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ORIGINAL ARTICLE

Assessing 'Observer Effects' from a Research Aircraft on Behavior of Three Delphinidae Species (*Grampus griseus*, *Delphinus delphis*, and *Orcinus orca*)

M.A. Smultea[1] & K. Lomac-MacNair[1,*]

[1] Smultea Sciences, PO Box 256 Preston WA, 98050, USA.

* Corresponding author email: kate@smulteasciences.com.

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Abstract

Three species of Delphinidae: Risso's dolphin (*Grampus griseus*), common dolphin (*Delphinus delphis*), and killer whale (*Orcinus orca*) were systematically video-documented during aerial surveys in the Southern California Bight (2009-2011) to assess whether the observation aircraft (fixed-wing Partenavia) affected selected behavioral variables. Focal observations were conducted to examine potential changes in group cohesion and heading reorientation rate to the plane circling at four altitudes: 213 m, 305 m, 457 m, and 610 m, whilst maintaining a lateral distance >500 m. Paired t-tests were used to test the null hypothesis that mean maximum cohesion and mean reorientation of groups do not vary significantly based on plane altitude. For cohesion, no significant effects were found for the eight *G. griseus* focal sessions ($p = 0.447$), one *D. delphis* session ($p = 0.602$) and one *O. orca* session ($p = 0.197$). For reorientation, no significant effects were found for the eight *G. griseus* focal sessions ($p = 0.591$) and one *O. orca* session ($p = 0.936$); the sample size was too small to calculate reorientation for *D. delphis*. Results suggest that our small plane circling at lateral distance >500 m and altitude 213 – 610 m did not cause measurable changes in cohesion and reorientation, or other observable changes for the three species. This may be due to the aircraft remaining >500 m lateral distance from the animals and at altitudes well outside (>2.5-9.2 times) the theoretical lateral distance of the 13° radial sound transmission cone ("Snell's cone") below the aircraft (via which sound can pass through the air-water interface under calm sea conditions), thus avoiding adverse levels of sound intercepting the delphinids.

Introduction

The objective of our study was to investigate the behavior of three species of Delphinidae: *Grampus griseus* (Risso's dolphin), *Delphinus delphis* (common dolphin), and *Orcinus orca* (killer whale) in response to a small fixed-wing research

survey aircraft in the Southern California Bight. To achieve this, focal observations were conducted on groups of delphinids to examine behavioral responses to the aircraft circling at various pre-determined altitudes and time durations. The selected behavioral variables *cohesion* and *reorientation* were used to investigate behavioral changes in response to the survey aircraft. It was expected that the magnitude of the disturbance would be directly proportional to proximity of the aircraft to animals. We thus predicted that the greatest behavioral response would occur when the plane circled at the lowest altitudes. The greatest behavioral response would then result in increased group cohesion (i.e. closer inter-animal spacing) and increased magnitude of reorientations, both indicators of increased disturbance. Normal behaviors such as feeding, mating, and socializing were also expected to be reduced, or absent, with increasing disturbance.

Group cohesion is described as a means for group members to keep better track of one another's movements, allowing for accelerated reactions to danger [e.g., 1,2]. Terrestrial mammals are known to increase group cohesion in response to disturbance [3,4], and fish often school in response to predation threats [5]. Many delphinid species reportedly increase cohesion in the presence of motorized vessels [e.g., 6,7,8,9,10,11]. In addition, *Physeter macrocephalus* (sperm whales) were found to increase cohesion in response to a closely circling aircraft [12]. Mysticetes have also been reported to increase group cohesion in the context of presumed surprise or threat [e.g., 13,14].

Reorientation rates can be used as a measure of how often an animal changes direction, sometimes an indicator of disturbance when the animal is trying to flee from stressful stimuli. For several delphinid species, reorientation rates increased when exposed to stressful conditions such as boat presence [e.g., 9,15,16,17,18,19,20], human swimmers [21], and spilled oil [22]. Among mysticetes, reorientation rates have been found to increase or decrease in response to motorized vessels [e.g., 23,24], as well as offshore seismic exploration [e.g., 25,26] and sonar sounds [27,28]. Mysticete blow intervals have been shown to decrease, while surfacing intervals, dive times, and speed of travel were shown to increase in response to stressful stimuli such as an approaching vessel or underwater sounds, including among *Balaena mysticetus* (bowhead), *Eschrichtius robustus* (gray), and *Megaptera novaeangliae* (humpback whales) [29,25,26]. Some odontocetes also respond to stressful stimuli by increasing dive times, as well as aerial activity, travel speed, and time resting [e.g., 18,19,30,31,31]. Based on these reports, two variables that seemed appropriate and could be reliably measured were 'cohesion and 'reorientation'.

Important criteria in determining the effects of human disturbance on wildlife is the existence of pre-disturbance baseline data, including species distribution, movements, group sizes and behavior. To effectively describe disturbed behavior in response to anthropogenic sources, it is critical to understand what constitutes normal, undisturbed behavior. Documenting natural, undisturbed behavior can be challenging if the act of observing is itself disturbing to the animal. This "observer effect" may have a profound effect on the subjects being observed, potentially confounding what is considered undisturbed behavior. Observer effects such as fleeing, avoidance, alarm calls and vigilance towards human observers have been reported for mammals [e.g., 33,34] including cetaceans [e.g., 35,36], birds [e.g., 37] and fish [e.g., 38]. This altered behavior can be mistaken as natural behavioral responses, confounding or biasing hypothesis testing in behavioral experiments [40]. Additionally, certain species, or

even certain classes of individuals within a species, can be more prone to the observer effect than others [41].

In the last two decades, one of the most concerning threats to marine mammals has been exposure to anthropogenic noise [reviewed in 32,42,44]. Disturbing sound sources include large and small vessels, aircraft, marine construction, oil and gas exploration/production, sonar, and renewable energy platforms, all of which have the potential to disrupt normal animal behavior [e.g., 17,28,29]. Observed effects of noise on marine mammals include changes in vocalizations, respiration, diving, swim speed, heading, and behavior state (e.g., foraging, resting), as well as displacement, avoidance, shifts in migration path, stress level, potential hearing damage, and strandings [e.g., 45,46,47]. Theoretical and modeled impacts from exposure to disturbing noise include decreased foraging efficiency and thus decreased caloric intake, higher energetic demands, higher predation risk, and decreased reproduction and nursing that could have serious impacts on a population [e.g., 48,49,35].

The primary disturbance variable of an aircraft to a marine mammal is sound, though cetaceans have also been reported to apparently look up at the overflying aircraft or react to its shadow created on the water surface [e.g., 50,51,52,12,]. In general, sounds emitted by aircraft are within the hearing range of most cetaceans, particularly those with good low- (<1 kHz) and mid-frequency (1-10 kHz) hearing abilities, such as whales and delphinids [42,43,52,53,54]. The sound emitted from an aircraft varies with aircraft type (e.g., engine number/size, helicopter or fixed wing) and maneuvers performed (e.g., straight-line pass, tight or wide circles, speed or engine bursts, etc.) [e.g., 53,54,42]. For example, studies suggest that cetaceans are more likely to react to helicopters than fixed-wing aircraft overflights [42,51,52]. In addition, proximity of the aircraft to the animals being observed appears to be one of the most significant determinations of whether an animal will react, based on both altitude and lateral distance [55,12,52,56]. The response given by the animal under observation can be highly variable and complicated not only by the characteristic of the sound source and its duration, but by the life history characteristics of the species, habitat type, season, behavioral state, sex and age of individuals, level of previous exposure, and existence of other physical stresses such as food availability or predation pressure [57,58,52].

Aerial surveys provide several advantages and unique observation perspectives for marine mammal research over other research platforms such as vessels and shore [e.g., see 59,60,61]. One advantage is the ability to survey a large area in a short period to document species presence or absence, distribution, abundance, and variables such as group size, orientation, and behavior state. Another benefit is the ability to cover a large area to identify dead or highly distressed marine mammals at the water's surface, stranded, or washed up on the coastline. In addition, detailed focal observations of marine mammal behavior can be performed from an overhead 'bird's eye' vantage point where most or all individuals can be viewed at once and sometimes differentiated in real time, even when just below the surface [e.g., 62,60]. Example behaviors include individual interactions involving sex, aggression, apparent nursing, birthing, and chasing/consuming fish or zooplankton patches [e.g., 63,64,65]. Another important advantage of an aerial platform allows relatively long-term observation of the same animal while not impaired by the near sea-level limited perspective from a boat [65,62]. When flown at distances that do not disturb marine mammals, reliable

baseline information can be collected from aircraft that can be used as a benchmark to help detect behavior that is disturbed [e.g., 25,50]. However, to ensure collection of reliable, baseline behavioral data it is important to ascertain whether observed behaviors are indeed representative of undisturbed behavior and not behavior that is impacted by the presence of the plane. The latter objective was the primary purpose of our study described herein: to assess potential effects of our fixed-wing aerial research platform on selected cetacean species that had not previously been studied in this manner, using a systematic approach from various altitudes.

Methods

Flights were conducted in a Partenavia P68, twin-engine, fixed-wing aircraft. Pre-determined line-transects were systematically flown at an average altitude of 330 m and generally consisted of one 4.5-hr survey, weather permitting [see 61]. When environmental conditions were conducive to focal follows (Beaufort sea state <3-4, high cloud cover), the plane increased its altitude to 660 m immediately after a cetacean(s) was sighted, regained visual contact with the sighting, and a focal observation session was initiated. The focal group was circled at lateral distance of 500 m for approximately 5-minute durations at each of four pre-determined *a priori* altitudes of 610 m, 457 m, 305 m, and 213 m. Although the goal was to begin observations at 610 m after the animals were first sighted, and progressively decrease to each of the other three lower altitudes, this was not always possible due to low-lying clouds or restrictions by nearby air traffic. The focal group was circled at a lateral distance of 500 m to remain well outside *Snell's cone*. *Snell's cone* is the theoretical 26° inverted sound cone (radius 13°) within which the sound ray of an over-flying aircraft intersects at and propagates through the sea surface, under calm flat sea conditions, i.e. Beaufort sea state 0-2 (Fig. 1). Increasing disturbance of surface waters (i.e. increasing Beaufort sea state >2) and sound wave reflection off shallow water bottoms can increase the size of the radius beyond the theoretical 13° radial sound cone [42,53] (Fig. 1). However, the strongest received sound levels and predominant sound transmission paths are generally considered to occur within Snell's cone [54]. By maintaining a lateral distance of 500 m at the four altitudes during Beaufort sea state 1-3 over water depths of >500 m during our study, theoretically, aircraft noise would be limited at and below the sea surface to within or near Snell's cone lateral distance outside the dolphin's range. Our 500-m lateral flight distance from the focal group was calculated to be 359-451 m outside and beyond the theoretical calculated lateral distances of Snell's cone at the minimum and maximum study altitudes of 213 m and 610 m (Table 1).

The focal group point sampling method [41,66,67] was used to systematically collect data on group cohesion, orientation (i.e. magnetic heading), and behavioral state, recorded at one-minute intervals (Table 2, 3). To do this, a primary observer continuously observed animals through a bubble window from the center seat of the plane. At the prompting of the recorder at each one-minute interval, the primary observer spoke out loud the focal group's most recent cohesion, orientation, and behavior state, following an ethogram (Table 2, 3). If the focal group had not been observed at the surface since the previous 1-minute point, the primary observer indicated that there

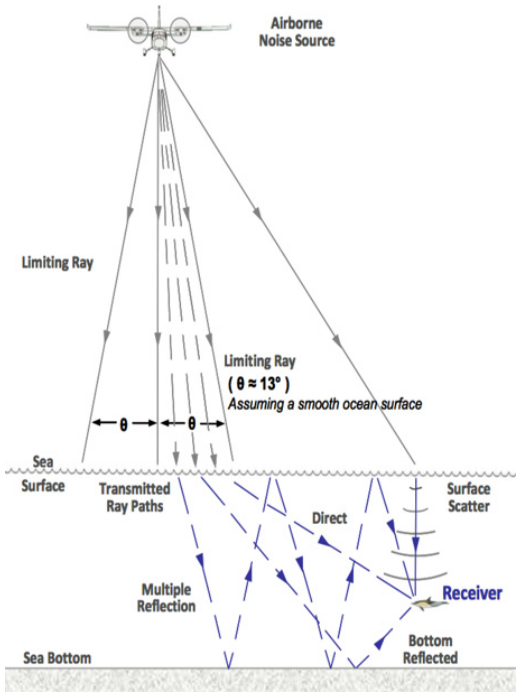

Figure 1: Diagram illustrating the theoretical 26° inverted sound cone (radius 13°) within which the sound ray of an overflying aircraft is limited at the sea surface under calm flat sea conditions (Beaufort 0-2). Also illustrated are ways in which the transmission of sound rays through the water surface can increase the size of the ensonified area via shallow bottom reflection and surface scatter (i.e., increasing disturbance of surface waters/increasing Beaufort sea state) to beyond the theoretical 26° sound cone (Modified from source) [42,53].

Table 1: Lateral distance to the edge of Snell's theoretical 26° inverted sound cone (radius 13°) within which the sound ray of an overflying aircraft is limited at the sea surface under calm flat sea conditions (Beaufort 0-2) for each of the four pre-determined fixed-wing aircraft altitudes while circling at radius 500 m.

Aircraft Altitude (m)	Snell's Cone Lateral Distance (m)[1/]	Distance of Aircraft Beyond Snell's Cone (m)
213	49	451
305	70	430
457	105	395
610	141	359

[1/]Assumes flat Beaufort sea state conditions of <3. Actual Beaufort sea state during study focal follows ranged from 1-3. See Urick (1972) for trigonometric formulas used to calculate lateral distance corresponding to the theoretical 13° lateral inverted Snell's cone.

were no relevant data for that interval. Cohesion was defined as the farthest (maximum) distance between neighboring individuals within a group, to be used as an index of estimated social association and group dynamics, as has been done with monkeys [68], sheep [69], and birds [70]. Cohesion distance was described as multiples of body lengths, using the average body length of a presumed adult subject delphinid species under observation as a reference. Focal group orientation was estimated in 5-degree intervals relative to the aircraft's heading by referring to a GPS compass mounted on the dashboard of the plane, and was based on the orientation of most of the animals.

If >50% of the individuals had different orientations, then no orientation was given, and a behavioral state of "milling" was assigned. Behavioral state was assigned one of five categories (slow travel/rest, travel, surface-active travel, mill, or unknown) based on what >50% of individuals within a group exhibited (Table 3). Observations of other behavioral events suggestive of no or low anthropogenic disturbance were also noted if observed, such as feeding, nursing, and socializing [e.g., 71]

A dedicated recorder recorded data onto an iPod Touch using "SpectatorGO!", a behavioral data collection program created by Biobserve (www.biobserve.com). The program allowed recording of *a priori* user-defined behavioral states and behavioral events that were time-stamped automatically. A third biologist on the plane video recorded the focal group through an open porthole window using a high-definition Sony Handycam HDR-XR550 or HDR-XR520 video camera. Photographs were taken using a Canon EOS 40D or 60D or a Nikon D300 or D7000 DSLR camera with a 100–400 mm f/4.5-5.6 IS USM lens. Voices of all persons on the aircraft (the three biologists and one or two pilots) were recorded by connecting a mini digital voice recorder to the plane's audio system. For post-survey analyses, data were initially divided into four categories based on the altitude of the plane during sampling: ~213 m, 305 m, 457 m, and 610 m. These were subsequently pooled into "low" (<213 m and 305 m) and "high" (457 m and >610 m) altitude datasets to increase sample size robustness. Paired t-tests were used to test the null hypothesis that mean cohesion, and mean reorientation rate, of groups did not vary significantly in response to "low" or "high" plane altitude.

Table 2: Variables used to measure behavioral disturbance in response to the proximity of the fixed-wing survey aircraft by altitude.

Variable	Definition	Analysis Approach/Method
Aircraft altitudes	*Low altitude*: >213 & 305 m *High altitude*: 457 & >610 m	Maintain lateral distance of >500m
Cohesion (C)	Maximum distance between nearest neighbors in estimated adult body lengths [BL]	• Mean maximum cohesion calculated per group • Paired t-test of cohesion at *low* and *high* altitude categories
Reorientation rate (R)	Orientation of the majority (>50%) of the group	• Sum of the difference between successive travel orientations, divided by the total number of minutes of observation (degrees per minute) • Paired t-test of reorientation rate at *low* and *high* altitude categories

Table 3: Ethogram of behavioral states used during the study (per 61).

Behavioral State	Definition
Rest/Slow Travel	>50% of group exhibiting little or no forward movement (<1 km/hr) remaining at or near the surface in the same location or drifting, with no observable wake or white water produced
Travel	>50% of group swimming with an obvious (e.g., wake-producing) consistent orientation (directional) and speed, no individual surface-active behavioral events that create a conspicuous splash (e.g., breach, leaping out of water, head slap, tail slap)
Mill	>50% of group swimming with no obvious consistent orientation (non-directional) characterized by asynchronous headings, circling, changes in speed, and no surface-active behavioral events
Surface-Active Travel	While traveling, occurrence of individual surface-active behavioral events

Results

Ten focal sessions were analyzed: eight *G. griseus* focal sessions, one *D. delphis* focal session, and one *O. orca* session. A total of 194 minutes (min) was spent observing *G. griseus* at a minimum altitude of 154 m and a maximum altitude of 610 m. A total of 27.4 min was spent observing *D. delphis* at a minimum altitude of 152 m and a maximum altitude of 610 m. One focal session was conducted on *O. orca* for 29.4 minutes, with a minimum altitude of 305 m and a maximum altitude of 457 m. During the *O. orca* focal session, the plane remained at a higher altitude; therefore, there was no <213-m altitude category for this focal session. During the *O. orca* focal session, a yearling appeared to nurse its presumed mother while the mother remained inverted for nearly a full minute (Fig. 1) [64]; this occurred while the plane was at an altitude of 290 m.

For cohesion, no significant effects were found for the eight *G. griseus* focal sessions ($p = 0.447$), nor the one *D. delphis* ($p = 0.602$) or one *O. orca* sessions ($p = 0.197$; Tables 4, 5 and 6). For reorientation, no significant effects were found for the *G. griseus* focal sessions ($p = 0.591$) nor for the *O. orca* session ($p = 0.936$); the sample size was too small to calculate reorientation for *D. delphis* (Table 3).

Table 4: Results of paired t-tests for focal group cohesion and reorientation behavioral response parameters for low and high fixed-wing aircraft altitudes.

Species	No. of Groups	Cohesion (No. of 1-min samples)	Cohesion (Paired t-test, *low* to *high* altitudes)	Reorientation (No. of 1-min samples)	Reorientation (Paired t-test, *low* to *high* altitudes)
G. griseus	8	152	p = 0.447	121	p = 0.591
D. delphis	1	24	p = 0.602	14	n/a (small sample size)
O. orca	1	21	p = 0.197	17	p = 0.936

Table 5: Summary statistics for the group cohesion behavioral response parameter for each focal follow session by species and by aircraft altitude.

Species	Group Size	Aircraft Lateral Distance (m)	Aircraft Altitude min/max (m)	Beaufort Sea State	Focal Duration (hh:mm:ss)	No. of 1-min Intervals with Cohesion				Mean Max Cohesion*			
						Low		*High*		*Low*		*High*	
						<213 m	305 m	457 m	>610 m	<213 m	305 m	457 m	>610 m
G. griseus	13	693	213/610	1	0:24:09	5	7	5	5	6.4	5.7	5	4.2
	38	678	305/457	3	0:43:14	-	14	8	7	-	3.6	3.5	2.9
	65	1076	305/457	3	0:21:28	-	13	4	-	-	32.1	6.6	-
	35	500	305/457	2	0:20:37	-	3	13	-	-	6	8.9	-
	6	500	152/610	1	0:34:56	10	3	5	7	4.6	4.3	6.4	4.3
	20	549	305/457	3	0:15:20	-	7	7	-	-	3	6.9	-
	22	958	305/457	1	0:14:47	-	5	9	-	-	2.6	1.8	-
	12	736	305/457	3	0:19:56	-	4	11	-	-	12.5	11.5	-
D. delphis	135	861m	152/610	2	0:27:23	10	4	5	5	2.6	7.5	4.6	3
O. orca	55	1624m	305/457	3	0:29:23	-	11	5	5	-	35.9	42	30

*maximum cohesion distance (i.e., maximum inter-individual distance) in estimated body lengths at 1-min point-sampling intervals

Table 6: Summary statistics for the group reorientation response parameter for each focal follow session by species and by aircraft altitude.

Species	Group Size	Aircraft Lateral Distance (m)	Aircraft Altitude min/max (m)	Beaufort Sea State	Focal Duration (hh:mm:ss)	No. of 1-min Intervals with Reorientation				Mean Max Reorientation Rate			
						Low		*High*		*Low*		*High*	
						<213 m	305 m	457m	>610 m	<213 m	305 m	457 m	>610 m
G. griseus	13	693	213/610	1	0:24:09	4	6	4	-	2.5	11.7	2.5	-
	38	678	305/457	3	0:43:14	-	13	9	5	-	17.7	13.3	14
	65	1076	305/457	3	0:21:28	-	13	3	-	-	14.6	10	-
	35	500	305/457	2	0:20:37	-	2	14	-	-	45	22.9	-
	6	500	152/610	1	0:34:56	10	3	5	6	13.3	10	2	7.5
	20	549	305/457	3	0:15:20	-	7	5	-	-	28.6	66	-
	22	958	305/457	1	0:14:47	-	5	8	-	-	8	22.5	-
	12	736	305/457	3	0:19:56	-	3	10	-	-	76.7	26.6	--
D. delphis	135	861	152/610	2	0:27:23	10	3	1	-	30.6	53.3	10	-
O. orca	55	1624	305/457	3	0:29:23	-	8	5	4	-	0	2	17.5

Discussion and Conclusions

Comparisons of group cohesion (based on maximum inter-individual spacing) and magnitude of reorientation rate were investigated relative to airplane altitude, for three species of Delphinidae: *G. griseus*, *D. delphis*, and *O. orca*. Based on these quantified parameters, no significant differences were found in response to changes in the plane's altitude. Considering these variables are often used as indicators of assumed disturbance in cetaceans, our findings suggest that, in this case, our aerial research platform did not have an observable impact on the behavior of the animals subject to focal observations. Results suggest that our small research aircraft circling at lateral distances ⩾500 m and altitudes of ~200-600 m did not cause statistically significant changes in the cohesion, orientation, or general behavioral state of the three species we observed. This result was to be expected, as our 500-m lateral distance was well outside the theoretical lateral distance of *Snell's cone* for the transmission of overhead sound from air through water during flat seas, based on the altitudes we flew. Thus, observed animals were assumed to be well outside the zone ensonified by the aircraft noise under the water surface while it circled them, despite Beaufort sea state conditions of 1-3 during our focal sessions.

The rather sparse information available on behavioral responses by cetaceans to aircraft has been summarized in the last decade in several reviews [e.g., 52,12]. Most studies involved helicopters, mysticetes and/or anecdotal observations, with few such data collected systematically, on odontocetes, or in response to small twin-engine aircraft, as done in our study. Cross-study comparisons should thus be considered cautiously. Systematic studies of odontocete responses to small, fixed-wing aircraft are limited primarily to *Delphinapterus leucas* (beluga whales) [51], *P. macrocephalus* [12], and delphinids in the Gulf of Mexico [58]. For example, Patenaude et al. (2002) reported that *D. leucas* reacted most frequently to a passing Twin Otter fixed-wing aircraft by exhibiting short surfacings, immediate dives or turns, changes in behavior state, vigorous swimming, and breaching, primarily at altitudes <150 m and lateral distances <250 m [51]. During straight line passes (<360 m lateral distance) by a Cessna 172, Skymaster, and Partenavia aircraft during aerial surveys in Hawaii, 3 of 24 sightings of *P. macrocephalus* reacted by abruptly diving. *P. macrocephalus* off Kaikoura, New Zealand, responded to small, fixed-wing whale-

watching planes circling at 150 m above whales [72,73]. Transient males delayed time to first click (vocalization) and reduced surfacing time near the aircraft, while residents slightly increased their surface time near the aircraft; however, no change in frequency of heading changes was exhibited by residents or transients [72,73]. Würsig et al. (1998) and Smultea et al. (2008) present some of the largest sample sizes available on responses of odontocetes during systematic passes and circling of animals by small fixed-wing research aircraft [58,12]. Würsig et al. (1998) flew a DeHavilland Twin Otter at altitude 229 m and a speed of 204 km/hr during aerial line-transect surveys in the Gulf of Mexico. Among delphinid groups, behavioral changes (mainly 'diving' or 'other') were documented among 16% (6 of 37) of *G. griseus*, 43% (18 of 42) *Stenella attenuata*, 71% (5 of 7) *S. clymene*, 75% (6 of 8) *S. coeruleoalba*, and 100% of 4 *S. longirostris* [58]. In general, 'milling' and 'rest' behavioral states appeared to be most sensitive to aircraft disturbance, although no *G. griseus* groups responded while in these states [58]. However, lateral distance flown relative to the animals was not indicated, which affects the lateral extent of penetration of associated airborne sound through the water surface.

Among mysticetes, the most extensive and systematic studies of responses to small fixed-wing aircraft have been conducted on *B. mysticetus* and *Eschrichtius robustus* [reviewed by 42,52]. Richardson et al. (1985) reported that *B. mysticetus* frequently reacted to an approaching fixed-wing aircraft flying at $\leqslant$305 m altitude, reacted infrequently at 457 m flight altitude, and exhibited no detectable behavioral reactions at 610 m altitude. When a Britten-Norman Islander (a twin-engine, high-winged aircraft) circled above *B. mysticetus* at an altitude of 457 m, for 0.8 to 1.9 hr, "fast dives" and movement away from the aircraft were noted [25]. When the whales were feeding, however, no response was observed, even with the aircraft circling at 305 m altitude for 30 min. Patenaude et al. (2008) documented behavioral responses to a fixed-wing Twin Otter by 2.2% of 506 *B. mysticetus* sightings; most of these responses occurred when the plane was at altitudes <182 m and $\leqslant$250 m of the whales [51]. Ljungblad (1985) observed *B. mysticetus* diving when P-3 patrol aircrafts flew overhead at an altitude of 250 m. *E. robustus* mothers were opportunistically observed moving over the top of their calf, or the calf moving underneath the mother, in response to small turboprop survey aircraft circling at an altitude of 335 m [76]. These and other studies suggest that aircraft flying overhead cetaceans at relatively low altitude and likely within or near Snell's cone, appear more likely to elicit behavioral responses than aircraft flying well outside Snell's cone distance. This pattern appears logical, in that cetaceans below the water surface and directly below the aircraft are more likely to be exposed to aircraft sounds known to penetrate the air-water interface within Snell's cone (and near it, depending on Beaufort sea state, water depth).

In general, helicopters appear to elicit stronger and more frequent responses by cetaceans than small, fixed-wing planes [52]. This is consistent with results reported by Patenaude et al. (2002) indicating that a directly overflying Bell 212 helicopter was 7–17.5 dB re 1 μPa (rms) noisier than a Twin Otter (10–500 Hz band) based on sounds measured underwater at depths of 3 m and 18 m in the Arctic [51]. Bell 212 sound consisted mainly of main rotor tones ahead of the helicopter and tail rotor tones behind it. Thus, it is important to consider the type of aircraft when assessing cetacean behavioral responses. However, Hewit (1985), and Au and Perryman (1982) found no behavioral reactions for multiple species of dolphins, including *Stenella*

longirostris and *S. coeruleoalba*, in response to a Bell 204 helicopter surveying at an altitude of 370 m (lateral distance was not indicated) [36,6].

Relatively few systematic studies of mysticete responses to helicopters have been conducted [51]. In response to helicopters, *E. robustus* exhibited avoidance behavior to a Bell 212 that produced an estimated underwater received level sound source of 115 dB re 1µPa (rms) [75]. *Balaenoptera acutorostrata* (minke whales) changed their course, rolled onto their side, or dove, in response to a Sikorsky S-62 turbine helicopter (HH-52A) at a closest approach altitude of 229 m [77]. Koski et al. (1988), while performing aerial photogrammetry from a helicopter at an altitude of 150 m, observed that *B. mysticetus* made abrupt turns and hasty dives yet returned to the same area the following day. No change in behavior was observed in response to a turbine helicopter that made 5 passes directly over *B. mysticetus* at an altitude of only 153 m [78].

It is important to note that numerous studies indicate that cetacean sensitivity to anthropogenic sound disturbance and that of other mammals is related to several factors, including behavioral state, age/sex class, group size, previous exposure, etc. [e.g., reviewed in 50,20]. For example, feeding and socializing/mating cetaceans are often less sensitive to aircraft, vessel, seismic and sonar disturbance than traveling and migrating individuals. This is presumably because for example, feeding is an essential, energetically critical behavior to survive, thus animals do not have the luxury of disrupting feeding in response to disturbance.

Our study suggests that a small fixed-wing Partenavia airplane circling at altitude 200-600 m and lateral distance >500 m did not cause significant measurable, or observable, changes in the group cohesion, reorientation rate, or general behavior state of the *G. griseus*, *D. delphis*, and *O. orca* we observed. Our results are consistent with most studies on cetaceans that non-feeding *D. leucas*, *P. macrocephalus*, *T. truncatus*, *G. griseus*, *B. mysticetus*, and *M. novaeangliae*, indicating that a small airplane circling well outside the theoretical Snell's cone at ~366-457 m altitude and lateral distance >500 m, does not appear to cause measurable changes in selected behavioral parameters (e.g., respiration and dive rates, reorientation, cohesion, behavioral state, etc.; 51,12,22, 25, 58). However, it is important to note that there are other studies that do show behavioral change in response to small aircraft, particularly while feeding [58]. Available data suggest that different behavioral states (e.g., feeding vs. traveling) and different group numbers can strongly affect how animals react to certain human potential disturbances. Similarly, different species, or different classes of individuals, within a species may be more predisposed to different levels of sensitivity, some reacting more than others, including mothers with calves [41,58,29].

In summary, when protocol is adequately followed, ensuring that the observation aircraft is well outside (>2.5-4 times) the theoretical 13° sound radius of Snell's cone relative to observed animals, in relatively deep waters and Beaufort sea states <4, small fixed-wing aircraft appear to provide a relatively non-disturbing platform from which potential impacts of other activities can be observed. Flying in this manner seems to avoid confounding observations via disturbance from the research platform itself, i.e.,the "observer effect" (based on results of this small sample size and many previous similar studies). Thus, small fixed-wing aircraft can provide an advantage over studying behavior from vessels that emit underwater engine sounds that carry

much further distances and at varying levels and thus likely compromise behavioral study results. To better understand the parameters under which cetaceans are likely to react to aircraft, further studies are needed to systematically record the underwater received sound levels associated with different aircraft types, flight patterns, and lateral distances and altitudes, including relative to water depth, bottom depth, and Beaufort sea state, and to correlate received sound levels with behavioral changes. Underwater aircraft sounds should be measured not only directly beneath the aircraft but also away from the aircraft track within and outside of Snell's cone, following a systematic approach. Anecdotal reports that cetaceans may react to visual stimuli such as the aircraft's passing shadow or by looking up at the aircraft also remain to be systematically studied, as do the effects of aircraft overflights on cetacean vocalization patterns, an area of limited previous study.

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Five "key references", selected by the authors, are marked below (*Three recommended* (●) *and two highly recommended* (●●) *papers*).

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