraft audibility site were audible in 71.2% of samples, aircraft in 19.9% of samples, and 14.4% of samples when aircraft noise was present.

- The authors suggest that elevated avian vocalization at the site with lower aircraft activity perceive aircraft noise as a threat or contributes to masking. Conversely, the authors suggest that lack of response at the lower noise site may be attributable to habituation, species tolerance, or site-specific features capable of influencing aircraft noise propagation and perception (Vincelette et al., 2021).In short, stronger behavioural responses at sites with infrequent disturbance stimuli reduce the potential for habituation (Ditmer et al., 2019).

Importantly, interested readers should consult the Discussion section of the paper by Vincelette et al. (2020) for alternative explanations for the results. In addition to differences in aircraft overflight type and frequency, other differences include elevation, different temporal conditions, and habitat features capable of influencing sound spreading loss. In addition, the amplitude of sound signals may be attenuated, refracted, or scattered in response to interactions involving climate, topography, and land cover (Attenborough, 2002) (Forrest, 1994). Further, wind-induced vegetation noise may reduce vocalization during an aircraft event as a masking response. Finally, sound levels associated with aircraft overflights have been shown to vary in response to atmospheric conditions (Zaporozhets et al., 2011).

Although community bird vocalization responses can be influenced by factors cited by the above authors, Vincelette, Bixton et al. (2021) concluded that “the simplest explanation for the documented increase in bird vocalization richness [at the site with lower aircraft audibility] is the presence of the aircraft itself, regardless of modulation by site-specific effects” (Vincelette et al., 2021). In their concluding remarks, the authors reinforce the idea that protected areas are more vulnerable to long-term ecological impact (Lynch et al., 2011), and loss of biodiversity (Vincelette et al., 2021). In terms of a systems approach, such factors are believed to “impose selection pressure on the avian community and alter species composition, drive evolutionary change and ultimately impact ecosystem functioning” (Swaddle et al., 2015) .

3.4.7 Masking

Acoustic masking describes a process whereby sensory perception is adversely affected by a competing source of auditory stimuli. Specifically, masking has been described as noise that “interferes with the perception of a sound of interest” (Bowles, 1995) or “the inability of an animal to hear important environmental signals” (Manci et al., 1988). In day-to-day terms, an example of masking is when someone is trying to count change for a customer while someone in the background is reciting a series of home addresses out loud.

In the context of sensory interference, masking is likely far more prevalent and consequential for animals with higher sensitivities compared to humans. In short, the impact of auditory masking probably increases in some proportion to increases in auditory stimuli, particularly if the competing stimuli is aircraft traffic (Vincelette et al., 2021).

3.4.8 Population structure

Note: This section and the next are the least developed of this report thus far. Although noise sources are not specified – and they need to be for inclusion in this report – the results hint and reinforce the ecological scale and ripple effect of noise on broader ecosystems.

Population structure represents a major biological component that bridges the gap between species and community structure. The following paragraphs appear as largely verbatim abstracts from several articles I have yet to study and synthesize for purposes of this report. They are, however, potentially useful to readers of this report.

Impacts of chronic noise anthropogenic noise from energy-sector activity on abundance in the boreal forest (Bayne et al., 2008)

This article suggests that anthropogenic noise adversely impacts habitat quality. In particular, such noise interferes with acoustic signals necessary for communication among birds, in this case passerines. Study results showed significantly reduced species richness as proximity to the noise source increased. Anthropogenic noise was shown to impact avian abundance in one third of the species tracked. In addition, seven of another cohort of 23 species exhibited lower conditional and unconditional rates of occupancy as proximity to noise generating facilities increased.

Noise pollution changes avian communities and species interactions (C. D. Francis et al., 2009; HGMPA, 2021)

The authors conclude that noise alone reduces nesting species richness and leads to modified avian communities. Noise was also found to indirectly facilitate reproductive success of individuals nesting in noisy areas in response to disrupted predator-prey interactions. An unexpected result was that reproductive success for birds in noisy habitats may contribute to the success of urban-adapted species (habituation) and the loss of birds less tolerant of noise.

Avian reliance on acoustical communication makes them particularly vulnerable to the novel acoustics of noise, which is capable of disrupting “acoustic communication, interfering with detection of warning signals, and elevating stress levels” (Slabbekoorn & Ripmeester, 2008).

Noise pollution filters bird communities based on vocal frequency (Francis et al., 2011)

“Human-generated noise pollution now permeates natural habitats worldwide, presenting evolutionarily novel acoustic conditions [that]…not only harm humans, but threaten wildlife, and especially birds, via changes to species densities, foraging behavior, reproductive success, and predator-prey interactions. Explanations for negative effects of noise on birds include disruption of acoustic communication through energetic masking, potentially forcing species that rely upon acoustic communication to abandon otherwise suitable areas”.

3.4.9 Community structure

The costs of chronic noise exposure for terrestrial organisms (Barber et al., 2010)

In terms of acoustical ecology, the authors suggest that acoustic masking interferes with intentional communication between avian males and females during mate selection by reducing the number of message recipients in the communication network. Then authors further address the threat of noise to multiple taxa regarding species diversity and richness, foraging, antipredator behaviours, reproductive success and community structure.

Songbird community structure changes with noise in an urban reserve (Mena & Garcia, 2018).

Urban noise has the potential to interfere with avian communication associated with predator detection or breeding activity, thereby potentially adversely impacting bird communities and local distribution patterns. This article reiterates that not all bird species are negatively impacted, and that the mechanisms affecting tolerance or disturbance are under-studied. This study assessed the “association between (i) anthropogenic noise and bird richness, (ii) noise level and song modification and (iii) species noise tolerance and detection frequency”.

This research team concluded that “increase[s] in noise may lead to urban bird communities dominated by a limited number of noise-tolerant species”, and that “species richness is negatively affected by increasing anthropogenic noise, but also by the increase of shrub cover. Nevertheless, over 90% of our species did not display significant song modifications”. Further, the authors “…expect that by limiting anthropogenic noise and providing diversity of vegetation cover, cities could be made attractive to bird species with different degrees of noise tolerance, promoting urban bird diversity. and parent–offspring.”

3.5 Ecological Community

Noise pollution alters ecological services: enhanced pollination and disrupted seed dispersal (C. D. Francis et al., 2012)

The bird species in this article are not found in New Zealand. However, the potential value of this article exemplifies ecological services birds can provide, how noise disturbance can adversely impact such services, and how service interruption can ripple through broader ecological systyems. The impact under study revealed community-level consequences in response to limited passionfruit (*Pinusa edulis*) seed pollination and dispersal. The following is verbatim from the article Abstract:

“Specifically, noise pollution indirectly increased artificial flower pollination by hummingbirds, but altered the community of animals that prey upon and disperse *Pinus* *edulis* seeds, potentially explaining reduced *P. edulis* seedling recruitment in noisy areas. Despite evidence that some ecological services, such as pollination, may benefit indirectly owing to noise, declines in seedling recruitment for key-dominant species such as *P. edulis* may have dramatic long-term effects on ecosystem structure and diversity."

Seed dispersal is an important ecological function influenced by species biodiversity. This article examines the relationship between biodiversity of frugivores (fruit-eating animals, particularly birds) and seed dispersal.

- Results suggest that the abundance and richness of dispersed seeds were positively related to frugivore abundance and richness.

- A conclusion of the authors is that frugivore richness was "the only attribute of the frugivore assemblage affecting the probability of seed dispersal into deforested areas of the landscape".

- This is relevant because evidence suggests a connection between noise pollution and species biodiversity (Sordello et al., 2020).

Ecological research now deals increasingly with the effects of noise pollution on biodiversity. Indeed, many studies have shown the impacts of anthropogenic noise and concluded that it is potentially a threat to the persistence of many species.

4.0 Physiological responses of birds

Hoang, 2015, suggests that impacts from aircraft overflights on birds can be behavioural and physiological. Suggested behavioural responses include:

- Reduced reproductive success
- Increased predation
- Increased energy expenditure
- Reduced habitat use, and
- Reduced food intake.

Other researchers have suggested that colony size, and continued use of the colony over time can reflect the impact of aircraft overflights (Rokek et al., 2007).

Excessive arousal, alertness or chronic stress, and physiological energy budgets of birds have also been cited as adverse impacts (NPS, 1994). In more general terms, noise has been shown to impact bird acoustic sensory conditions at the molecular, behavioural, population and community levels of organization (Vincelette et al., 2021).

The sensitivity of organism response to auditory stimuli should not be underestimated. In *The Niche Hypothesis* (Krause, 1993), suggests that every organism has an ‘aural niche” for its particularly unique voice and position in a habitat based on the relative frequency, amplitude, timbre, and duration of the sound it produces. If noise disturbance crosses individual tolerance thresholds, the organism may be forced into different areas with consequently different aural zones in which they lack an established niche. A conclusion of this hypothesis is that aural zones may be so unique and important for successful communication and other uses of auditory senses, “that disturbance to this soundscape could be detrimental to the future of the individuals, populations or entire species” (Krause, 1993).

It has also been reported that birds display a spectrum of responses from being alert to mild disturbances to an intention to fly, pecking at each other, broken-wing displays, and walking, swimming or flying short distances (Bowles, 1995). In addition, panic induced by particularly noisy disturbances is known to cause egg loss in some colonial birds (Bunnell et al., 1981), or frightening some birds into colliding with human-made structures such as power lines (Blokpoel & Hatch, 1976). Importantly, studies show that animals rarely display uncontrolled flight, and that species normally known to run or fly away in fright do not usually injure themselves (Bowles, 1995). Equally as important, although panic responses may not be as serious for wildlife as they might appear, cumulative effects such as habitat displacement from sustained disturbances “may cause longer term problems for individuals and overall populations (Harbrow et al., 2011).

Aircraft disturbance is defined as “aircraft activity that changes the behavior or physiology of a bird,” (Hoang, 2015). Behavioral changes include:

- Scanning and alert behaviors (head turning, neck extension or body reorientation)

- Agitation (increased calling, head bobbing, restlessness, and wing-flapping), and

- Protective or escape behaviors (crouching, flushing, running, diving or swimming away) (Brown, 1990; Kempf & Huppop, 1998).

In addition, wildlife refuge managers have suspected that chronic stress from overflights increase waterfowl susceptibility to disease (Gladwin et al., 1987).

An example of physiological changes in birds include changes in heart rate (Wilson et al., 1991). If not specifically for helicopter noise, 'disturbance' as stimuli is thought to initiate some level of a 'fight or flight' response, also referenced as an "active defense response" (Gabrielson & Smith, 1995).

Gabrielson and Smith (1995) prefer the terms 'active defense response' in place of the more common 'fight or flight response' terminology used by earlier researchers. Physiological changes associated with active defense responses include increased:

- Behavioural activity
- Heart rate
- Metabolism
- Blood sugar
- Body temperature
- Skeletal muscle blood flow
- Respiration rate
- Respiration depth
- Oxygen consumption
- Brain blood flow
- Heart blood flow

While the following parameters decrease:

- Blood flow to the gut
- Gut motility
- Digestive secretions
- And perhaps blood flow to the skin

Most of the responses outlined above “are controlled by the sympathetic portion of the autotomic nervous system and involves release of adrenalin” (Gabrielson & Smith, 1995).

- Each physiological response contributes to chances of survival to a given stimulus. The antithesis of an active defense response is the freezing / playing dead response. An example cited by Gabrielson and Smith (1995) is a motionless response by a Ptarmigan hen; her chance of losing her eggs to predators if she is flushed are much greater when she remains motionless.

- Citing studies of the impact of human disturbance on wildlife, Gabrielson and Smith (1995) suggest that the most critical periods of response in mammals is the immediate postnatal period and breeding period in some birds. For example,

    - Common eiders do not eat for 25 days during incubation, instead relying on stored energy reserves.

    - Human disturbances cause repeated heating of the eggs upon return from repeated flushing incidents. In time, the weight loss due to energy demand may cause the bird to abandon incubation or surrender the chicks at hatching in order to save itself. Although eiders are not endemic to News Zealand, passive defense processes whereby repeated disturbances during breeding periods are terminated may not be unique to this species.

5.0 Impact of aircraft stimuli on cetaceans and pinnipeds

Note: Chapter 5.0 remains a work in progress. Three main resources will be examined in further detail for this Chapter:

1. A synthesis of The effects of aircraft on cetaceans: implications for whalewatching (Luksenburg & Parsons, 2009), a review of literature on cetaceans from 1995 to 2008.
2. Select articles regarding the impact of human-generated noise on cetaceans and pinnipeds from International Society for Comparative Psychology (Kuczaj, 2007).

3. Articles addressing the potential impact of anthropogenic noise on marine mammals published after 2008 or otherwise relevant and informative to previously published articles.

5.1 Introduction

The following verbatim Abstract has yet to be synthesized for this report. It is included here as an overview of traits and characteristics of marine mammals that provides a conceptual framework for understanding the potential impacts of anthropogenic noise on marine mammals. *Note: Although verbatim, the Abstract has been set in bullet points by this author to aid in readability and accessibility to content:*

- "Marine mammals, especially cetaceans, are highly vocal and dependent on sound for almost all aspects of their lives, e.g. food-finding, reproduction, communication, detection of predators/hazards, and navigation. They are thus likely sensitive to anthropogenic noise.

- Sound has a large potential area of impact, sometimes covering millions of square kilometres of ocean with levels high enough to cause possible disturbance in marine mammals.

- There can be great variation in the reaction of marine mammals to noise, depending on such factors as species, individual, age, sex, prior experience with noise, and behavioral state. Species with similar hearing capabilities can respond differently to the same noise.

- Observed effects of noise on marine mammals include: changes in vocalizations, respiration, swim speed, diving, and foraging behaviour; displacement, avoidance, shifts in migration path, stress, hearing damage, and strandings.

- Responses of marine mammals to noise can often be subtle and barely detectable, and there are many documented cases of apparent tolerance of noise. However, marine mammals showing no obvious avoidance or changes in activities may still suffer important, even lethal, consequences.

- Acoustically induced strandings may displace a local beaked whale (*Ziphiidae)* population (for an extended period if not permanently) or even possibly eliminate most of its members. As beaked whales seem to be found in small, possibly genetically isolated, resident populations, even a transient and localized acoustic impact could have prolonged population consequences.

- Observed reactions to noise in marine mammals could theoretically result in impacts such as decreased foraging efficiency, higher energetic demands, less group cohesion, higher predation, decreased reproduction, and thus seriously impact the population.

- Alternatively, they may be harmless. However, noise is thought to contribute to at least some species' declines or lack of recovery (Southern resident killer whales (*Orcinus orca*), western gray whales (*Eschrichtius robustus*) off Sakhalin)" (Weilgart, 2007) .

Recall that acoustic masking is the effect of man-made sounds interfering with an animal's ability to detect, recognize or understand sounds of interest (e.g., mating, navigation, feeding and others) (Frankel & Gabriele, 2017). At the same time, cetaceans are known to rely on sound for communication, navigation, and detection of predators and prey (Würsig & Richardson, 2009), life activities closely associated with cetacean biology and survival (Luksenburg & Parsons, 2009).

- Besides transportation, military training, off-shore oil and gas activities, recreational flights involving helicopters and fixed-wing aircraft are used for cetacean research and whale watching (Patenaude et al., 2002; Smultea et al., 2008).

- Seminal work by Richardson et al. (1995) revealed that the impact of aircraft noise on marine mammals is complicated by virtue of the fact that aircraft noise frequencies are easily within range of cetacean calls while also producing visual differences such as the aircraft itself (Richardson, 1995).

- Richardson et al. (1995) also proposed that one difference between aircraft and boat noise is that the former is present for shorter periods and moves at greater speeds.

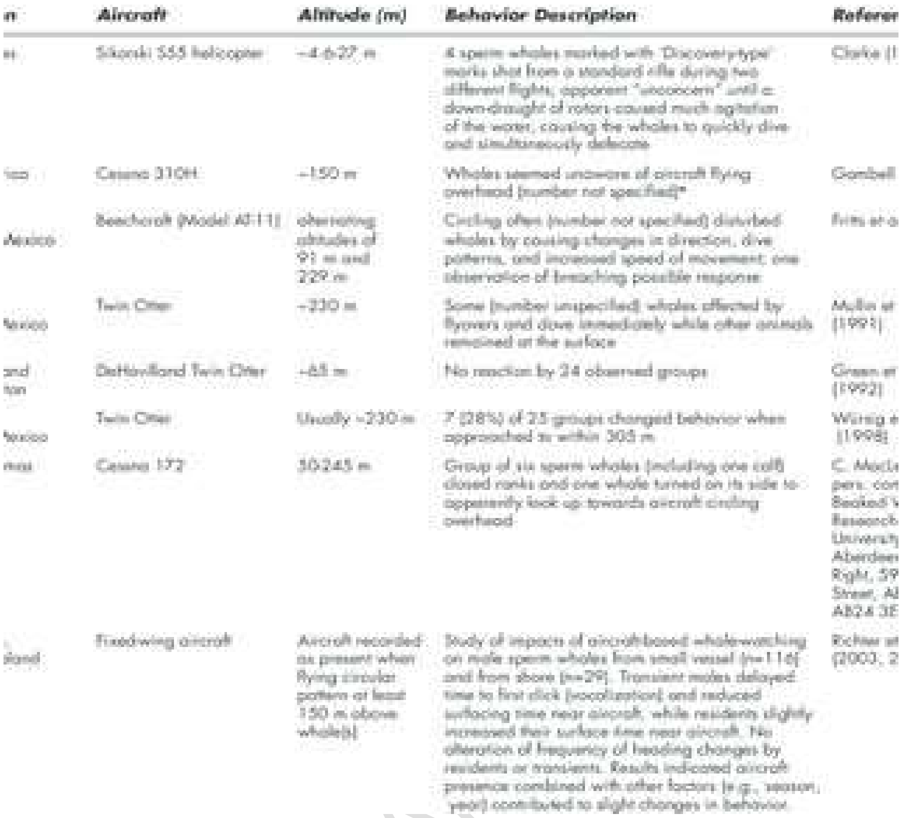
- However, sound pressure levels of even small aircraft may be very high (exceeding 120 dB re 20 20 µPa at 1m) and could therefore have profound impacts on cetacean populations.

- Cetacean responses to aircraft noise has been show to be highly variable, ranging from no visual reaction to active avoidance (Richardson, 1995).

Ed. Note: The following are verbatim abstracts of articles that have yet to be fully synthesized for final inclusion in this report:

An unusual reaction and other observations of Sperm Whales near fixed-wing aircraft (Smultea et al., 2008)

> Reported behavioral reactions by sperm whales to aircraft are sparse, highly variable, and largely anecdotal as summarized below. Observers since the whaling era began have noted that sperm whales tend to be skittish (Whitehead 2003). When documented, sperm whale reactions to both planes and helicopters range from no reaction (Clarke 1956, Gambell 1968, Green et al. 1992) to reactions such as increased surface intervals and dramatic behavioral changes (Clarke 1956, Fritts et al. 1983, Mullin et al. 1991, Würsig et al. 1998, Richter et al. 2003, 2006).
>
> Given the lack of supporting data for either case, it is important that these types of data are collected and consolidated into a cohesive document. Therefore, the specific objectives of our paper are to report our visual observations of sperm whale reactions to straight-line aircraft fly-bys (i.e., passes), to report a unique observation of a recognized “stress behavioral reaction” exhibited by sperm whales during an overhead circling by small fixed-wing aircraft, and to provide a summary review of published related studies.



n	Aircraft	Altitude (m)	Behavior Description	Referer
es	Sikorski S55 helicopter	~4.6-27 m	4 sperm whales marked with 'Discovery-type' marks shot from a standard rifle during two different flights; apparent "unconcern" until a down-draught of rotors caused much agitation of the water, causing the whales to quickly dive and simultaneously defecate	Clarke (I
ico	Cessna 310H	~150 m	Whales seemed unaware of aircraft flying overhead (number not specified)*	Gambell
Aexico	Beechcraft (Model AT-11)	alternating altitudes of 91 m and 229 m	Circling often (number not specified) disturbed whales by causing changes in direction, dive patterns, and increased speed of movement; one observation of breaching possible response	Fritts et a
Aexico	Twin Otter	~230 m	Some (number unspecified) whales affected by flyovers and dove immediately while other animals remained at the surface	Mullin et (1991)
and ton	DeHavilland Twin Otter	~65 m	No reaction by 24 observed groups	Green et (1992)
Aexico	Twin Otter	Usually ~230 m	7 (28%) of 25 groups changed behavior when approached to within 305 m	Würsig e (1998)
mas	Cessna 172	30-245 m	Group of six sperm whales (including one calf) closed ranks and one whale turned on its side to apparently look up towards aircraft circling overhead	C. MacLe pers. con Beaked V Research University Aberdeen Right, 59 Street, Al AB24 3E
aland	Fixed-wing aircraft	Aircraft recorded as present when flying circular pattern at least 150 m above whale(s)	Study of impacts of aircraft-based whale-watching on male sperm whales from small vessel (n=116) and from shore (n=29). Transient males delayed time to first click (vocalization) and reduced surfacing time near aircraft, while residents slightly increased their surface time near aircraft. No alteration of frequency of heading changes by residents or transients. Results indicated aircraft presence combined with other factors (e.g., season, year) contributed to slight changes in behavior.	Richter et (2003, 2

Influences of man-made noise and other human action on cetacean behaviour (Richardson & Würsig, 1997)

Behavioral reactions of cetaceans to man-made noises are highly variable, ranging from attraction (*e.g.* bow riding by dolphins) or no response through short-term changes in behaviour to short- or long-term displacement. Noise can also mask important natural sounds or (if strong enough) cause hearing impairment or perhaps stress. This review summarizes the observed behavioral reactions of cetaceans to noise and other stimuli from aircraft, boats, tourism, marine industrial activities, seismic exploration, sonars, explosions, and ocean acoustics studies.

Specific response thresholds have been determined for only a few combinations of species and noise type, and they tend to be quite variable even within species. In general, response thresholds are often low for variable or increasing sounds, *e.g.* approaching boat; intermediate for steady sounds, *e.g.* offshore drilling noise; and high for pulsed sounds, *e.g.* seismic survey pulses. With repeated exposure, many cetaceans habituate at least partially. However, cases of increased sensitivity following harassment are known. Long-term effects on individuals and populations are little known.

Aircraft sound and disturbance to Bowhead and Beluga whales during Spring migration in the Alaskan Beaufort Sea (Richardson & Würsig, 1997)

Short-term behavioral responses of bowhead whales (*Balaena mysticetus*) and beluga whales (*Delphinapterus leucas*) to a Bell 212 helicopter and Twin Otter fixed-wing aircraft were observed opportunistically during four spring seasons (1989–1991 and 1994). Behaviors classified as reactions consisted of short surfacings, immediate dives or turns, changes in behavior state, vigorous swimming, and breaching.

The helicopter elicited fewer detectable responses by bowheads (14% of 63 groups) than by belugas (38% of 40). Most observed reactions by bowheads (63%) and belugas (86%) occurred when the helicopter was at altitudes ≤150 m and lateral distances ≤250 m. Belugas reacted significantly more frequently during overflights at lateral distances ≤250 m than at longer lateral distances (*P*= 0.004). When the helicopter was on the ice with engines running, 7 of 14 groups of belugas reacted, up to 320 m away, sometimes with small-scale (≤100 m) diversion; only 1 of 8 groups of bowheads reacted.

For the fixed-wing aircraft, few bowheads (2.2%) or belugas (3.2%) were observed to react to overflights at altitudes 60–460 m. Most observed reactions by bowheads (73%) and belugas (70%) occurred when the fixed-wing aircraft was at altitudes ≤182 m and lateral distances ≤250 m. However, the proportions reacting, especially to low-altitude flights (*e. g.*, ≤182 m), were underestimated for both species because observation opportunities were brief. Even so, reactions were more common when the aircraft was low (≤182 m): *P*= 0.009 for belugas, *P*= 0.06 for bowheads. There was little if any reaction by bowheads when the aircraft circled at altitude 460 m and radius 1 km.

Aircraft sounds measured underwater at depths 3 m and 18 m showed that a Bell 212 helicopter was 7–17.5 dB noisier than a Twin Otter (10–500 Hz band). Bell

212 sound consisted mainly of main rotor tones ahead of the helicopter and tail rotor tones behind it. Twin Otter sound contained fewer prominent tones. Peak sound level as received underwater was inversely related to aircraft altitude, and received levels at 3 m depth averaged 2.5 dB higher than at 18 m depth. The dominant low-frequency components of aircraft sound are presumed to be readily audible to bowheads. For belugas, these components may be inaudible, or at most only weakly audible. Mid-frequency sound components, visual cues, or both, are probably important in eliciting beluga reactions to aircraft.

An Unusual Reaction and Other Observations of Sperm Whales Near Fixed-Wing Aircraft (Smultea et al., 2008)

Reported behavioral reactions by sperm whales to aircraft are sparse, highly variable, and largely anecdotal as summarized below. Observers since the whaling era began have noted that sperm whales tend to be skittish (Whitehead 2003). When documented, sperm whale reactions to both planes and helicopters range from no reaction (Clarke 1956, Gambell 1968, Green et al. 1992) to reactions such as increased surface intervals and dramatic behavioral changes (Clarke 1956, Fritts et al. 1983, Mullin et al. 1991, Würsig et al. 1998, Richter et al. 2003, 2006). Given the lack of supporting data for either case, it is important that these types of data are collected and consolidated into a cohesive document. Therefore, the specific objectives of our paper are to report our visual observations of sperm whale reactions to straight-line aircraft fly-bys (i.e., passes), to report a unique observation of a recognized “stress behavioral reaction” exhibited by sperm whales during an overhead circling by small fixed-wing aircraft, and to provide a summary review of published related studies.

Behaviour reactions of bottlenose dolphins (Tursiops truncatus) to multirotor Unmanned Aerial Vehicles (UAVs) (Fettermann et al., 2019) .

Unmanned aerial vehicles (UAVs) represent a novel and cost effective research tool to investigate cetacean behaviour, as conventional aircraft are expensive, limited in the altitude they can fly at and potentially disturb sensitive wildlife. In addition, the aerial observation from the UAVs allows assessment of cetacean behaviour from an advantageous perspective and can collect high spatial and temporal resolution data, providing the opportunity to gather accurate data about group size, age class and subsurface behaviour. However, concerns have been raised about the potential risks of disturbance to animals caused by the UAV's visual and acoustic stimuli. Boat-based surveys were conducted to assess the short-term behavioural responses of resting bottlenose dolphins (*Tursiops truncatus*) to a lightweight Vertical take-off and landing (VTOL) UAV flown at 10, 25, and 40 m altitude. Changes in group swim direction and frequencies of surface and aerial behavioural events were recorded from an anchored research vessel before (control) and during the aerial survey. The number of reorientation and tail slap events increased significantly between controls and flights when the UAV was flown at 10 m over the animals. In contrast, no significant differences were detected when the aircraft was flown at 25 and 40 m altitude. However, a precautionary approach is recommended for research applications requiring lower flight altitudes, with further research recommended to assess how different cetacean species and age class may respond to the UAV presence.

The effects of aircraft on cetaceans: implications for aerial whalewatching (Luksenburg & Parsons, 2009)

The effects of anthropogenic noise on marine mammals are a rich subject for study and have attracted considerable attention in the past two decades. Aircraft noise may not only affect the biology of cetaceans but may also skew aerial survey data. Since 1995 few studies have been published, but these have documented behavioral responses of cetaceans to aircraft in much greater detail.. This paper reviews and discusses progress in the study of aircraft noise effects on marine mammals since the landmark review of Richardson et al. (1995). In each of the studies reviewed here, cetaceans responded to aircraft to some extent, in most cases by diving. Several major gaps in knowledge on the effects of noise on marine mammals also apply to aircraft noise, e.g. quantification of received sound level, the role of vision, knowledge of baseline behavior, the effect on vocalizations. The possible implications for whale watching by aircraft are discussed.

Aircraft sound and disturbance to Bowhead and Beluga whales during Spring migration in the Alaska Beaufort Sea (Patenaude et al., 2002).

Short-term behavioral responses of bowhead whales (Balaena mysticetus) and beluga whales (Delphinapterus leucas) to a Bell 212 helicopter and Twin Otter fixed-wing aircraft were observed opportunistically during four spring seasons (1989–1991 and 1994). Behaviors classified as reactions consisted of short surfacings, immediate dives or turns, changes in behavior state, vigorous swimming, and breaching.The helicopter elicited fewer detectable responses by bowheads (14% of 63 groups) than by belugas (38% of 40). Most observed reactions by bowheads (63%) and belugas (86%) occurred when the helicopter was at altitudes ≤150 m and lateral distances ≤250 m. Belugas reacted significantly more frequently during overflights at lateral distances ≤250 m than at longer lateral distances (P= 0.004). When the helicopter was on the ice with engines running, 7 of 14 groups of belugas reacted, up to 320 m away, sometimes with small-scale (≤100 m) diversion; only 1 of 8 groups of bowheads reacted.For the fixed-wing aircraft, few bowheads (2.2%) or belugas (3.2%) were observed to react to overflights at altitudes 60–460 m. Most observed reactions by bowheads (73%) and belugas (70%) occurred when the fixed-wing aircraft was at altitudes ≤182 m and lateral distances ≤250 m. However, the proportions reacting, especially to low-altitude flights (e. g., ≤182 m), were underestimated for both species because observation opportunities were brief. Even so, reactions were more common when the aircraft was low (≤182 m): P= 0.009 for belugas, P= 0.06 for bowheads. There was little if any reaction by bowheads when the aircraft circled at altitude 460 m and radius 1 km.Aircraft sounds measured underwater at depths 3 m and 18 m showed that a Bell 212 helicopter was 7–17.5 dB noisier than a Twin Otter (10–500 Hz band). Bell 212 sound consisted mainly of main rotor tones ahead of the helicopter and tail rotor tones behind it. Twin Otter sound contained fewer prominent tones. Peak sound level as received underwater was inversely related to aircraft altitude, and received levels at 3 m depth averaged 2.5 dB higher than at 18 m depth. The dominant low-frequency components of aircraft sound are presumed to be readily audible to bowheads. For belugas, these components may be inaudible, or at most only weakly audible. Mid-frequency sound components, visual cues, or both, are probably important in eliciting beluga reactions to aircraft.

6.0 Impact of noise on amphibians, arthropods, fish, mollusks, and reptiles

TBD

7.0 General Discussion

TBD

Appendix A: Study methodology

For the purpose of this report, aircraft stimuli is the primary independent variable that includes noise, vibration, visual presence, wind (prop or rotor wash) and operating necessities such as oil and petrol. Primary response variables are extensive but broadly include behavioural and physiological impacts on individual wildlife species, ecosystem equilibrium, population dynamics, and community structures that qualify the Hauraki Gulf Marine Park as “outstanding within New Zealand.”

Scientific journal databases were accessed for peer reviewed articles containing combinations of relevant search items. the following search terms: *Aircraft, Behaviour, Birds, Disturbance, Ecology, Ecosystem, Hauraki Gulf, Human-generated, Impact, Mammals, Marine, Noise, Physiological, Review, Sea Birds, Shorebirds, Stimuli,* and *Wildlife.* Article abstracts were analysed for response variables expressed in empirical terms, and whether conclusions supported or challenged the following hypothesis: aircraft stimuli do not adversely impact wildlife and associated ecosystems in the Hauraki Gulf Marine Park.

The criteria for reference and study citations for this report include:

- Papers describing controlled experiments.
- Compelling private and government generated commentaries based on rigorous qualitative evidence.
- Peer-reviewed book sections or lecture presentations
- Natural science textbook authorities
- Legislative, regulatory and administrative documents cited in *Section 1.0 Introduction*, above. Note that these resources are thoroughly referenced and cited herein, but not always repeated in their entirety.

A review of every article regarding the potential impact of aircraft on wildlife is beyond the scope of this report. Instead, information contained herein represents peer-reviewed scientific papers and publications that specify the impact of aircraft stimuli on wildlife. However, in cases of particular interest and relevance, original research was further investigated and cited. All of the information in this report is publicly available and open access. Discussion sections in this report reflect my interpretations or comments regarding scientific rigour and potential significance and caveats to presented data.

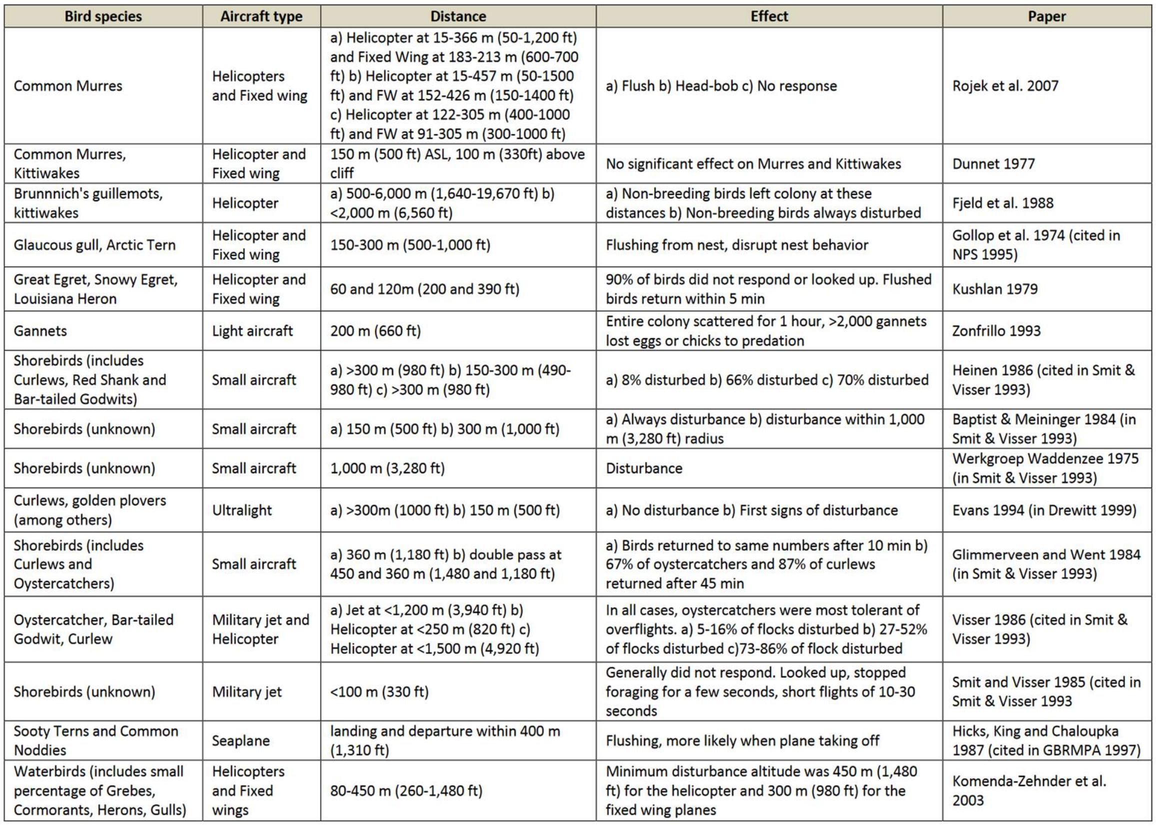
Every effort has been made to include wildlife found in the Hauraki Gulf Marine Park. However, wildlife found elsewhere in the world share similarities to species found in the Gulf have been included. An example of inclusion would be birds or marine mammals of the same order or family. Examples of exclusion include wolves, bison, big horn sheep or desert iguana.

Appendix B: Summary of Haruaki Gulf Marine Park seabird and shorebird traits, classifications, and conditions

- New Zealand dotterel
    - Nest along the shell spit opposite the Te Matuku Scenic Reserve
    - Nationally vulnerable
    - Weight: ~60 g (2.1 oz.)
    - Two-three eggs incubated for 28 days (Time of year?)
    - Breeding sites: sandspits, sandy beaches, shell banks, dunes, tidal estuaries, and river mouths.
    - Diet: Mollusks, small crustaceans, crickets, and other insects.
    - Known to make a 4500km winter getaway to New Caledonia, but typically migrate within New Zealand.
- Banded dotterel
    - Nationally vulnerable
- Bar-tailed godwit
    - Migratory
    - Known to fly at altitudes above 5,000 m during 21% of migratory flights, with maximum altitudes of 6,000 m.
    - Known to fly 13,558 km (8,425 miles) non-stop for eleven days.
- Caspian tern
    - Nationally vulnerable
    - Te Matuku is breeding location
- White-fronted tern
    - In decline
- Reef Heron
    - Nationally vulnerable
- Pied oystercatcher
    - Migratory
- Variable oystercatcher
    - In recovery
- South Island pied oystercatcher (same?)
    - In decline
- Sandpiper

- Turnstone
    - Migratory
- Wrybill
    - Nationally vulnerable
    - Migratory
- Brown Teal
    - In recovery
- Spotless crake
    - Wetlands and islands are primary habitats
    - Relict
- Banded rail
    - Nationally vulnerable
- Knot
    - Migratory
- Australasian Bittern
    - Wetlands and islands are primary habitats
    - Nationally endangered
- New Zealand pigeon
- Grey warbler
- Fantail
- Silver eyeiles (Zosterops lateralis)
- Morepork
- Tui
- Shining cuckoo

Appendix C: Summary of studies on seabirds and shorebirds in disturbance and distance contexts (Hoang, 2015)



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

Appendix D: Reference sound levels (FICN 1992) (In Pepper, et al., 2003)

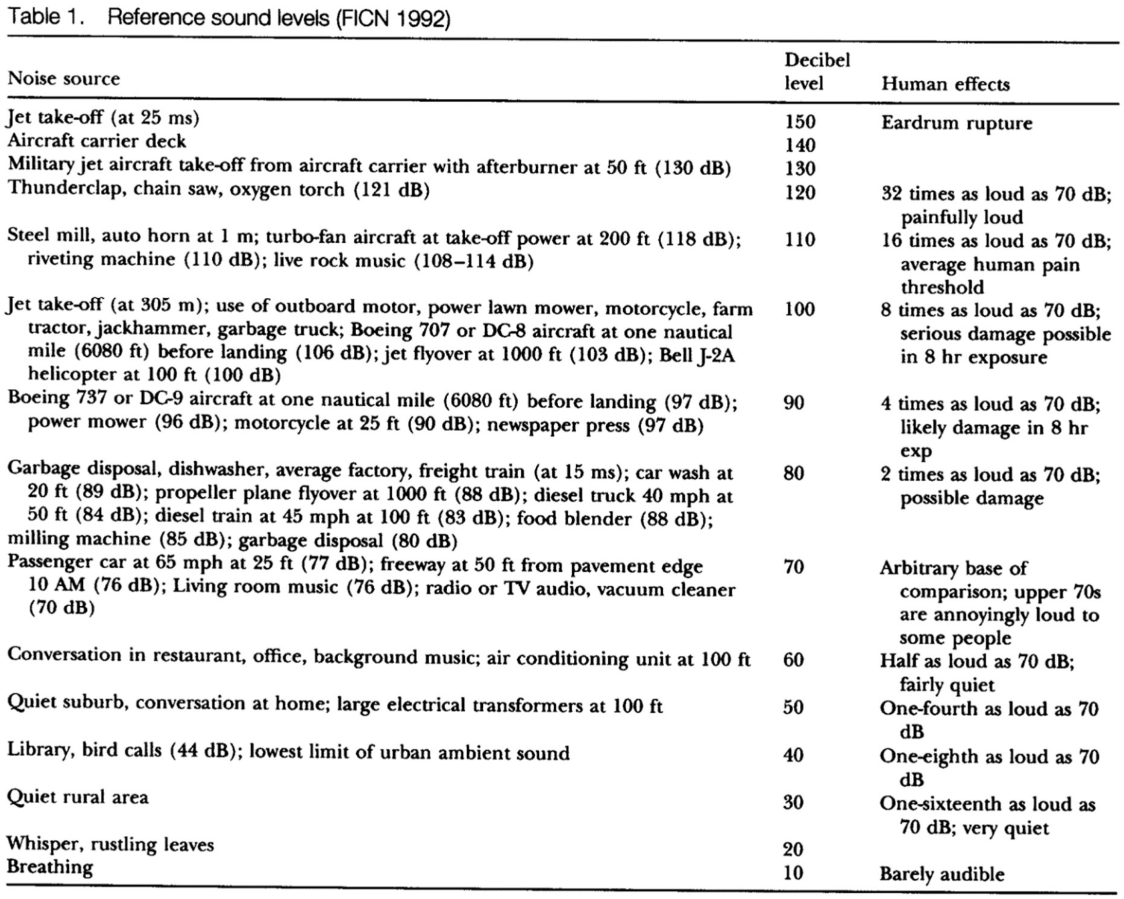


Table 1. Reference sound levels (FICN 1992)

Noise source	Decibel level	Human effects
Jet take-off (at 25 ms)	150	Eardrum rupture
Aircraft carrier deck	140	
Military jet aircraft take-off from aircraft carrier with afterburner at 50 ft (130 dB)	130	
Thunderclap, chain saw, oxygen torch (121 dB)	120	32 times as loud as 70 dB; painfully loud
Steel mill, auto horn at 1 m; turbo-fan aircraft at take-off power at 200 ft (118 dB); riveting machine (110 dB); live rock music (108–114 dB)	110	16 times as loud as 70 dB; average human pain threshold
Jet take-off (at 305 m); use of outboard motor, power lawn mower, motorcycle, farm tractor, jackhammer, garbage truck; Boeing 707 or DC-8 aircraft at one nautical mile (6080 ft) before landing (106 dB); jet flyover at 1000 ft (103 dB); Bell J-2A helicopter at 100 ft (100 dB)	100	8 times as loud as 70 dB; serious damage possible in 8 hr exposure
Boeing 737 or DC-9 aircraft at one nautical mile (6080 ft) before landing (97 dB); power mower (96 dB); motorcycle at 25 ft (90 dB); newspaper press (97 dB)	90	4 times as loud as 70 dB; likely damage in 8 hr exp
Garbage disposal, dishwasher, average factory, freight train (at 15 ms); car wash at 20 ft (89 dB); propeller plane flyover at 1000 ft (88 dB); diesel truck 40 mph at 50 ft (84 dB); diesel train at 45 mph at 100 ft (83 dB); food blender (88 dB); milling machine (85 dB); garbage disposal (80 dB)	80	2 times as loud as 70 dB; possible damage
Passenger car at 65 mph at 25 ft (77 dB); freeway at 50 ft from pavement edge 10 AM (76 dB); Living room music (76 dB); radio or TV audio, vacuum cleaner (70 dB)	70	Arbitrary base of comparison; upper 70s are annoyingly loud to some people
Conversation in restaurant, office, background music; air conditioning unit at 100 ft	60	Half as loud as 70 dB; fairly quiet
Quiet suburb, conversation at home; large electrical transformers at 100 ft	50	One-fourth as loud as 70 dB
Library, bird calls (44 dB); lowest limit of urban ambient sound	40	One-eighth as loud as 70 dB
Quiet rural area	30	One-sixteenth as loud as 70 dB; very quiet
Whisper, rustling leaves	20	
Breathing	10	Barely audible

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