AN ABSTRACT OF THE THESIS OF

Timothy K. Marcella for the degree of Master of Science in Wildlife Science presented on June 18, 2014.

Title: Cruise Ship Disturbance to Kittlitz's Murrelets (*Brachyramphus brevirostris*) in Glacier Bay National Park and Preserve, Alaska.

Abstract approved: ____

Daniel D. Roby

The Kittlitz's murrelet (*Brachyramphus brevirostris*), a small pursuit-diving seabird in the family Alcidae, occurs across much of coastal Alaska and parts of the Russian Far East. Glacier Bay National Park, located in Southeast Alaska, is believed to support approximately 37% of the worldwide breeding population of Kittlitz's murrelets during the summer months. Recent concern over apparent population declines in Alaska, coupled with the Park's dual mandate of resource preservation and visitation, led to this study. Cruise ships, although not the most numerous vessel type operating in Glacier Bay, have previously been identified as the vessel type eliciting the greatest disturbance response from Kittlitz's murrelets.

During the murrelet breeding seasons in 2011 and 2012, my field assistants and I collected focal observations of 4,251 *Brachyramphus* murrelets from the bow of cruise ships traveling through Glacier Bay. Identification of murrelets to species was hampered by both the distance at which murrelets responded to the approaching ship and the type of response to the ship (diving vs. flushing). For roughly 40% of focal observations of

murrelets from cruise ships, the species of murrelet (Kittlitz's murrelet or marbled murrelet [*B. marmoratus*]) could not be identified. Apparent habitat partitioning by the two murrelet species in Glacier Bay resulted in 79% of identified murrelets in the upper section of the Bay (Upper Bay) being Kittlitz's murrelets, while 83% of identified murrelets in the lower section of the Bay (Lower Bay) were marbled murrelets. In the Upper Bay, cruise ships are predicted to disturb 61% of all murrelets within 850 m on either side of the cruise ship's course (i.e., elicited a flushing or diving response), whereas in the Lower Bay, cruise ships are predicted to disturb 72% of murrelets within 850 m of the ship's course.

Using Cox multistate models, I demonstrated that murrelets in the Upper Bay (predominantly Kittlitz's murrelets) were more likely to dive than flush in response to approaching cruise ships, whereas murrelets in the Lower Bay (predominantly marbled murrelets) were more likely to flush than dive. Also, murrelets in the Upper Bay responded to cruise ships by flushing or diving at shorter distances from the ship compared to murrelets in the Lower Bay. Murrelets in both areas of Glacier Bay generally reacted to cruise ships at greater distances when the ship approached indirectly, presumably because of the larger profile presented by a passing ship as opposed to a directly advancing ship. Absolute distance of the cruise ship from a focal murrelet was a strong predictor of murrelet disturbance response; no other management-relevant covariates that were measured during this study (e.g., ship velocity, distance to shore, whether a cruise ship had entered the Bay earlier that day) explained a significant proportion of the variation in murrelet response.

Inferences based on data collected on-board cruise ships were limited to murrelet disturbance responses that occurred within 1 km of the ship. This was because of limits to the distance from the ship at which behavioral responses could be observed and the *a priori* assumption that disturbance to murrelets by cruise ships was unlikely at distances greater than 1 km. Results from shipboard observations indicated that some proportion of murrelets encountered at the farthest distance we could make inferences were on occasion disturbed (point estimate at 850 m perpendicular distance from ship's course = 15-30% probability of flushing or diving). This suggests that disturbance of murrelets by cruise ships in Glacier Bay exceeded expected distance thresholds.

In order to investigate the effects of cruise ships on murrelet behavior at distances greater than 1 km, my assistants and I collected a total of 643 focal observations of Kittlitz's murrelets during 181 hours of observation from land-based observation sites in the Upper Bay during the 2012 field season. By combining these data with AIS and GPS ship tracks, I was able to append distance to the nearest cruise ship to each focal murrelet observation and search for patterns in murrelet behavior. By collecting data in this manner, I was able to avoid biasing the study based on pre-conceived notions of what constituted a threshold distance for cruise ships to disturb Kittlitz's murrelets. Using a segmented regression model within a logistic regression framework, I found that Kittlitz's murrelets exhibited a disturbance threshold (defined as an increased incidence of flushing from the water) by cruise ships at distances of at least 1.6 km, and perhaps as great as 6.0 km, with a best estimate of threshold disturbance distance at 3.8 km from a cruise ship.

When cruise ships were greater than 3.8 km from focal Kittlitz's murrelets, the baseline probability of murrelets flushing during a focal observation period was 12.5%. When cruise ships were less than 3.8 km from focal Kittlitz's murrelets, the probability of flushing increased logistically with decreasing distance to an estimated 48% for the closest approach distances. The unexpectedly long distances at which murrelet behavior was affected by cruise ships in Glacier Bay is most likely attributable to social facilitation by other disturbed murrelets, because similar numbers of murrelets flushed when cruise ships were approaching ($n = 30$) as when they were receding ($n = 27$). Once a Kittlitz's murrelet flushed from the water, the subsequent duration of flight did not vary with distance to the nearest cruise ship. Instead, the duration of Kittlitz's murrelet flight was associated with time of day.

The strong association between the proximity of cruise ships and the probability of a murrelet flushing, even at distances of several kilometers, demonstrates that Kittlitz's murrelets in Glacier Bay are susceptible to disturbance from cruise ships at distances greater than has previously been published for any seabird.

Cruise Ship Disturbance to Kittlitz's Murrelets (*Brachyramphus brevirostris*)
in Glacier Bay National Park and Preserve, Alaska.

by

Timothy K. Marcella

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APPROVED:

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Timothy K. Marcella, Author

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CONTRIBUTION OF AUTHORS

Dr. Daniel D. Roby assisted with the study design, interpretation of results and provided editorial comments for all Chapters. Dr. Scott M. Gende acquired the majority of the funding, assisted with the study design, interpretation of results, and provided editorial comments for Chapters 2 and 3. Arthur Allignol assisted in data analysis, interpretation of results, and provided editorial comments for Chapter 2.

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CHAPTER 1

GENERAL INTRODUCTION AND BACKGROUND

Timothy K. Marcella

The Kittlitz's murrelet (*Brachyramphus brevirostris*), a small pursuit-diving seabird in the family Alcidae, occurs across much of coastal Alaska and parts of the Russian Far East (Day et al. 1999). Most (> 70%) of the range-wide population of the species is thought to breed in Alaska (USFWS 2010), where they appear to be habitat specialists (Day et al. 1999, Day et al. 2003, Federal Register 2013). Kittlitz's murrelets prefer glacially influenced marine waters as foraging habitat (Day et al. 2003), and recently de-glaciated or sparsely vegetated alpine habitats for nesting (Day et al. 1983, Kaler et al. 2009).

Unlike most seabirds, which nest colonially, Kittlitz's murrelets are cryptic, solitary nesters (Day et al. 1999). This life history trait makes obtaining accurate and precise population estimates extremely difficult, as surveys must be conducted at sea. Prior to the 1970s, total population size was believed to be in the hundreds of thousands of individuals (Isleib and Kessel 1973), while more recent estimates place the global population between 30,900 and 56,800 individuals (USFWS 2010). Due to the challenges of surveying Kittlitz's murrelets at sea (Kuletz et al. 2001), the inconsistency of historical and contemporary survey methods (Kirchhoff et al. 2014), and the vast range across which the species is distributed (Federal Register 2013), the magnitude and persistence of these apparent population declines are currently the subject of debate (Kirchhoff et al. 2014, Federal Register 2013).

Low recruitment (Kaler et al. 2009, USFWS 2011), possibly associated with poor food availability; adult mortality due to by-catch in gill net fisheries (Wynne et al. 1992, USFWS 2011); direct mortality from oil pollution (van Vliet and McAllister 1994, Piatt and Anderson 1996, Kuletz et al. 2003); and disturbance from vessels (Day et al. 1999, 2003; Agness et al. 2008, 2013; USFWS 2011) have all been proposed as factors contributing to the apparent population decline. As a result the Kittlitz's murrelet is considered a species of conservation concern by the National Audubon Society (2006) and BirdLife International (2014) and, until recently, was designated a Candidate Species for listing under the U.S. Endangered Species Act by the U.S. Fish and Wildlife Service (USFWS; Federal Register 2007). In 2013, the USFWS issued a determination to not list Kittlitz's murrelets under the Endangered Species Act, owing largely to insufficient information to conclude the species is at global risk of extinction (Federal Register 2013).

Due to the reliance of Kittlitz's murrelets on glacially influenced coastal habitat, an estimated 30-50% of the range-wide population is believed to occur within or adjacent to a few coastal units of the U.S. National Park System during the murrelet breeding season (van Vliet 1993), making the National Park Service a global steward of the species. Of specific concern is Glacier Bay National Park and Preserve, hereafter referred to as Glacier Bay, which is believed to support approximately 37% of the worldwide breeding population (Federal Register 2013). Like most other National Parks in the U.S., Glacier Bay has a dual mandate of both resource preservation and visitation; therefore, Park managers seek to provide opportunities for enjoyment and use by visitors, while also protecting the natural resources within Park boundaries. As a result of this mandate, the National Park Service has funded this thesis research in order to investigate ways to promote visitation while protecting Kittlitz's murrelets.

Glacier Bay National Park and Preserve is located in Southeast Alaska, 100 km northwest of Juneau, and is part of the 24.3 million-acre Kluane/Wrangell-St. Elias/Glacier Bay/Tatshenshini-Alsek World Heritage Site, which includes some of the most pristine coastal and marine habitat in the world. Although the Park includes areas on the outer coast adjacent to the open North Pacific Ocean, most of the vessels that enter the Park access the 110-km, Y-shaped fjord for which the Park was named. The Park's jurisdiction includes both the land and marine waters, making it one of the few 'ocean parks' in the U.S. National Park System.

Kittlitz's murrelets may congregate in Glacier Bay due to the combination of abundant foraging opportunities (Arimitsu et al. 2007, 2008) and vast areas of preferred early successional alpine habitat for nesting that has been created by glacial retreat (Day et al. 1999). The area now encompassed by Glacier Bay National Park was completely covered by glaciers ca. 300 years ago, but in the past few centuries the ice has retreated rapidly to expose deep fjords and steep mountain slopes (Cooper 1937). There are currently seven tidewater glaciers within Glacier Bay (National Park Service 2012), which contribute large amounts of nutrients and labile carbon to fjord waters (Hood et al. 2009). The glacial dynamics of advance and retreat have created underwater sills, most notably near the mouth of Glacier Bay and at the entrance of the East Arm. These sills result in tide-forced upwelling, which can enhance spring phytoplankton blooms. Tidewater glaciers and underwater sills together enhance the productivity of the marine ecosystem in Glacier Bay and support abundant zooplankton and forage fish communities (Arimitsu et al. 2007). Due in part to this concentration of prey resources, the areas near tidewater glaciers and underwater sills tend to be "hotspots" for foraging and loafing Kittlitz's murrelets, resulting in a highly heterogeneous distribution of Kittlitz's murrelets within the Park (Romano et al. 2007, Piatt et al. 2011, Hoekman et al. 2014).

Tidewater glaciers within the Park, in addition to providing foraging opportunities for seabirds such as Kittlitz's murrelets, are a huge draw for tourists. Nearly all of the visitors to Glacier Bay access the Park via marine vessels (cruise ships, tour boats, private vessels, or kayaks; National Park Service 2012). Although private vessels are the most numerous vessel type, 95% of all visitation to the Park is aboard commercial cruise ships (upwards of 3,000 passengers per ship; National Park Service 2012). Visitation to the Park has steadily increased in the past decade, owing in large part to an increased level of cruise ship-based tourism (National Park Service 2012).

In an effort to protect natural resources while allowing for sustainable visitation, a Final Environmental Impact Statement (EIS) was completed in 2003 and a Record of Decision was signed by the Park Service establishing vessel quotas and operating requirements for vessels operating within the Park (USDOI 2003). The Final EIS defined the management strategy for cruise ships and other vessels operating within Glacier Bay, and limited the number of vessels permitted within the Park on a seasonal and daily basis by requiring all vessels to obtain a Park-issued permit before entry. On a daily basis, no more than two cruise ships are permitted to enter the Park throughout the summer. On a seasonal basis, a maximum of 153 cruise ship entries are allowed during the 92-day peak season (June through August). Thus, there are still a number of days during the peak season when only one cruise ship, and occasionally no cruise ships, are allowed to enter Glacier Bay. Additional cruise ship entries are coveted by the cruise ship industry, as there is high tourist demand during the summer months, and each year managers of Glacier Bay must consider industry requests to increase cruise ship operating quotas. During the shoulder season (May and September), up to 122 cruise ship entries are permitted, but current demand for entries during the shoulder season is lower, thus only 90 or so cruise ships enter the Park during the months of May and September.

Agness et al. (2008) documented that larger vessels, such as cruise ships, elicit the greatest disturbance response by Kittlitz's murrelets in Glacier Bay, resulting in a 30-fold increase in the incidence of flight when approached within 1 km, indicating that cruise ships may be the most frequent potential disturbance to Kittlitz's murrelets. Cruise ship disturbance could have significant impacts on vital rates of Kittlitz's murrelets in the Park due to (1) increased energy expenditure, especially associated with flight responses (Agness et al. 2013), (2) displacement of Kittlitz's murrelets from preferred foraging or resting habitat (Davidson and Rothwell 1993, Gill et al. 2001, Bellefleur et al. 2009, Velando and Munilla 2011), and (3) increased allocation of time and energy to flight, resulting in lost foraging opportunities (Galicia and Baldassarre 1996, Ronconi and St. Clair 2002, Speckman et al. 2004, Agness et al. 2013).

With these considerations in mind, I chose to focus my thesis investigations on the effects of cruise ships on the behavior of Kittlitz's murrelets in Glacier Bay. A range of potential impacts of cruise ships on Kittlitz's murrelets were considered, from direct mortality to eliciting an alert posture. Although mortality of pursuit-diving waterbirds has been attributed to vessel strikes in other areas of the country (Sidor et al. 2003), there have been no documented cases of Kittlitz's murrelets being killed or injured due to collisions with cruise ships or other vessels within the Park. Several incidents of peregrine falcons (*Falco peregrinus*) using cruise ships as hunting platforms for seabirds, and in particular murrelets, have been documented in Glacier Bay, but likely represent an extremely rare event. For the purposes of this study I chose to define taking flight from the surface of the water ("flushing") as the primary disturbance response to quantify, as this behavior likely incurs the greatest energetic cost of any response exhibited by murrelet (Pennycuick 1987). Diving was considered a secondary disturbance response to be quantified only when diving prevented further observation of individual murrelets.

Previous studies of vessel disturbance to wildlife have noted that certain operating characteristics can influence the magnitude of disturbance. In an effort to provide management relevant results, I investigated the effects of vessel speed (Agness et al. 2008, Ronconi and St. Clair 2002), distance of the vessel from shore (Ronconi and St. Clair 2002), and habituation to vessel traffic both daily (Bright et al. 2003, Chatwin et al. 2013) and across the season (Burger et al. 2010), amongst other environmental and biologically-relevant variables.

In Chapter 2 of this thesis, I quantify the incidence and magnitude of response by murrelets to cruise ships. Specifically, I address the probability of a murrelet reacting to an approaching cruise ship as a function of perpendicular distance to the cruise ship's course, as well as define the operating characteristics and environmental variables that affect both the murrelet's response type and response distance. By employing observers with high-powered, rangefinder binoculars positioned on the bow of cruise ships traveling through the Bay, I was able to explore the variability in disturbance rates based on location in the Bay, ship speed, ship distance to shore, and habituation to cruise ships, among other covariates. The study design limited the scope of inference of disturbance rates to within 1 km in front of and 90 degrees abeam of the bow, both to the port and starboard of the ship. This shortcoming was due in part to visual detection limits of murrelets on the water, and in part from an *a priori* assumption that 1 km would encompass the furthest distance at which murrelets would respond to approaching ships.

In order to explore the idea that cruise ships were causing disturbance to Kittlitz's murrelets beyond 1 km, in Chapter 3 I investigate the behavioral responses of Kittlitz's murrelets as a function of distance to the nearest cruise ship from land-based observation sites in the upper reaches of Glacier Bay. Observational data were collected on Kittlitz's murrelets and distance to the nearest ship was appended later. By using GPS and AIS ship tracking technology to determine the distance of the nearest cruise ship from each focal murrelet, I was able to monitor both the potential disturbance factor and the potentially disturbed murrelets independently and search for patterns I was unable to detect based on data collected from cruise ships. By collecting data in this manner, I was able to avoid biasing the study based on pre-conceived notions of what constituted a threshold distance for cruise ships to disturb Kittlitz's murrelets, and offer some insights into the potential drivers of disturbance to murrelets at greater distances.

In Chapter 4, I provide an overall summary and synopsis of research findings and management considerations, as well as insights into what can be gained from future research into the effects of cruise ships on the behavior of Kittlitz's murrelets in Glacier Bay. By using both shipboard and land-based observations of murrelet behavioral responses to cruise ships, it was my intent that this thesis would provide new insights and understanding of the mechanisms that drive disturbance of murrelets by cruise ships in Glacier Bay, which are important considerations for managers evaluating cruise ship quotas in the Park.

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CHAPTER 2

USING SURVIVAL ANALYSIS TO DETERMINE DISTURBANCE LEVELS TO RARE SEABIRDS IN A MARINE PROTECTED AREA

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ABSTRACT

Managers of Marine Protected Areas must often seek ways to allow for visitation while minimizing impacts to the resources they are intended to protect. Using shipboard observers, we investigate the "zone of influence" of cruise ships as they traveled the Bay and further quantified factors that influence the incidence and magnitude of disturbance to Kittlitz's and marbled murrelets (*Brachyramphus brevirostris* and *B. marmoratus*) by large cruise ships visiting Glacier Bay National Park, Alaska. Murrelets of both species were commonly disturbed by approaching cruise ships, although the type and magnitude of response (flush, dive) varied spatially, apparently due to habitat partitioning between the two species. In the upper reaches of the Bay, where Kittlitz's murrelets were more commonly encountered, cruise ships are predicted to disturb 61% of all murrelets within 850 m perpendicular distance of a cruise ship's course (i.e., elicit a flushing or diving response), although diving was the more prevalent response. In the lower reaches of the Bay, where marbled murrelets predominated, this percentage increased to 72%, with more murrelets responding by flushing than diving. Murrelets in both areas of the Bay generally reacted at greater distances when ships approached indirectly, presumably because of the ship's larger profile. Results suggest that there was not habituation to cruise ship travel during the study season and distance from the cruise ship accounted for the majority of the explained variation in response. Due to visual limitations we were unable to fully define the cruise ship zone of influence and results demonstrated that some proportion of murrelets encountered at the farthest distance we could make inferences were still predicted to be disturbed (point estimate at 850 m perpendicular

distance =15-30% probability of flushing or diving). These results suggest that murrelets in Glacier Bay are more susceptible to disturbance from cruise ships than previously thought.

INTRODUCTION

A recurring issue in the management of marine protected areas (MPAs), particularly those focused on biodiversity conservation, is finding optimal solutions to conflicting mandates. For example, MPAs that function to conserve habitat utilized by upper trophic level organisms, such as marine mammals and seabirds, are regularly targeted for ecotourism activities (Hoyt 2011, Reyes-Arriagada et al. 2013, Rosciano et al. 2013). 'Non-extractive' activities, such as whale-watching, are often promoted because they can provide direct economic benefits to local, gateway communities, increasing the acceptance of the MPA and ultimately offer a greater chance for success (Kelleher 1999, Jones 2001, Abecasis et al. 2013, Bennett and Deardon 2014, Rossiter and Arielle 2014). Yet ecotourism activities within MPAs can also negatively impact the organisms they are intended to conserve (Velando and Munilla 2011, Reyes-Arrigada et al. 2013). These impacts may vary from short-term behavioral modification to chronic acute disturbances leading to reduced vital activities, such as feeding or altered spatial distribution (Lusseau 2005, Christiansen et al. 2013, Williams et al. 2009). The population-level consequences of such disturbance may not be detected for years (Bejider et al. 2006). For this reason, generating regulations that both promote visitation and minimize impacts remains a challenge. Managers cannot readily attribute impacts from disturbance to population persistence, as is more feasible for impacts from extractive activities, such as by-catch from fishing (e.g., Jaramillo-Legorreta et al. 2007, Gerrodette and Rojas-Bracho 2011, Senko et al. 2014).

Glacier Bay National Park and Preserve (Glacier Bay) provides an excellent case study for the types of tradeoffs commonly faced by MPA managers. Located in southeastern Alaska, Glacier Bay is part of the 24.3 million-acre Kluane/Wrangell-St. Elias/Glacier Bay/Tatshenshini-Alsek World Heritage Site, which serves as one of the largest marine protected areas in the United States. Glacier Bay is a coveted destination for visitors to Alaska because it encompasses some of the most pristine coastal and marine habitat in the world, including a number of tidewater glaciers, productive marine ecosystems, and a diverse array of marine wildlife, including large aggregations of marine mammals and seabirds (Mathews and Pendleton 2006, Womble et al. 2010, Hendrix et al. 2012, Sarracco et al. 2013, Kirchhoff et al. 2014). Like most other National Parks in the U.S., Glacier Bay has a dual mandate of both resource conservation and visitation. Glacier Bay encompasses over 600,000 acres of marine ecosystems, and nearly all visitors access the Park via marine vessels (National Park Service 2012); thus, a recurring issue is providing opportunities for visitors to experience the Park while still protecting marine resources.

Here we focus on quantifying factors that influence the incidence and magnitude of disturbance by cruise ships to the Kittlitz's murrelet (*Brachyramphus brevirostris*), a species of conservation concern (National Audubon Society 2006, BirdLife International 2014). The Kittlitz's murrelet, a small pursuit-diving seabird in the family Alcidae, is endemic to Alaska and the Russian Far East (Day et al. 1999). While there is significant debate regarding the status of the Kittlitz's murrelet across the species' range (Drew and Piatt 2008, Piatt et al. 2011, Kirchhoff et al. 2014), the species remains a priority conservation concern for the National Park Service (NPS). Recent estimates suggest that approximately 37% of the world's known population of Kittlitz's murrelets is found within Glacier Bay during the summer (USFWS 2013), making the NPS a steward to a globally significant fraction of the population. Murrelets are distributed patchily throughout the marine waters of Glacier Bay, with some of the highest aggregations occurring near tidewater glaciers (Hoekman et al. 2014), resulting in significant spatial and temporal overlap of murrelet habitat and high-use visitor areas. Consequently, previous studies have documented murrelet disturbance from large vessels within Glacier Bay (Agness et al. 2008), and suggest that repeated disturbance may negatively affect foraging activities (Agness et al. 2013). The U.S. Fish and Wildlife Service recently issued a determination not to list Kittlitz's murrelets under the U.S. Endangered Species Act, owing largely to insufficient information necessary to conclude the species is at global risk of extinction (USFWS 2013). Yet, the NPS still has a mandate to avoid impacts within Park boundaries from visitors or other activities that can impair species or alter the natural processes within Glacier Bay (National Park Service 2006).

The specific objective of this study was to quantify the extent to which cruise ship visitation may disturb murrelets within Glacier Bay, and explore potential factors that may influence the probability of disturbance. We focused our study on cruise ships because they play a disproportionate role in visitation to the Park compared to other vessel types. Although not the most numerous vessel type operating within Glacier Bay, cruise ships bring more than 400,000 passengers to Glacier Bay each summer, constituting over 95% of all visitors annually to the Park (National Park Service 2012).

Thus, any regulation of cruise ship volume or activity intended to meet the NPS's conservation mandate would simultaneously affect the overwhelming majority of visitors to the Park. Also, unlike the management of other marine vessels, the Park Superintendent must make an annual determination regarding the number of allowable cruise ships within the Park, weighing the benefits of visitation with their potential conservation impacts.

METHODS

Study Area

Glacier Bay National Park and Preserve (the Park) is located in southeastern Alaska, 100 km northwest of Juneau. Although the Park includes areas on the outer coast adjacent to the open North Pacific Ocean, much of the viewable wildlife and all the tidewater glaciers, and thus the focus of visitation, occurs in the protected, 110-km, Y-shaped fjord, commonly referred to as Glacier Bay (Figure 2.1). The Park's jurisdiction includes both the land and marine waters, making it one of the few 'ocean parks' in the U.S. National Park System.

Cruise Ships in Glacier Bay

The NPS regulates the number and type of marine vessels allowed in Glacier Bay on both a daily and seasonal basis. For cruise ships, the Park allows no more than two entries per day during May through September. However, the Park Superintendent has currently set a seasonal quota of 153 cruise ship entries during the 92-day peak season (1 June – 30 August). Thus on most days during the peak season, the daily maximum of two ships visit the park, but there are still a number of days when one or no cruise ships are permitted to enter the Park. There is high demand for entries into Glacier Bay during the peak season, and the decision whether to increase the seasonal quota, including up to its maximum of 184 (two ships every day for 92 days) is made annually by the Superintendent (USDOI 2003).

May and September constitute the 61-day ‘shoulder’ season. Currently the shoulder seasonal quota for cruise ship entries is set at 92. However, due to weather conditions in Alaska, there is a lower demand for entries into Glacier Bay during the shoulder season and thus there are typically far fewer ships that enter Glacier Bay relative to the 92-ship quota.

Cruise ship characteristics and operations within the Park are remarkably similar. Ships entering Glacier Bay average 260 m in length (SD = 36 m), and typically carry 1800-3000 passengers (Webb and Gende, In press). Cruise ships enter the Park at the mouth of Glacier Bay in the morning, generally between 06:00 and 10:30 ADT, and proceed up the fjord until reaching the tidewater glaciers at the head of the West Arm of the Bay three to four hours later. During their transit, cruise ships generally remain mid-channel and, due to navigational hazards, as well as regulations prohibiting access to the East arm of the fjord, tend to follow the same general route (Webb and Gende, In press; Figure 2.1). Cruise ships typically spend two to three hours in the upper reaches of the fjord before proceeding back along the same route, typically exiting 9-11 hours after entering. Most variation in visitation time can be attributed to speed restrictions that may be in place for whale conservation measures during periods of high humpback whale (*Megaptera novaeangliae*) use of the Bay (USDOI 2003). No large cruise ships are present in the Park at night, and all passengers remain on board the ship during the entire visit.

For our study, observers were transferred by an NPS boat out to the cruise ships as they entered the Park, spending the day recording murrelet response behavior, before disembarking the ship as it exited the Bay. We built on successful methods developed by Jansen et al. (2010) and Harris et al. (2012), wherein the observer stood at the forward-most position on the bow with rangefinder binoculars and, with unencumbered views of the waters in front and adjacent to the ship, recorded responses of murrelets to the ship as it traveled within the Park. We note that cruise ships provide some inferential advantages to understanding the magnitude of disturbance to wildlife: they tend to take an almost identical route during each visit and travel at nearly identical speeds. They also cannot abruptly change course or speed, which could confound observational efforts (e.g., Young et al., In press). Cruise ships also do not change their operations due to the presence of the observer.

Experimental Design

From June through mid-August in both 2011 and 2012, a total of 45 cruise ships were boarded and murrelet observations recorded (N = 22 cruises in 2011; N = 23 in 2012). Observation time onboard the ships averaged just over six hours per cruise in each year of the study (range = 3.5 – 8 h). Thirteen different ships from either the Holland

American Line (HAL) or Princess Cruise Lines (Princess) were boarded during the two-year study. The ship sizes were typical of those operating in Alaska, ranging in length from 228 to 294 m, and 29 to 37 m wide at the beam. HAL and Princess ships accounted for over 60% of the entries by cruise ships into Glacier Bay in 2011 and 2012; thus, our results are representative of the population of cruise ships that enter the Park annually.

Observations were made from the forward-most accessible position on the ship, approximately 20 m above the water line. While the distance to the focal murrelets recorded from this height differs slightly from the distance at waterline, we chose not to correct for this discrepancy because over 50% of recorded distances were estimates, rather than true measurements (although measurement error was recorded and quantified; see below). We acknowledge this shortcoming and, therefore, only make statements about reaction probability at a coarse scale (50 - 100 m). The configuration of the bow prevented observing murrelets closer than about 50 m directly in front of the ship, or closer than about 100 m abeam, although our results demonstrate that nearly all murrelets encountered had reacted before being approached by the ship to such close distances. The surveyed area was inclusive of the water surface about 1 km to the front and side of the bow of the cruise ship, and alternated between port and starboard sides of the cruise ship during consecutive cruises (see also Harris et al. 2012). Observations were collected only while the ship was traveling through the Bay, and were temporarily terminated when the ship was stopped to allow passengers to view glaciers, or when fog or heavy rain impeded visibility.

Observers spent several weeks training prior to boarding cruise ships to accurately identify murrelets to species at a distance (Kittlitz's or marbled murrelet [*B. marmoratus*]). For estimating disturbance, our protocol dictated that observers haphazardly chose either a single murrelet, or one murrelet from a group of murrelets, as far from the ship as possible, and at varying bearings off the ship's course. Groups of murrelets were defined as two or more birds within two meters of each other or multiple murrelets acting in unison (e.g., swimming in a line). Observations were only initiated on 'undisturbed' murrelets that were on the surface of the water, which we termed 'loafing.' Thus, as defined, loafing included any behavior other than flying or diving, and encompassed a range of behaviors conducted on the surface of the water, including comfort (resting/sleeping), maintenance (preening), or vigilance (alert, calling, swimming away). We recognize that by defining birds as undisturbed in this manner we are underestimating the true rate of disturbance, because murrelets on the water may be disturbed and reacting to the approaching ship while still on the water's surface (e.g., oriented and moving away from the ship). However, owing to difficulties in ascertaining when such orientations began, and the much larger energetic consequences of flight and dive responses vs. orienting away from the ship, we chose to define taking flight (flushing) as the primary disturbance response and diving as the secondary disturbance response with which to quantify disturbance.

Observations of murrelets were collected using rangefinder binoculars (Leica Vector IV, 7x 42mm, Heerbrugg, Switzerland; range up to 6 km +/- 1 m) mounted on a tripod (Manfrotto 3021BPRO, Upper Saddle River, NJ, USA) with an attached compass rose (compass rose only used in 2012). In addition to the distance at which the focal murrelet flew or dove, bearing angle of the focal bird relative to the cruise ship heading was recorded. Because these two values generally change during a focal observation as the ship progressed towards the focal murrelet (i.e., are distance-dependent), repeated measurements were collected approximately every 10 sec until the focal murrelet reacted by flushing or diving, or the observation was terminated as the murrelet passed abeam of the ship's bow. Additionally, for each focal murrelet we recorded: (1) the species of murrelet, if discernable, (2) the murrelet group size, (3) Beaufort wind force, (4) whether there was one to two ships in the Park that day, and (5) the number of days since June 1. Ship location and velocity data were collected using a handheld Garmin GPS (GPSMAP 76Cx, Olathe, KS, USA) set to record a location every five seconds during the cruise. Ship speed was calculated as a ratio of the distance covered per 60-sec period centered on the observation time, and was converted to nautical miles per hour (knots; see also Gende et al. 2011). Data on ship distance from shore and location within the Park were generated using the base functions in ArcMap 10. Although these additional variables could have changed slightly over the course of one focal murrelet observation, they were considered fixed for all repeated measurements of a particular focal murrelet. Observational data were dictated in real time into a hands-free digital voice recorder (Olympus DS2400, Centerville, PA, USA). The recorded data were then played back using Wave Pad Sound Editor v 4.52 (NCH Software 2014), transcribed onto paper data sheets, and later entered into an Excel database.

The rangefinder binoculars were most successful at measuring distances to murrelets less than about 500 m. For distances greater than 500 m, we experienced less success at ‘hitting’ the target murrelet with the laser, resulting in a non-measurement. When a distance measurement from the rangefinders could not be obtained, the observer estimated the distance. The accuracy of these distance estimates was measured in 2011 by visually estimating a range of distances to floating objects in the water (e.g., icebergs, logs, or birds) immediately before measuring distance with the rangefinder binoculars ($N = 417$). In 2012, the accuracy of distance estimation was measured in real time by estimating distance to every focal murrelet before releasing the button on the rangefinder ($N = 917$). Paired estimated and measured distances were tested for systematic bias separately for each year of the study.

Estimate error was calculated by subtracting the measured value from the corresponding estimated value. Mean average error (AVEerror) and the root mean square error (RMSE) were calculated for 2011 (AVEerror = 48.5 m, RMSE = 68.0 m) and 2012 (AVEerror = 47.6 m, RMSE = 62.0m) separately. Empirical cumulative distribution functions of the errors in each year were overlaid onto normal distribution functions and appeared normally distributed (Figure 2.2). A two-sample Kolmogrov-Smirnov test confirmed that the errors between the two years followed the same distribution ($D = 0.034$, p-value = 0.887; Young 1977). Because no systematic bias appeared to be present when distances were estimated rather than measured, either within or between years, we chose not to treat estimated distances differently from measured distances.

Statistical Analysis

The primary research question of our study was to determine the 'zone of influence' to murrelets as cruise ships travel through Glacier Bay, and to identify any biological, environmental, or management-relevant covariates that might lessen this zone of influence (Table 2.1). In an effort to offer easy to interpret and management-relevant results, as well as to better understand the influence of cruise ships on murrelet behavior, we chose to investigate the zone of influence at a distance perpendicular to the ship's course using logistic regression. We also investigated the mechanistic factors that influence murrelet disturbance response (flush or dive) across a range of approach angles using survival analysis. All statistical analyses were conducted in program R, version 3.0.0 (R Core Team 2013).

Survival Analysis

Survival analysis, also referred to as event time analysis, is commonly used for analyzing the amount of time that elapses before an event of interest occurs (Cox 1972). Typical survival analysis studies originate at time zero (study onset) and follow an individual until the time the event occurs or until the predetermined end of the study. Thus, the basic survival analysis function takes the form $S(t) = Pr(T > t)$, where survival (S) or persistence to some time (t) is equal to the probability (Pr) that the failure or event time (T) is greater than the specified time (t). Survival analysis studies often need to account for alternate events that preclude or prevent observation of the event of interest. These situations are referred to as competing risks. Observations may also be terminated prior to experiencing an event of interest when a subject is lost from the study due to an independent or non-informative reason, or remain event-free for the duration of the observation period. Additionally, a subject may enter the study at a time later than the study initiation time. These last two scenarios are referred to as right-censoring and left-truncation, respectively. Methods have been developed to handle these scenarios when maximizing the likelihood of the survival function and the related hazard function (Kaplan and Meier 1958, Beyersmann et al. 2012).

Unlike typical survival analysis studies that focus on time-to-event (Cox 1972), we were interested in the distance-to-event (see also Bellefleur et al. 2009, Chatwin et al. 2013). For our study, we were particularly interested in the flushing response because taking off from the water is arguably the most energetically costly avoidance behavior that a passing cruise ship can elicit, as compared to a swimming or diving in response to the vessel (Pennycuick 1987). Diving, however, was also a common response that precluded us from following the individual longer, and was thus analyzed alongside flushing as a competing risk. We note, however, that diving birds may have surfaced and then flushed, and thus our results represent conservative estimates of flushing response. Our data are also characterized as being right-censored, as there were certain situations when an event of interest was not observed during the study period, i.e., when a bird was lost from sight due to glare or because it passed abeam of the ship without diving or flushing. Left-truncation was present when observations of focal murrelets were initiated closer than 1,000 m from the ship, the furthest observation distance considered for this analysis, or when a distance-dependent variable changed.

Standard survival analysis deals with the passage of time, wherein the starting time for observation of each subject (e.g., year 1) is necessarily smaller than the ending time (e.g., year 12). For our analysis, however, the distance at which we initiated observations of a focal murrelet was greater than the ending distance (the ship was constantly getting closer to the focal murrelet). In order to account for this, the data were transformed by subtracting all observation distances from 1,000 m, resulting in the increasing measurement values needed for the analysis. All reaction distances were back-transformed after analysis and prior to presenting results; therefore, all results reflect the distance (in meters) where each murrelet ultimately responded to the ship.

In order to test for an effect of the distance-dependent variable “approach angle”, we needed to effectively censor and truncate observations every time the angle changed. Approach angle was dichotomized into categories of 0° - 44° or 45° - 90° from the ship’s course. Each time the approach angle category changed for a focal murrelet, the observation was censored and a new left-truncated observation began. The truncation process created two pseudo-individuals, each only contributing follow-up information to the estimated hazard when the covariate value was equal to one specific category. By right censorship and left truncation we ensured that each portion of the focal murrelet observation spanning the two bearing bins is independent of each other (Beyersmann et al. 2012).

Species-specific Reaction to Approaching Cruise Ships

There were several obstacles to identifying murrelet species relative to our objectives. First, Kittlitz's murrelets and marbled murrelets are notoriously difficult to distinguish at a distance during seabird surveys (Kuletz et al. 2011a, Kirchhoff et al. 2014). Commonly used techniques to differentiate between murrelet species in the field include plumage characteristics and bill size (Day et al. 1999), which can be difficult to distinguish at great distances. More importantly, however, our ability to distinguish between Kittlitz's and marbled murrelets was a function not just of distance, but response type. While we could easily differentiate murrelets (*Brachyramphus* spp.) from other waterbird species at distances up to 1,000 m based on body size and profile, distinguishing between Kittlitz's and marbled murrelets was much more difficult, especially if the murrelets did not flush. For example, 65% of murrelets between 300 m and 400 m from the cruise ship that responded to the ship by flushing were identified to species, while only 11-13% of murrelets between 300 m and 400 m were identified to species if they dove or remained on the surface of the water as the ship passed. Focal murrelets that responded to the approaching ship at distances greater than 400 m were usually not identified to species.

These species-specific biases were explored (and confirmed) statistically by calculating the nonparametric cause-specific estimates of the cumulative incidence function for the probability of flushing and diving for identified Kittlitz's and marbled murrelets separately, as well as for all murrelet observations combined, using the 'etm' package in R (Allignol et al. 2011). The cumulative incidence function at a given distance is the probability of experiencing a particular event prior to a given distance and prior to experiencing any other competing event.

Because of the inherent bias associated with our species identification rates (see below), we chose to lump identified and unidentified murrelets together and complete all further analyses at the genus level. A dichotomous variable representing habitat portioning during the two years of our study was analyzed as a covariate in the genus level analysis in an effort to highlight possible differences in behavioral responses of Kittlitz's and marbled murrelets to cruise ship approaches. With this technique we lose the ability to make definitive statements about inter-specific variability in both reaction distance and reaction type, but preserve the ability to accurately assess and compare the two behavioral responses (flush vs. dive) of murrelets encountered by cruise ships in Glacier Bay.

Perpendicular Disturbance Distance

From a management perspective, the NPS seeks to understand the zone of influence as a result of allowing cruise ships to enter the Park, i.e., how far on either side of the ship's course are murrelets likely to be disturbed. To this end, we calculated the perpendicular distance to the cruise ship's course using planar geometry from the last collected distance and bearing angle for each focal murrelet. Murrelets responding to the approaching ship (flushing or diving combined) prior to passing abeam of the bow were scored a 1, while those remaining on the water as the ship's bow passed the perpendicular were scored a 0. Observations that were terminated prior to the focal bird reacting or passing abeam were eliminated from this analysis. Binary logistic regression was used to estimate the probability of a murrelet responding to the ship prior to passing abeam, with consideration to the perpendicular distance from the ship's course, among other biological and management relevant covariates (see Table 2.1 for covariates explored). The best fit model was chosen by forward and backward stepwise AIC model selection using the 'MASS' package in R (Venables and Ripley 2002). For ease of management recommendations interaction terms were not investigated as part of this analysis. Model fit was assessed by investigating the receiver operator characteristic (ROC) and calculating the area under the curve (AUC) statistic using the 'ROCR' package in R (Sing et al. 2005).

Multistate Modeling

Using only the last data point (disturbed or not) and only the perpendicular distance from the ship's course fails to utilize information about responses by murrelets that may lead to better management or insight into biological or environmental factors that influence responses. Thus, in order to investigate the mechanistic processes driving the disturbance events we developed a multistate Cox regression model that allowed us to investigate the effects of the covariates across the different approach angles and disturbance responses (Putter et al. 2007). The process modeled follows a uni-directional, multistate model without recurrent events. Approach angle was a distance-dependent variable because its value could change as the distance between the ship and the focal murrelet decreased. This fact made it possible for a focal murrelet to start in the 0° - 44° approach angle state and transition to the 45° - 90° state, prior to entering an absorbing state by flushing or diving. The transition between transient states is considered uni-directional and non-recurring, as no murrelets were observed transitioning from the 45° - 90° approach angle state to the 0° - 44° state. This process was assumed to follow a Markov property, i.e., only the present state occupied and distance from the ship, not the process leading to this occupation, would affect the subsequent transition (Putter et al. 2007).

The multistate model was constructed using the ‘mstate’ package in program R (de Wreede et al. 2011). Five transitions were considered: one between the transient states (0° - 44° to 45° - 90°), and two each from the transient bearing states to either of two absorbing states (flushing or diving; Figure 2.3). The effect of each explanatory variable was explored within a non-parametric Cox proportional hazards framework for each of the five transition types (Putter et al. 2007). Because sample sizes were large and interpretation of observed behaviors was the goal of the modeling exercise, we chose to include all variables in the final model, even if not statistically significant. The proportional hazard assumption was checked by exploring the Schoenfeld residuals. Interaction terms were not explored in the multistate model.

Given that a primary purpose of this study was to provide managers with an average reaction distance for Kittlitz’s murrelets in response to cruise ships traveling through Glacier Bay, we chose to not include year (even though slightly significant) as an explanatory variable in either model explored, allowing the covariate effects to reflect the average murrelet reaction across both study years.

RESULTS

Over the two years of the study, 4,251 focal *Brachyramphus* murrelets were followed from an initial detection at ≤ 1,000 m from the ship across a range of bearings until the murrelet flushed, dove, or passed abeam of the ship (Figure 2.4). A total of 1,191 of the focal murrelets (28.0%) were identified as Kittlitz's murrelets, 1,225 (28.8%) were identified as marbled murrelets, and the remaining 1,835 (43.2%) were recorded as unidentified *Brachyramphus* murrelets (Table 2.2). Summarized for all *Brachyramphus* murrelets, most focal murrelets ultimately reacted to the approaching ship by either flushing or diving, and these two responses occurred with similar frequency (47.0% and 41.5%, respectively). Passing abeam of the ship without flushing or diving was a rare event for focal murrelets, accounting for only 5.8% of all observations. Visual contact with the murrelet was lost prior to observing a response or the murrelet passing abeam of the ship for the remaining 5.7% of focal follows (Table 2.2).

As expected, our species identification rates were hindered at greater distances from the ship, and when murrelets reacted to the approaching ship by diving. Nonparametric, cause-specific estimates of the cumulative incidence function for identified Kittlitz's murrelets and identified marbled murrelets demonstrated a strong bias towards greater identification rates for murrelets that reacted by flushing as opposed to diving. This is evident from the cumulative incidence functions plotted for all focal murrelets combined (identified and unidentified), which demonstrates an equal occurrence of flushing and diving reactions across the range of sampled distances from the ship (Figure 2.5). To avoid biasing murrelet disturbance distance low by focusing solely on flushing and diving responses of murrelets that were identified to species, we chose to lump all observations and conduct all further analyses at the genus level. Nevertheless, 79% of identified murrelets in the Upper Bay were Kittlitz's murrelets and 83% of identified murrelets in the Lower Bay were marbled murrelets, suggesting pronounced habitat partitioning by the two study species during the period of the study. We present the effects of location in models, when significant, as an indicator of potential species-specific differences in the response to cruise ships, but these results should be interpreted with caution.

Response Distance

The perpendicular distance of a murrelet to the cruise ship's course accounted for roughly 93% of the explained variation in disturbance response; seasonal and location effects were also important in predicting reaction probabilities within the binomial logit model. For each 100-meter increase in the perpendicular distance from a murrelet to the ship's course, there was an estimated 58% reduction in the odds of reacting (95% c.i. = 54% - 62% reduction, $p < 0.001$; Table 2.3). Assuming equal distribution of murrelets across the range of perpendicular distances, on average, as cruise ships travel through Glacier Bay, they are expected to disturb nearly 100% of all murrelets encountered within a 200-m perpendicular distance from the ship's course; 85.5% of all murrelets encountered between 0 and 600 m perpendicular distance are expected to be disturbed; and 68% of all murrelets encountered between 0 and 850 m perpendicular distance are expected to be disturbed (Figure 2.6).

Focal murrelets in the Lower Bay tended to exhibit a greater reaction to cruise ships compared to those in the Upper Bay; there was a 141% increase in the odds of reacting at any given distance for murrelets in the Lower Bay compared to murrelets in the Upper Bay (95% c.i. = 78% - 227% increase, $p < 0.001$; Table 2.3). There was a slight but significant positive seasonal effect on the probability of murrelets reacting to a passing cruise ship. On average, the probability of murrelets reacting to a cruise ship tended to be higher at slightly greater perpendicular distances to the ship as the season progressed, providing no evidence of habituation to cruise ship traffic. This resulted in a 0.8% increase in the odds of reacting for each additional day after June 1 (95% c.i. = 0.04% - 1.6% increase, $p = 0.037$; Table 2.3). Management-relevant covariates, including number of ships in the Bay per day, ship speed, and ship distance to shore, did not explain a significant proportion of the variation in the probability of a murrelet response as a function of perpendicular distance to the ship's course.

When considering absolute, rather than perpendicular, distance of a murrelet from a cruise ship within the Cox multistate regression model, similar results were evident. Straight-line distance to a cruise ship was a strong predictor of the incidence of both flushing and diving responses, and exhibited a monotonic increase in the observed probability of reaction for murrelets approached by ships both directly and tangentially (Figure 2.7). On average, murrelets showed a greater tendency to respond to cruise ships approaching indirectly at further distances, compared to murrelets approached directly. Additionally, there appeared to be a slight increase in the proportion of murrelets that responded by flushing, instead of by diving, when approached indirectly rather than directly.

Covariate Effects on Response Type

Location in the Park was the only factor that explained a significant proportion of the variation in all four behavioral transition states within the Cox multistate model. Focal murrelets in the Lower Bay experienced a 91% and a 93% increase in the hazard of diving when approached directly and indirectly respectively, compared to focal murrelets in the Upper Bay (95% c.i. = 65 - 121% increase, $p < 0.001$; 49 - 152% increase, $p < 0.001$; Table 2.4). Similarly, focal murrelets in the Lower Bay also exhibited a 51% and 34% increase in the hazard of flushing when approached directly and indirectly, respectively, compared to focal murrelets in the Upper Bay (95% c.i. = 32 - 74%, $p < 0.001$; 5 - 70%, $p = 0.019$; Table 2.4).

Season, murrelet group size, and number of ships in the Bay per day were significant in explaining some variation in response type, but the effects were not consistent between the two approach angles or the two response types. Advancing season was associated with a decline in the diving response by murrelets when approached directly by a cruise ship, but was associated with an increase in the flushing response by murrelets when approached indirectly. With each additional day after June 1, focal murrelets that were approached directly by cruise ships exhibited a 0.5% decline the hazard of diving (95% c.i. = 0.2 - 0.8%, $p = 0.002$; Table 2.4), while as the season advanced focal murrelets that were approached indirectly by cruise ships exhibited a

1.1% increase in the hazard of flushing (95% c.i. = 0.4 - 1.4%, $p < 0.001$; Table 2.4). Murrelets encountered in groups exhibited a 38% reduction in the hazard of diving when approached directly (95% c.i. = 30 - 45%, $p < 0.001$; Table 4), but group size was not a significant predictor of murrelet response either when cruise ships approached indirectly or for flushing responses. Similarly, when two cruise ships entered Glacier Bay during a day, there was a 15% decline in the hazard of a diving response when the ship approached directly (95% c.i. = 2 - 25%, $p = 0.023$; Table 4), but this effect was not detectable for indirect ship approaches or for flushing responses. No other management-relevant explanatory variables investigated within this study were significant in explaining the observed variation in flushing or diving responses to direct or indirect approaches by cruise ships.

DISCUSSION

Our results clearly demonstrate that disturbance to murrelets by cruise ships in Glacier Bay is common. Our data demonstrate that as cruise ships travel through the Bay, on average 68% of all murrelets encountered between 0 and 850 m perpendicular distance are predicted to respond by flushing or diving. Point estimates suggest that murrelets at 850 m perpendicular distance from the ship's course are still predicted to respond to cruise ships roughly 10% of the time.

As part of our study design, we limited the area of data collection around the ship to no more than 1 km, because this was the upper end of the range of our ability to detect murrelets on the surface of the water. Furthermore, we assumed that this distance would encompass the area in which passing cruise ships would disturb murrelets sufficiently to elicit a flushing or diving response. However, extrapolating our results beyond our detection distance suggests that the probability of disturbance did not reach 0% until at least 1200 m perpendicular distance from the ship's course. This estimate likely represents a minimum because murrelets may have flushed or dived in response to cruise ships after they passed abeam (Bulova 1994, Fernández-Juricic et al. 2005, Chapter 3), as we only followed murrelets until they were 90 degrees from the ship's bow, yet the cruise ships averaged over 260 m in length.

The vast majority of the variation in behavioral response by murrelets to cruise ships was attributable to the absolute distance of the murrelet from the ship. The strong avoidance by murrelets of approaching cruise ships, both directly and indirectly, may be responsible for the paucity of other significant explanatory variables among the environment, biological, and management-related variables explored by this study. The exception was location of the ship in the Bay, which was a significant factor explaining variation in both the binary logistic model predicting response or no-response by encountered murrelets, and the multistate model predicting the probability of response type (i.e., flushing vs. diving) for both direct and indirect approaches. Murrelets in the Upper Bay were almost twice as likely to dive, rather than flush, in advance of an approaching cruise ship. Murrelets in the Lower Bay reacted almost twice as often by flushing rather than by diving when a cruise ship approached. Considering both response types combined (flushing and diving), murrelets in the Lower Bay on average responded at greater distances from the ship than murrelets in the Upper Bay, for both direct and indirect approaches. We offer three plausible explanations for this difference.

First, there may simply be species-specific differences in murrelets responding to approaching ships. Due in part to concentration of prey resources (Arimitsu et al. 2007), areas near tidewater glaciers and underwater sills tend to be “hotspots” for foraging and loafing Kittlitz’s murrelets (Allyn et al. 2012). In general, the upper reaches of the Bay are more heavily influenced by tidewater glaciers and glacial runoff, while the lower reaches of the Bay are influenced more by marine processes (Etherington et al. 2007). Owing in part to this environmental gradient within Glacier Bay, Kittlitz’s murrelets tend to predominate in the upper reaches of the Bay, while marbled murrelets make up the majority of murrelets in the lower reaches of the Bay (Hoekman et al. 2014). Strong differences in both response type and response distance may, in part, be explained by the observed differences in murrelet species composition in the two sections of the Bay. Other studies have also noted differing responses to vessel disturbance between closely-related species when faced with similar disturbance regimes (Rogers and Smith 1997, Rogers and Schwikert 2002, Schummer and Eddleman 2003, Chatwin et al. 2013).

Secondly, the significance of location in the Bay as an explanatory variable for murrelet response to cruise ships may be due in part to the absolute number of murrelets in the lower reaches of the Bay. The Lower Bay can have extraordinarily high densities of murrelets (Hoekman et al. 2014), increasing the likelihood that a flushing murrelet influences the response of other murrelets, consistent with the “many eyes hypothesis”

(Lima 1990; Owens 1977, Creswell et al. 2000). The many eyes hypothesis states that as group size increases there are more eyes scanning the environment for predators, allowing individual vigilance to decrease without an increase in predation risk. For the purposes of our study, we defined a group of murrelets as two or more birds within 2 m or murrelets behaving in concert. Although group size, as defined by us, was not a consistent predictor of flushing distance, marbled murrelet density and population estimates in the Bay are consistently higher than those of Kittlitz's murrelets (Romano et al. 2007, Hoekman et al 2014). The higher density of murrelets in a given area may explain the increased rate and distance of murrelets flushing in the Lower Bay, as murrelets may be reacting to other disturbed murrelets nearby. When observing murrelet behavior in the Lower Bay from shore, an increase in the number of flying birds, even at distances as great as 3 km in front of the ship, was noted prior to a cruise ship passing (TKM, pers. obs.). If murrelets are reacting to a cue of predation risk, an increase in the number of birds taking flight could trigger others in the area to flush, even if they have yet to detect the threat (Lima 1994, Sirot 2006, Fernández-Juricic and Kowalski 2011).

Lastly, birds exhibiting a greater threshold distance for avoidance flight are often assumed to be more sensitive to the disturbance stimulus, and therefore more susceptible to the impact of disturbance. With this in mind, flight response distance is often used when setting wildlife buffer zones in an effort to reduce the impact of disturbance (Ronconi and St. Clair 2002, Blumstein et al. 2003, Fernández-Juricic et al. 2005, Burger et al. 2010). However, in a review by Stankowich and Blumstein (2005), the authors make the case that dependence on a particular area for forage, shelter, or reproduction may be associated with a reduction in the distance where flushing occurs. It has also been noted that animals defending territories, young, or mates can exhibit a decreased distance where flight is initiated (Rodgers and Smith 1997). In addition, when food for ruddy turnstones (*Arenaria interpres*) was artificially supplemented, their flight initiation distance increased, presumably due to either increased body condition or the perception of high-quality habitat nearby (Beale and Monaghan 2004).

Kittlitz's murrelets are known to migrate to Glacier Bay for the summer months, where some portion of the population nests in adjacent alpine habitat (Fox and Hall 1982; Day 1996; Marcella et al., unpubl. data). The breeding status of a portion of Kittlitz's murrelets encountered in the upper reaches of Glacier Bay, and the proximity of these murrelets to their nesting habitat, may partly explain their shorter average flushing distance. Thus, the higher apparent tolerance to cruise ships of murrelets in the Upper Bay may not be entirely attributable to higher innate tolerance of vessel disturbance by Kittlitz's murrelets. In contrast, the large numbers of marbled murrelets found in the lower reaches of Glacier Bay during summer are thought to be nesting in other areas of Southeast Alaska, and commuting considerable distances to feed in Glacier Bay (Whitworth et al. 2000). The transient status of marbled murrelets using Glacier Bay may result in lower site fidelity to particular foraging areas within the Bay, a greater area of core use (Irons 1998), and potentially a greater average distance for flight in response to cruise ships.

While our study quantified the incidence and magnitude of response by murrelets within 1 km of a cruise ship, we were unable to fully define cruise ships zone of influence on murrelet behavior. Furthermore, the overall impact of the disturbance we were able to measure will further require coupling these estimates with the physiological or fitness-related costs of disturbance. The unmeasured physiological stress caused by cruise ship disturbance could potentially lead to declines in reproductive success and survival rates (Ellenberg et al. 2013). Although this study cannot establish direct links between cruise ship disturbance and the demography or distribution of murrelets summering within Glacier Bay, the measured behavioral changes elicited by cruise ships in the Park are not trivial, and certainly exceeded our expectations when initiating the study. The relationship between approach distance by a cruise ship and the disturbance response by murrelets was so strong that no other biological or management-relevant covariates measured in our study had a statistically significant effect on the disturbance response.

We thus advocate for combining these results with survey data on the distribution and abundance of murrelets within Glacier Bay to estimate the numbers and species composition of murrelets disturbed by cruise ships on a daily basis. We acknowledge that the managers of this marine protected area (the NPS) must weigh all other considerations when deciding among alternative management strategies for cruise ship traffic in Glacier Bay National Park. Nevertheless, we recommend that the increase in murrelet disturbance rates associated with any increase in cruise ship quotas in Glacier Bay during the summer breeding season be given careful consideration.

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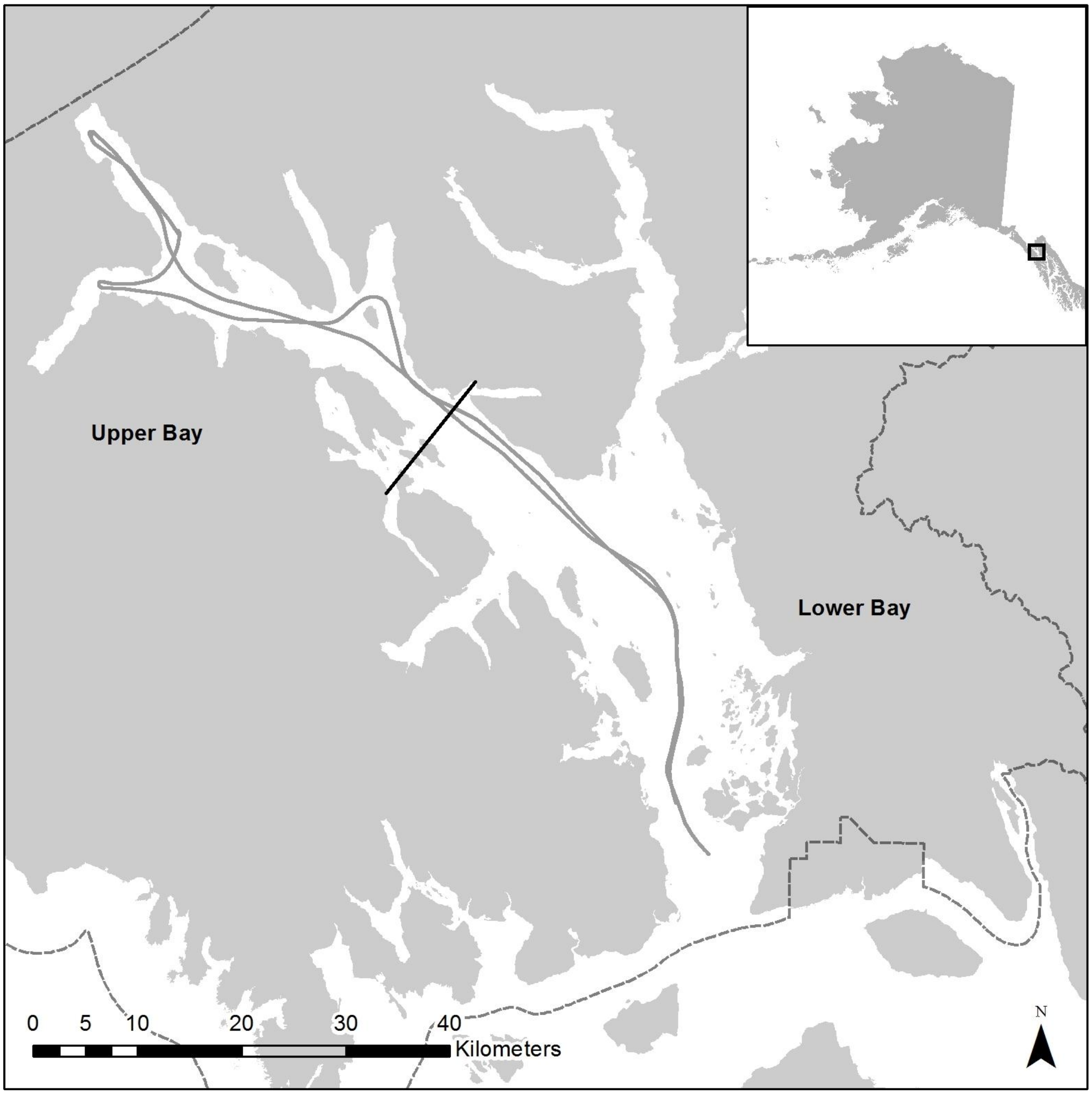

Figure 2.1. Map of Glacier Bay in Glacier Bay National Park, Alaska. Gray dashed line indicates the Park boundary. Solid gray line indicates a typical cruise ship route within the Bay. The black bar indicates the dividing line between the Upper Bay and the Lower Bay sectors of the study area.

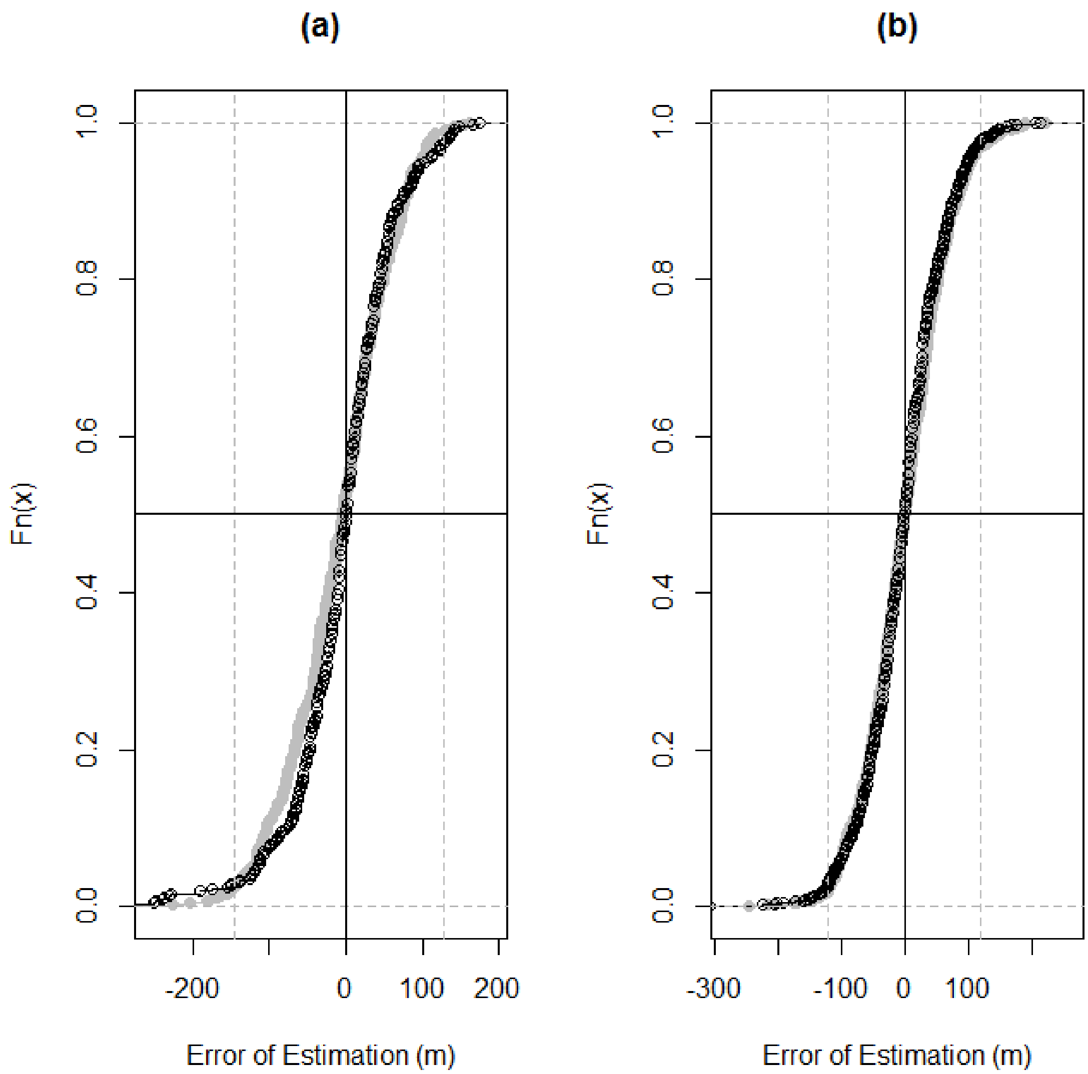

Figure 2.2. Plot of the empirical cumulative distribution (ecd) of the estimation errors for murrelet distance from ship from two different observers in two different years (black circles; 2011 = a; 2012 = b) while collecting behavioral observation data on murrelets from the bow of cruise ships in Glacier Bay National Park, Alaska. Gray dashed vertical lines indicate the 0.025 and 0.975 quantiles (2011 = -144.6 m, 128.6 m; 2012 = -121 m, 120 m). Gray plotted dots indicate a normal distribution (ecd) based on the mean, standard deviation, and sample size of the error estimates for each observer.

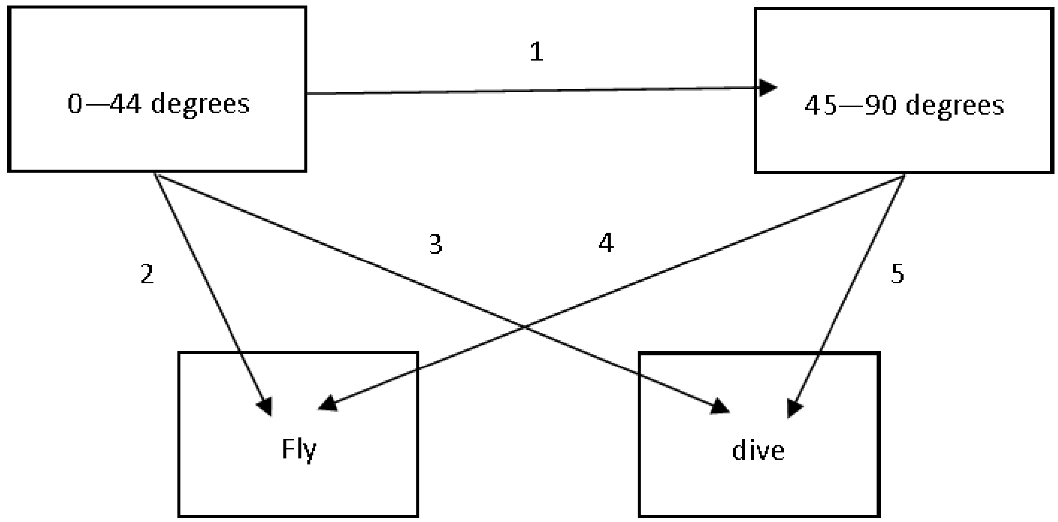

Figure 2.3. Multistate model depicting two transient states (0° - 44° and 45° - 90° from ship's course) and the two absorbing states (behavioral responses of flush or dive) for murrelets encountered by cruise ships in Glacier Bay, Alaska. Numbers indicate the five possible transitions that were modeled.

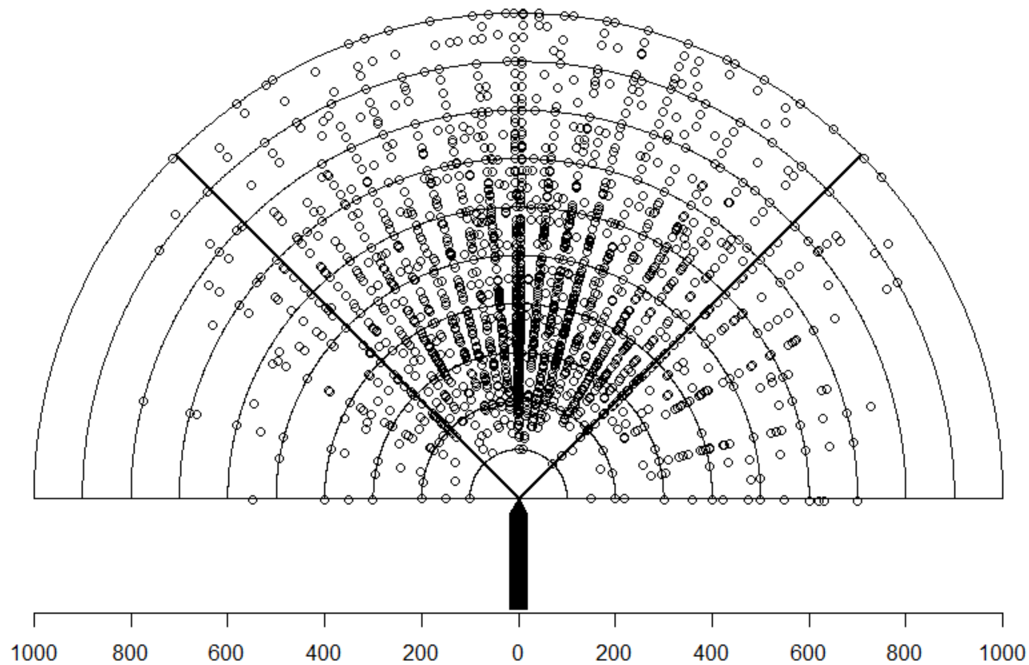

Figure 2.4. Initial locations of focal murrelets observed from the bow of cruise ships as they traveled through Glacier Bay National Park in 2011 and 2012. The silhouette of the ship is sized to scale and represents the average length of cruise ships that visit Glacier Bay. Wedges to port and starboard of the ship's course indicate the 45° - 90° bearing bins, while the wedge centered on the ship's course indicates the 0° - 44° bearing bin.

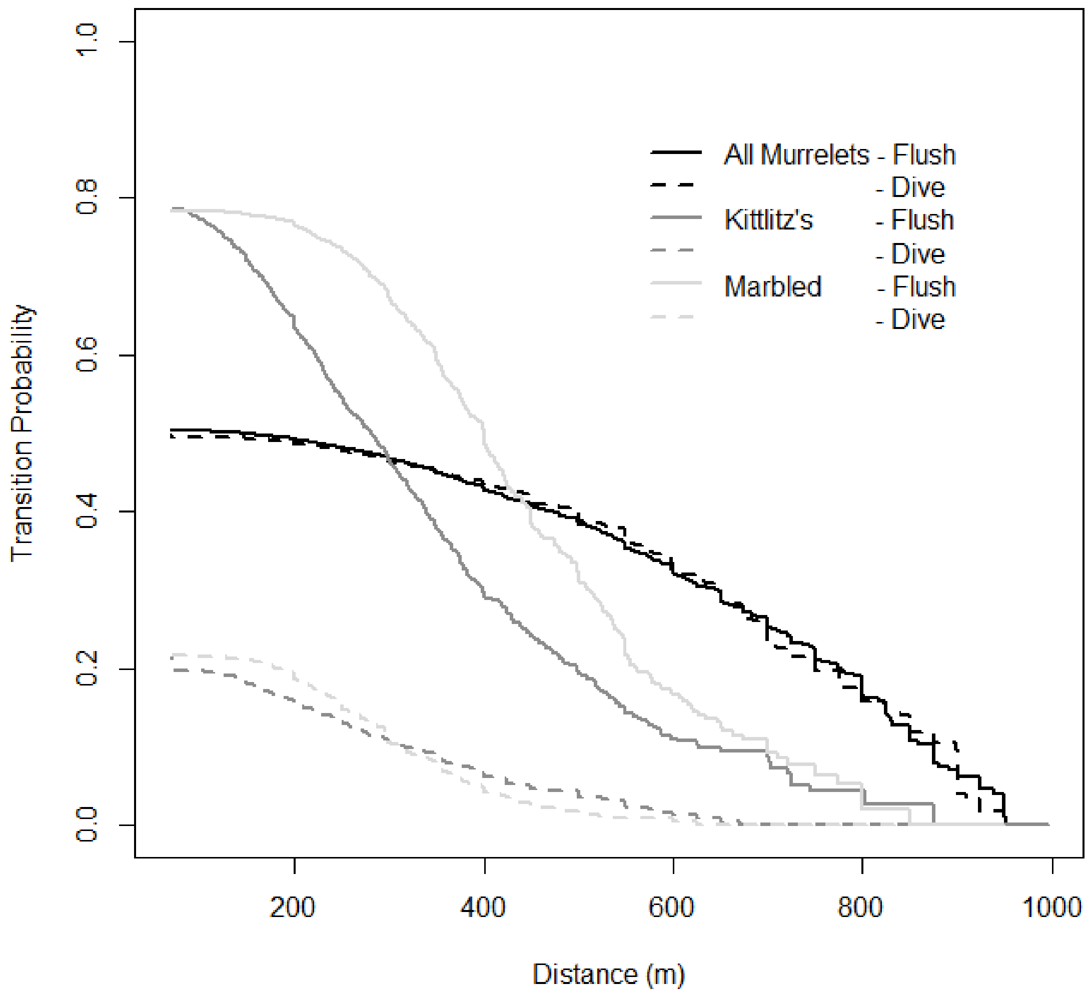

Figure 2.5. Cause-specific cumulative incidence curves indicating the transition probability from loafing to flying or diving for murrelets (all murrelets, Kittlitz's murrelets, and marbled murrelets) as a function of approach distance by cruise ships in Glacier Bay National Park, Alaska during 2011 and 2012.

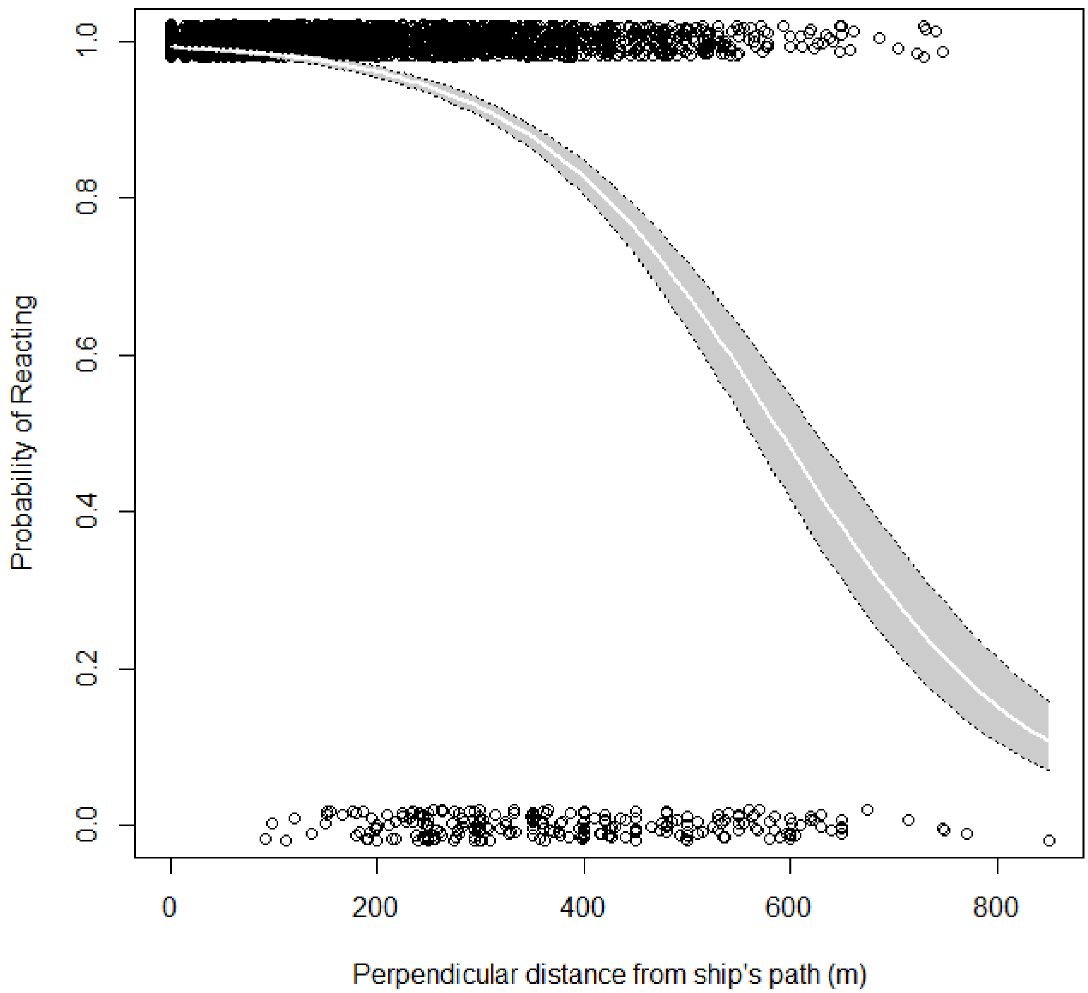

Figure 2.6. Fitted binary logistic curve representing the observed probability of response (flushing and diving combined) by murrelets encountered on the water as a function of the murrelet's perpendicular distance from the cruise ship's course (either to port or starboard). Shaded region represents the 95% confidence interval. Points were jittered so as to better observe the distribution of responses vs. no responses. Data were collected from onboard cruise ships in Glacier Bay National Park, Alaska, during 2011 and 2012.

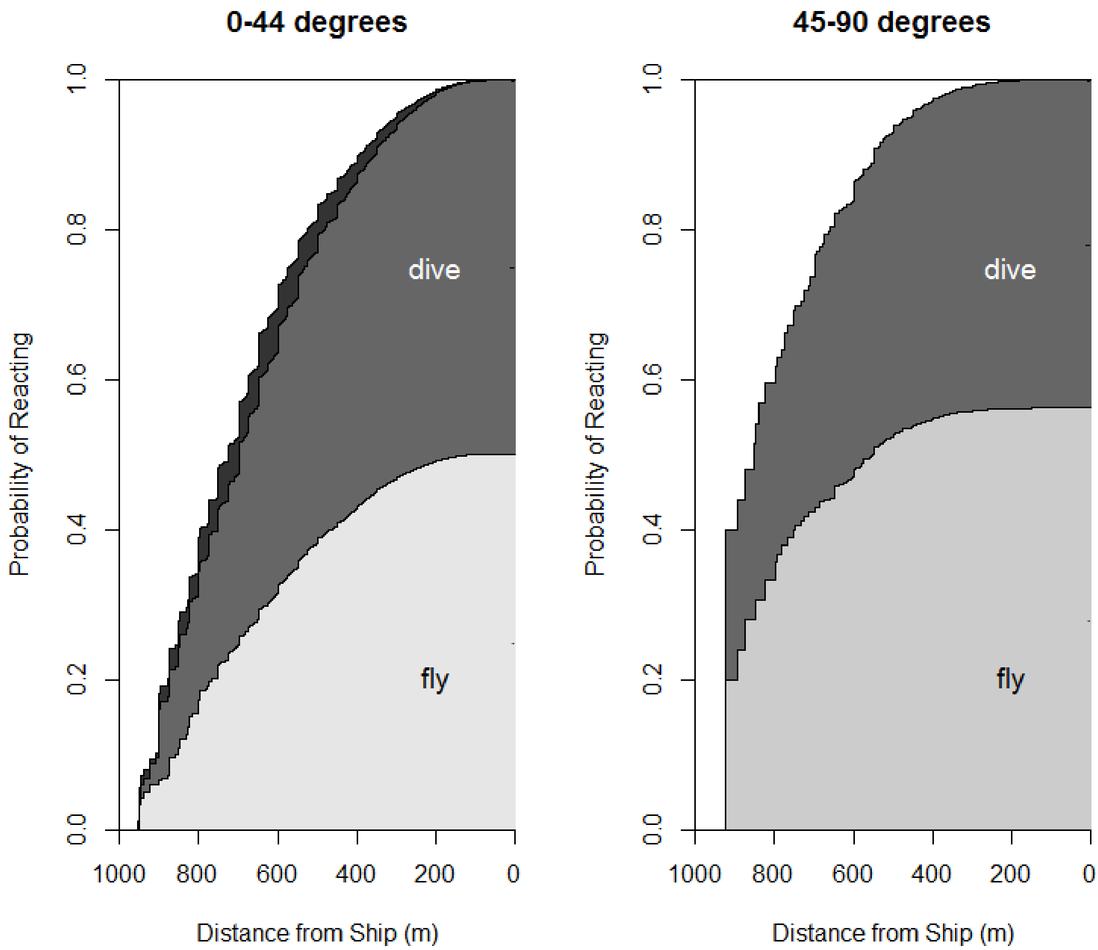

Figure 2.7. Behavioral transition to flight or diving for murrelets observed from cruise ships at two ship approach angles: 0° - 44° and 45° - 90° from the ship's course. Note reversed x-axis. Light gray indicates transitions to flight, darker gray indicates transitions to diving, and darkest gray indicates transitions from one bearing bin to the other. Data were collected from cruise ships in Glacier Bay National Park, Alaska, during 2011 and 2012.

Table 2.1. Explanatory variables considered when modeling the response of murrelets to cruise ships in Glacier Bay. Sample sizes included in parentheses.

Variable (sample size)	Classification
Year	
2011 (n = 2,365)	Year observation was collected
2012 (n = 1,886)	
Location in Park	
Upper Bay (n = 2,040)	North of Tidal Inlet to head of the Bay
Lower Bay (n = 2,211)	South of Tidal Inlet to Ripple Cove in lower Bay
Group Size	
Single (n = 1,181)	Solitary murrelet
Group (n = 3070)	≥ 2 murrelets within 2 meters or acting in concert
Ship Entries Per Day	
One (n = 1,517)	Only one cruise ship in the Bay during the day
Two (n = 2,734)	Two cruise ships in the Bay during the day
Sea State	
Light (n = 3,701)	0 or 1 on the Beaufort Sea State Scale
Moderate (n = 550)	2 or greater on the Beaufort Sea State Scale
Ship Speed	
continuous	Nautical miles per hour (knots)
Distance to Shore	
continuous	Kilometers from nearest shoreline
Stage of Season	
continuous	Days since June 1

Table 2.2. Behavioral response to approaching cruise ships for murrelets identified to species, murrelets unidentified to species, and all *Brachyramphus* murrelets in Glacier Bay National Park, Alaska, during 2011 and 2012. Murrelet species identification rates were negatively affected by both response distance and a dive response compared to a flight response.

Species	Fly	Dive	Pass Abeam	Censored	**Total**
Kittlitz's	782 (65.7%)	216 (18.1%)	78 (6.5%)	115 (9.7%)	**1191**
Marbled	742 (60.6%)	424 (34.6%)	18 (1.5%)	41 (3.3%)	**1225**
Unidentified	472 (25.7%)	1,126 (61.4%)	147 (8.0%)	90 (4.9%)	**1835**
Total	**1996 (47.0%)**	**1766 (41.5%)**	**243 (5.7%)**	**246 (5.8%)**	**4251**

Table 2.3. Results from a binary logit model of the probability of a murrelet exhibiting a response (flushing or diving combined) to a cruise ship as it approached in Glacier Bay National Park, Alaska. Data were collected from cruise ships in the Bay during 2011 and 2012.

Variable	β	Odds Ratio	95% c.i.	p - value
Intercept	4.212	67.461	43.623 - 106.659	< 0.001
Perpendicular distance from path (100 meters)	-0.871	0.419	0.382 – 0.457	< 0.001
Days since June 1	0.008	1.008	1.0004 - 1.016	0.037
Location				
Upper Bay (Ref)	1	---	---	---
Lower Bay	0.878	2.407	1.780 – 3.272	< 0.001
AUC statistic = 0.885				

Table 2.4. Hazard ratios explaining the variation in murrelet response type (flush or dive) and distance (m) in a multistate model for transitions from either the 0° - 44° or 45° - 90° approach angles and the two response types (flight, dive). P-values < 0.05 are shown in bold. Data were collected from onboard cruise ships in Glacier Bay National Park, Alaska, during 2011 and 2012.

Variable	Description	**0° - 44° to flight**		**45° - 90° to flight**	
		Hazard (95% c.i.)	p	Hazard (95% c.i.)	p
Group	1	1	---	1	---
	≥ 2	1.00 (0.88 – 1.13)	0.970	1.05 (0.85- 1.29)	0.652
Ship Entry	first	1	---	1	---
	second	0.98 (0.87 - 1.11)	0.736	0.93 (0.75 - 1.14)	0.481
Sea State	light	1	---	1	---
	moderate	0.96 (0.82 - 1.12)	0.607	1.07 (0.84- 1.41)	0.527
Ship Speed	knots	1.01 (0.99 – 1.03)	0.211	0.99 (0.96 – 1.02)	0.409
Distance to Shore	km	1.04 (0.95 – 1.13)	0.440	1.15 (0.98 – 1.34)	0.089
Stage of Season	days	1.00 (0.99 – 1.01)	0.404	1.01 (1.00 – 1.02)	**<0.001**
Location	Upper Bay	1	---	1	---
	Lower Bay	1.51 (1.31 – 1.74)	**<0.001**	1.34 (1.05 – 1.70)	**0.019**
		0° - 44° to dive		**45° - 90° to dive**	
		Hazard (95% c.i.)	p	Hazard (95% c.i.)	p
Group	1	1	---	1	---
	2	0.62 (0.55 – 0.70)	**<0.001**	0.91 (0.73 - 1.13)	0.385
Ship Entry	first	1	---	1	---
	second	0.85 (0.75 – 0.98)	**0.023**	0.99 (0.78 - 1.24)	0.908
Sea State	light	1	---	1	---
	moderate	1.06 (0.90 - 1.24)	0.487	1.09 (0.81 - 1.46)	0.568
Ship Speed	knots	1.01 (0.99 – 1.02)	0.543	0.98 (0.95 – 1.01)	0.272
Distance to Shore	km	0.92 (0.84 – 1.01)	0.086	0.91 (0.77 – 1.08)	0.301
Stage of Season	days	0.99 (0.99 – 0.99)	**0.002**	1.00 (0.99 – 1.01)	0.298
Location	Upper Bay	1	---	1	---
	Lower Bay	1.91 (1.65 – 2.21)	**<0.001**	1.93 (1.49 – 2.52)	**<0.001**

CHAPTER 3

LONG-DISTANCE RESPONSE OF KITTLITZ'S MURRELETS (*BRACHYRAMPHUS BREVIROSTRIS*) TO CRUISE SHIPS IN GLACIER BAY NATIONAL PARK, ALASKA

Timothy K. Marcella, Scott M. Gende, and Daniel D. Roby

ABSTRACT

During the summer months, Glacier Bay National Park in Southeast Alaska supports an estimated 37% of the global population of Kittlitz's murrelets (*Brachyramphus brevirostris*), a seabird species of conservation concern. We studied Kittlitz's murrelet behavior in the Upper West Arm of Glacier Bay, where cruise ship routes overlap with high densities of Kittlitz's murrelets. By investigating the threshold distance at which Kittlitz's murrelets respond to cruise ship presence, as well as the magnitude of the observed disturbance response, we can begin to understand the mechanisms that are responsible for observed disturbance rates. Using data collected from shore-based sites to parameterize a segmented regression model within a logistic regression framework, Kittlitz's murrelets were found to exhibit signs of disturbance (defined as flushing from the water) from cruise ships at distances of at least 1.6 km, and perhaps as great as 6.0 km, with a best estimate of threshold disturbance distance at 3.8 km. When cruise ships were > 3.8 km from focal murrelets the baseline probability of murrelets flushing during a focal observation period was 12.5%. When cruise ships were < 3.8 km from focal murrelets the probability of flushing increased logistically with decreasing distance to an estimated maximum of 48%. The unexpectedly long distance at which murrelet behavior was affected by cruise ships is most likely attributable to social facilitation by other disturbed murrelets; nearly equal numbers of focal murrelets flushed when ships were approaching (n = 30) compared to receding (n = 27). The strong association between the proximity of cruise ships and probability of flushing at distances in excess of 1 km demonstrates that Kittlitz's murrelets in Glacier Bay are susceptible to

disturbance from cruise ships at distances greater than have been previously published for any seabird.

INTRODUCTION

The concept of human disturbance as a form of predation risk has figured prominently in conservation biology in recent decades (reviewed by Frid and Dill 2002). Human intrusion into wildlife habitat, even for non-consumptive purposes, can negatively affect breeding (Bouton et al. 2005), foraging (Stolen 2003, Burger et al. 2004), and resting activities (Pease et al. 2005, Steckenreuter et al. 2011), which in turn may ultimately affect population dynamics (Ruhlen et al. 2003). As the rate of human disturbance has increased, the potential to negatively affect wildlife populations (Ciuti et al. 2012) has been acknowledged as a limiting factor in the recovery of some threatened or endangered seabirds (USFWS 1983, Croxall et al. 2012).

Of particular concern for conservation of coastal marine birds is disturbance from ship traffic (Schwemmer et al. 2011). In response to increased vessel traffic, marine birds have been shown to increase flushing rates (Ronconi and St. Clair 2002, Agness et al. 2008, Bellefluer et al. 2009, Burger et al. 2010), alter foraging patterns (Galicia and Baldassarre 1997, Velando and Munilla 2011), and exhibit lower reproductive success (Mikola et al. 1994, Bouton et al. 2005). The Kittlitz's murrelet (*Brachyramphus brevirostris*), a seabird species endemic to Alaska and the Russian Far East, is one such species of conservation concern (National Audubon Society 2006, BirdLife International 2014) for which cruise ship disturbance has previously been proposed as a potential threat to recovery (Federal Register 2007).

Concern over apparent major population declines resulted in the Kittlitz's murrelet being placed on the candidate species list in 2004 for potential listing as a threatened or endangered species under the U.S. Endangered Species Act (Federal Register 2004). Recently the Kittlitz's murrelet was deemed not warranted for listing by the United States Fish and Wildlife Service (USFWS) based on the limited availability of unequivocal scientific evidence for (1) a continued population decline (Kirchhoff et al. 2014) and (2) the factors responsible for such a decline (Federal Register 2013). Nevertheless, continued conservation concern for the species has resulted in a number of recent research projects on the ecology of Kittlitz's murrelets. Glacier Bay National Park and Preserve (hereafter Glacier Bay) was of specific interest to researchers and managers because an estimated 37% of the world's population of Kittlitz's murrelets occurs in Glacier Bay during the spring and summer breeding season (Federal Register 2013). Consequently, the U.S. National Park Service (NPS) is steward to a significant fraction of the global population of the species. Previous studies of ship disturbance to murrelets in Glacier Bay, although focused on all ship traffic in the Bay, highlighted cruise ships and other large vessels as having the greatest impact on the behavior of Kittlitz's murrelets, eliciting a 30-fold increase in the proportion of murrelets flying when ships were present (Agness et al. 2008), and associated increases in energetic demands during periods of heavy vessel traffic (Agness et al. 2013).

Cruise ship visitation to Glacier Bay accounts for 95% of visitors to the Park, and is highly regulated. The NPS imposes restrictions on the number of ships entering the Bay (both daily and seasonally), travel routes, and speeds (USDOI 2003). These restrictions were put in place to ensure that the Park Service meets its mandate for protecting natural resources while promoting visitor use and enjoyment of the Park. Furthermore, the seasonal quota of allowable cruise ship entries is reviewed and considered annually by Park managers.

Understanding how organisms respond to increasing disturbance is important in identifying both baseline activity rates and ecological thresholds. With this in mind, we focused our efforts on specifically isolating the effects of cruise ship presence on Kittlitz's murrelet behavior in Glacier Bay. Specifically, we aimed to quantify the disturbance rate, defined as flushing (flying) from the water, of Kittlitz's murrelets caused by cruise ships traveling within the upper reaches of Glacier Bay, where a large proportion of the Kittlitz's murrelets in the Park can be found (Hoekman et al 2014). In a related effort, we quantified disturbance rates of murrelets by observing them from the bow of cruise ships as they traveled through Glacier Bay (Chapter 2). Our study design in Chapter 2 limited our scope of inference regarding disturbance rates to distances ≤ 1 km from a cruise ship, due in part to detection limits and in part from *a priori* assumptions that this distance would encompass those murrelets that would respond to approaching ships. While our findings demonstrated that cruise ship disturbance rates were unexpectedly high (about 61% probability of a flushing or diving response within 850 m perpendicular distance of the ship's course), we were also able to observe murrelets flushing at the outer ranges of our detection limits (> 1 km), suggesting that the distances at which murrelets were disturbed by cruise ships also exceeded our expectations.

Building on these findings, we investigated the threshold distance at which cruise ships affect Kittlitz's murrelet behavior using land-based observations of focal individuals. Rather than use an *a priori* maximum distance at which we hypothesized murrelets would react to cruise ship presence, we investigated whether the baseline rate of murrelets flushing increases as a function of decreasing distance to the nearest cruise ship. Cruise ship operating characteristics enhanced this study, as cruise ships followed the same route and generally traveled at the same speed each day. Additionally, they had onboard tracking devices (AIC and GPS) that allowed us to identify their precise location even when out of our visual range, thus providing an opportunity to make inferences about murrelet responses across a large range of distances to cruise ships.

In addition to the quantifying the probability of flushing, we also measured the magnitude of behavioral responses by Kittlitz's murrelets to cruise ships by comparing the duration of flights that occurred in the presence of cruise ships with those that occurred in the absence of cruise ships (as a result of natural or other anthropogenic stimuli; e.g., other vessel traffic in Glacier Bay). By investigating the threshold distance at which murrelets responded to cruise ships, as well as the magnitude of the observed disturbance response, we sought to understand the potential mechanisms that lead to observed disturbance rates.

METHODS

Study Area

Glacier Bay National Park and Preserve is located in Southeast Alaska, about 100 km northwest of Juneau, and is part of the 24.3 million-acre Kluane/Wrangell-St. Elias/Glacier Bay/Tatshenshini-Alsek World Heritage Site. The Park encompasses coastal and marine habitat adjacent to the Gulf of Alaska, glacier-capped mountain ranges, and a deep-water, Y-shaped fjord carved by past glacial advances and retreats. Owing to its relatively protected waters, pristine marine habitat, and abundant wildlife, the majority of the visitation to the Park occurs within the Y-shaped fjord for which the Park was named.

Kittlitz's murrelets can be found distributed patchily throughout Glacier Bay, with some of the densest aggregations occurring in the Upper West Arm of the Bay (Hoekman et al. 2014), an area characterized by high levels of primary productivity driven by glacial runoff and strong upwelling (Arimitsu et al. 2007). Based on the high density of Kittlitz's murrelets, the proximity to cruise ship travel routes, and access to suitable shore-based observation areas, four sites were chosen in the Upper West Arm of the Bay from which to collect behavioral data on Kittlitz's murrelets (Figure 3.1).

Experimental Design

Focal observations were made of Kittlitz's murrelets from each of four land-based observation sites during June through mid-August 2012. Observations were collected between 07:00 and 18:00 ADT, ensuring a range of samples when ships were at varying distances from focal murrelets. Each day when observations were scheduled to occur one of the four observation sites was chosen based on cruise ship schedule, weather, ice floe density, murrelet density, and previous number of site visits, with the aim of nearly equal coverage at each observation site. A six-meter skiff was used to access sites and approached at low speeds parallel to the shore in an effort to avoid disturbing murrelets. Once observers landed on shore, focal observations were delayed for 15 minutes in an effort to let murrelets resume normal activity before initiating focal observations.

Focal observations were recorded for individual Kittlitz's murrelets on the water surface within a 90° arc centered perpendicular to the normal cruise ship travel route and extending offshore approximately 1 km (Figure 3.1). Focal observations were only initiated on Kittlitz's murrelets that were on the surface of the water, on the assumption that these murrelets were undisturbed. One murrelet was chosen as either a single murrelet or one murrelet from a group; murrelet groups were defined as two or more birds within 2 m or acting in concert. Each focal murrelet was observed for 10 minutes or until lost from sight. Focal murrelets that were engaged in foraging bouts (diving) were followed throughout the bout, when possible. Distance and bearing to each focal murrelet were estimated and later converted into an approximate location (latitude, longitude) using planar geometry. Because individual murrelets were not marked, and they could not be readily distinguished from one another, there is a chance that more than one focal observation could have been recorded for an individual murrelet. In an attempt to reduce repeated observations on the same individual, however, observers scanned the sampling area systematically in one direction, conducting focal observations on each murrelet present until all murrelets in the area had been observed. Focal observations would then not be collected until an hour had elapsed since the initial focal observation began, under the assumption that if two focal observations were made on the same individual murrelet, these observations would be independent in time if at least an hour had elapsed.

Observers used a spotting scope (Swarovski STS and ATS 80, 20-60x magnification, Absam, Austria) and/or binoculars (Swarovski EL 10x42 W B, Absam, Austria) to follow focal murrelets, and changes in behavior were dictated to a technician who entered the data onto data sheets. Three easily distinguishable behavioral states were defined for murrelets: (1) on the surface of the water, (2) diving under the surface of the water, and (3) flying. These three behavioral states were selected because there was little doubt when transitions occurred between them, even at distances up to 1 km from the observer. In addition to transitions between these three states, other variables were recorded for each focal observation, including number of murrelets in the group, time of day, time of season, and Beaufort sea state. In an effort to increase the sample size of focal observations when cruise ships were in the area, the observer who was serving as the data recorder also followed murrelets at times when ships were scheduled to pass. When this occurred the observers communicated with each other to ensure they were not following the same murrelet and transitions were dictated into digital voice recorders and later transcribed onto data sheets.

Shore-based observations occurred while 52 cruise ships traveled through Glacier Bay. For 27 of these cruise ships the ship’s location was recorded every 5 seconds using a small handheld GPS (Garmin GPSMAP 76Cx, Olathe, KS, USA) placed onboard the ship at the bow as part of a related study on murrelet disturbance (Chapter 2) and another study focusing on whale surveys (Harris et al. 2012). Tracks of the other 25 cruise ships passing our study sites during murrelet observations were obtained by downloading Automatic Identification System (AIS) tracks from the Alaska Marine Exchange Vessel Tracking website (www.mxak.org) at a resolution of one waypoint every 60 sec. AIS technology uses conventional VHF radio frequencies to transmit real time GPS data and other meta-data specific to each ship to other AIS equipped ships as well as to the Alaska Marine Exchange.

Due to poor VHF radio coverage in the Upper West Arm of Glacier Bay, there were gaps in the AIS coverage. These gaps were filled in by interpolation to estimate a ship's track based on time stamps of recorded points and previously recorded tracks using ArcMap 10. If the AIS track resolution was not accurate enough to interpolate between points on the track, or one of the two tracks for a specific day could not be interpolated, all observations from that day were discarded. Using the GPS and AIS ship tracks, an estimated distance between the focal murrelet and the nearest cruise ship was appended to each focal observation.

Smaller tour vessels, private pleasure craft, and kayaks were all present at some time within the study area when Kittlitz's murrelet behavior was being recorded. This temporal overlap made it difficult to objectively attribute particular flushing events to cruise ships or other vessels in the area at the same time. Further, these potential sources of disturbance may be affecting the behavior of murrelets to different degrees due to a variety of other factors, including vessel speed (Ronconi and St. Clair 2002), vessel size

(Agness et al. 2008), vessel approach angle (Chapter 2), and vessel type (Burger 1998). By including all flushing events in our analyses we were able to investigate whether distance to the nearest cruise ship explained a significant proportion of the variability in the incidence of flushing, even in the presence of other potential disturbances. As such, the baseline flushing rate from which we made inferences represents the rate from a combination of 'natural' flushing events and potential 'other disturbance' events (i.e., flushing due to small tour boats, private vessels, kayaks, etc.).

Statistical Analysis

Probability of Flushing

Flushing from the surface of the water during a focal observation was recorded as the response variable (1 = flight, 0 = no flight). Using binomial logistic regression, the probability of flushing was explored in relation to the following independent variables: distance to the nearest cruise ship (km), hour of the day, murrelet group size, Julian date, observation site, and Beaufort sea state. Distance to the nearest cruise ship, hour of the day, and Julian date entered into the analysis as continuous variables, while the remaining variables were converted into factors (Table 3.1). The best fit model was selected using forwards and backwards stepwise AIC model selection criteria within the 'MASS' package in R (Venables and Ripley 2002).

We further explored the relationship between cruise ship distance and probability of flushing using segmented regression (Muggeo 2003). Segmented regression allowed us to test whether the probability of flushing was better modeled with two or more separate slopes along the continuum of distance to the nearest cruise ship. We used the R package ‘segmented’ (Muggeo 2008) and a Davies’ test to ascertain whether two or more slopes were warranted when describing the probability of flushing (Muggeo 2008). The breakpoint in the data where the probability of flushing changed abruptly can be interpreted as the threshold distance at which murrelets reacted to stimuli associated with cruise ship presence (Muggeo 2003, Toms and Lesperance 2003). The le Cessie - van Houwelingen - Copas - Hosmer un-weighted sum of squares test was used to test for global goodness of fit (le Cessie and van Houwelingen 1991) using the package ‘MKmisc’ in R (Kohl 2013). The predictive power of the model was explored by plotting the Receiver Operator Characteristic (ROC) curve and calculating the associated area under the curve (AUC; Bradley 1997) using the package ‘ROCR’ in program R (Sing et al. 2005). For ease of interpretation, interaction terms were not explored within this analysis.

Duration of Flight

Total flight times of focal murrelets that flushed from the water were analyzed within a Cox proportional hazards regression framework (Cox 1972) using the ‘survival’ package in program R (Terneau 2014). Cox proportional hazards regression analyzes time-to-event data and can incorporate censored or incomplete observations into the estimate, assuming the reason for censoring was non-informative (i.e., was not dependent upon covariates; Kaplan and Meier 1958). This analysis is appropriate for our data structure because a fraction of the murrelets we visually followed after they took flight were lost from sight prior to the bird re-landing on the water. We tested the assumption that censored observations were uninformative using logistic regression. Flight observation time was the dependent variable and censored observations were scored as 1; uncensored, or complete flight times, were scored as 0. Covariates were modeled to test if there was an effect of one or more variables on the probability of censoring or completing an observation. Occasionally, two separate flushing events were observed during one focal observation. In order to ensure independence, only the flight time following the first flush was used for this analysis.

Covariates hypothesized to affect total flight time were considered in forward and backward stepwise AIC model selection using the 'MASS' package in program R (Venables and Ripley 2002; Table 3.2). Distance to the nearest cruise ship was included in all models to test the hypothesis that cruise ship distance affects flight time. The assumption of proportional hazards was checked by investigating the Schoenfeld residuals. Model performance was assessed by calculating how well the model predicted the ranking of the observed flight times versus the predicted flight times, also referred to as the concordance of the model (Schoenfeld 1982).

All statistical analyses were conducted in program R, version 3.0.0 (R Core Team 2013).

RESULTS

Probability of Flushing

A total of 643 focal observations of Kittlitz's murrelets were conducted during 181 hours of data collection when cruise ships were present in Glacier Bay National Park.

A total of 123 or 19.1% of the focal murrelets flushed from the water during focal observations. Estimated distance from each focal murrelet ($n = 643$) to the nearest cruise ship ranged from 0.012 km to 73.62 km. The duration of focal observations of murrelets averaged 472.9 sec ± 7.3 sec (SE; range = 9 – 600 sec).

Using AIC model selection, only distance to the nearest cruise ship and Beaufort sea state, a visual proxy for wind speed, were retained as significant explanatory variables when predicting the incidence of flushing in focal murrelets. The odds of a focal murrelet flushing declined by an average of 4% with each 1 km increase in distance to the nearest cruise ship (odds ratio = 0.962, $z = -3.432$, $p < 0.001$; Table 3.3). On average, when Beaufort sea state was greater than 2 (wind speed estimated to be greater than 4 knots), the odds of observing a flushing event increased 41% when compared to sea states 0 and 1, although the relationship was weak (odds ratio = 1.412, $z = 1.682$, $p = 0.093$; Table 3).

While the binary logistic regression demonstrated that distance to the nearest cruise ship was a significant explanatory variable for variation in the incidence of flushing response, this parameter was derived across the entire range of distances in the sample. When explored using segmented regression analysis, a breakpoint in the probability of a flushing response when cruise ships were at a distance of 3.8 km or closer was identified (95% c.i. = 1.5 – 6.0 km; Figure 3.2). The addition of the second slope significantly reduced the deviance of the fitted model (deviance reduction = 23.72, d.f. = 2, $p < 0.001$), suggesting that the effect of cruise ships on the flushing response of murrelets as a function of distance is better approximated by a model with two slopes rather than one (Figure 3.2). For the probability of flushing as a function of cruise ship distance, the slope of the response when cruise ships were 3.8 km or closer was best estimated at log odds = -0.492 ($z = -2.468$, $p = 0.014$; Table 3.3), while the slope of the response at distances greater than 3.8 km was best estimated at log odds = -0.001 (p-value not calculated as standard asymptotics do not apply [Muggeo 2008]; Table 3.3). The difference in slopes on either side of the breakpoint was significant (Davies test for difference in slopes; $p < 0.001$). This result indicates that the probability of a focal murrelet flushing decreased as a function of increasing distance to the nearest cruise ship, but this trend only held true for distances up to 3.8 km. For each 1 km increase in distance of a cruise ship from the focal murrelet, the odds of the murrelet flushing declined 39%, until the cruise ship was 3.8 km from the focal murrelet, at which point the probability of flushing approached the baseline flushing rate of 12.5% (Figure 3.2). Of the 57 flushing events observed for focal murrelets when a cruise ship was closer than 3.8 km, 30 occurred as the ship approached the focal murrelet and 27 occurred as the ship receded.

The le Cessie - van Houwelingen - Copas-Hosmer un-weighted sum of squares test indicated that there was insufficient evidence to suggest that the true probabilities of flushing by focal murrelets were not those specified by the fitted segmented model ($z = 0.950$, $p = 0.342$). Due in part to the low frequency of flushing in focal Kittlitz's murrelets, even in the presence of cruise ships (less than 50% probability), however, the

ROC curve and associated AUC indicated that the power of this model to predict flushing events in focal murrelets was only fair (AUC = 0.66; Figure 3.3).

Duration of Flight

Of the 123 flushes observed for focal murrelets, the duration of subsequent observed flight ranged from 1 sec to 183 sec (Figure 3.4). Forty of the focal murrelets that flushed were lost from sight prior to the murrelet re-landing on the water. When investigated with binomial logistic regression, none of the explanatory variables were statistically significant at predicting censoring, supporting the assumption that the reasons for censoring were independent and non-informative, thus allowing for inclusion of the censored observations in the analysis. Each covariate in the final model met the proportional hazards assumption as assessed by the Schoefeld residuals (global test $p = 0.994$). Although a large proportion of flights by focal murrelets occurred when a cruise ship was within 3.8 km ($n = 57$), distance to the nearest cruise ship did not affect the time spent flying (hazard ratio = 0.991, $z = -0.797$, $p = 0.425$; Table 3.4). In addition to distance to the nearest cruise ship, time of day, and murrelet group size were the only explanatory variables that were retained after AIC model selection. For each one-hour increase in time of day, a flushed Kittlitz's murrelet was 1.14 times more likely to re-land at any time during the flight, suggesting that flight times decreased as the day progressed (hazard ratio = 1.136, $z = 2.781$, $p = 0.005$; Table 3.4). Although retained in the final model, there was little evidence to suggest that focal murrelets in groups of two or more that flushed were more likely to re-land at any time during the subsequent flight than single murrelets (hazard ratio = 1.461, $z = 1.418$, $p = 0.156$; Table 3.4). The concordance of the final model was 0.613 (SE = 0.037), suggesting that the model adequately fits the observed distribution of flight times for Kittlitz's murrelets flushed in the Upper West Arm of Glacier Bay.

DISCUSSION

A primary management concern in Glacier Bay National Park is to understand the level of disturbance to murrelets by vessels, including cruise ships. As part of a separate but related study (see Chapter 2), we boarded cruise ships on 45 different days and conducted observations from the bow of ships to estimate the cruise ship's 'zone of influence' on murrelets. The results from that study suggested that murrelets responded to cruise ships at distances out to 1 km, but disturbance responses at distances greater than 1 km were not considered owing to limitations on detection of murrelets. We nevertheless noted that a large number of murrelets took flight in response to ships.

Building on these results and using shore-based observations, we demonstrated that Kittlitz's murrelets in Glacier Bay begin to react to disturbance from cruise ships at distances of at least 1.6 km, and perhaps as great as 6.0 km, with a best estimate of threshold disturbance distance at 3.8 km. The probability of a murrelet flushing from the water when a ship was closer than 3.8 km increased sharply from the baseline probability of flushing (approximately 12.5%) as the distance to the ship decreased.

In previous studies of ship disturbance specifically targeting species in the seabird family Alcidae, all but one study restricted the scope of inference to distances from the ship where a disturbance response was hypothesized to occur. Three of these studies focused on Kittlitz's murrelets in Glacier Bay (Agness et al. 2008, 2013; Chapter 2), two focused on marbled murrelets (*B. marmoratus;* Speckman et al. 2004, Bellefluer et al. 2009), and one investigated the effects of ship approaches on black guillemots (*Cepphus grylle;* Ronconi and St. Clair 2002). All six of these studies investigated potential ship disturbance at distances where an observer could simultaneously monitor both the ship and the bird, a common approach for understanding ship disturbance impacts in other taxa (Galicia and Baldassarre 1997, Bright et al. 2003, Burger et al. 2010). In all three studies involving Kittlitz's murrelets, the disturbance responses were investigated when ships were 1,000 m or closer to focal murrelets. Both studies involving marbled murrelets investigated disturbance when ships were closer than 100 m, while the study involving black guillemots did not appear to limit observations to a certain distance, with at least one observation of guillemot behavior when a ship was 1,136 m from the focal bird. All six of these studies noted an increase in the probability of disturbance as the distance from the ship to the bird decreased. For our study, cruise ship operation procedure provided some advantages because cruise ships followed the same course each day and had tracking devices aboard. Therefore, at any point in time we could identify where ships were located in the Park, negating the need to limit our study to distances where we could simultaneously visually monitor both individual birds and cruise ships.

Disturbance Cues

In order for a murrelet to respond to the presence of a cruise ship (or any other vessel), the cruise ship must first be detected. Secondly, the murrelet must assess the cruise ship as a potential threat. Lastly the murrelet must initiate an appropriate evasive response. Although our study cannot directly link increased flushing rates to any one specific cue, we identified three possible cues that may have facilitated these long distance flushing events. Additionally we recognize that murrelets reacting across such a large range of distances may be reacting to multiple cues simultaneously or to different cues at differing distances.

First, we acknowledge that murrelets may be able to detect cruise ships visually at distances of several kilometers, as vision is often used in predator detection and avoidance (Bednekoff and Lima 2005). Kittlitz's murrelets have relatively large eyes compared to congeneric species, a trait that may have evolved as an adaptation for foraging in turbid water (Day et al. 2003). As such, Kittlitz's murrelets may have adapted to seeing underwater, which may limit visual acuity above the water because adaptations for foraging underwater can result in emmetropic vision while submerged, but a tendency toward nearsightedness when in air (Katzir and Howland 2003). In some penguin species, however, emmetropic vision is retained in both air and water (Howland and Sivak 1984). While the distance at which murrelets may be able to detect cruise ships visually cannot be inferred, it seems unlikely that the increase in the probability of flushing at distances up to 3.8 km could be solely due to the visual perception of a threat. A ship 3.5 km away and traveling at 16 knots (30 kph), a typical velocity for cruise ships in Glacier Bay, would start to elicit flushing responses in murrelets more than 7 min before the ship reached the murrelet. Further, if murrelets were responding visually to the cruise ship, and thus using flight to avoid the ship, we would expect that flight would always be directed away from the ship. This was not always the case, however, as murrelets that flushed near cruise ships often flew parallel to or in front of the ship, and in some cases even re-landed in front of the ship only to flush again (TKM, pers. obs.). Also, when focal murrelets flushed within 3.8 km of a cruise ship, flushing occurred nearly as frequently when ships were receding as when they were approaching, i.e., in many cases the ships had already passed through the area when the murrelet decided to flush.

Alternatively, murrelets may be responding to either the above water or below water noise produced by cruise ships. Cruise ships traveling through Glacier Bay emit both surface and subsurface noise in the form of propeller cavitation, engine reverberations, and power generation noise that increases as the distance from the ship decreases (Kipple and Gabriele 2007). Further, sound profiles of cruise ships passing a hydrophone in Brehm Canal, Alaska have demonstrated that underwater noise emanates in front of the ship, i.e., there was no evidence of an acoustic ‘shadow’ (Terhune and Verboom 1999) or significant quiet zone in front of the ship (Gabriele and Kipple, unpubl. data). Although there is little evidence that pursuit-diving birds such as murrelets use their auditory sense to forage underwater, the ratio of tympanic to oval-window area for diving birds in the family Alcidae (5 – 13, compared to 20 – 30 in terrestrial birds) suggests underwater auditory acuity (Hetherington 2008). Thus, murrelets likely have the ability to hear cruise ships over long distances and, therefore, we cannot discount that cruise ship noise, either above (Goudie 2006) or below the surface (Tyack 2008, Rolland et al. 2012) is the mechanistic cue causing elevated murrelet disturbance at these longer distances.

The most likely explanation, in our view, for murrelets flushing several kilometers or more in front of cruise ships is social facilitation, i.e. they are responding to other murrelets that have previously flushed in response to the cruise ship. Animals can benefit from increased vigilance by means of the ‘many eyes hypothesis’ (Lima 1990), wherein vigilance is increased as group size increases. In order to benefit within this framework the group of individuals must take part in some form of group interaction, such as alarm calls or signals. In some cases, alarm calls are so ubiquitous as to be understood across species lines (Magrath et al. 2007), or complex enough to relay information about the specific threat (Templeton et al. 2005). In the absence of alarm calls, information may also be communicated visually by sensing conspecifics that are flying from the area of a perceived threat (Lima 1994, Sirot 2006, Fernández-Juricic and Kowalski 2011).

A few distinct calls have been described for Kittlitz’s murrelets at sea in Glacier Bay (van Vliet and Piatt 1999). Pairs of murrelets were recorded calling to each other as one resurfaced after a foraging dive, presumably in an effort to reunite. Two additional types of calls were recorded immediately after flushing from the water. Both flushing calls were higher frequency (1.95 kHz) and were modulated to create a rapidly repeating call. The authors noted that these calls were extremely faint, and were easily masked by the noise of their own vessel, as well as by ambient ocean noise (van Vliet and Piatt 1999). During our study, we noted an increase in the total number of flying murrelets passing our observation sites up to 15 minutes prior to a cruise ship passing (Marcella et al., unpubl. data). Murrelets in flight were either not calling or the calls were too faint to detect at distances of 100 m or more. The observed increase in flying murrelets, presumably individuals previously flushed by the cruise ship, may have contributed to the unexpectedly long distances over which cruise ships were observed to influence murrelet behavior, either via alarm calls or in response to the increase in numbers of flying murrelets. Although cruise ship presence within 1-3 km increases the probability of murrelets flushing above the baseline rate, the incidence of flushing is still not nearly as high as when cruise ships approach to within several hundred meters (Chapter 2).

We note several factors that may influence our results. First, our study was observational in nature and, while there was consistency in cruise ship operational characteristics, we could not control for other factors, including other anthropogenic flushing events (smaller tour vessels, private vessels, kayaks, etc.). As such, we chose to include within our measurement of the baseline probability of flushing the natural and anthropogenic-induced flushing probability as background variation. Our finding that cruise ship presence was a strong predictor of the probability of flushing, even against the background of all other vessel disturbances during our study, is consistent with the study of Agness et al. (2008), who concluded that cruise ships, compared to all other vessel types, elicited the greatest response from Kittlitz's murrelets in Glacier Bay. We also note that cruise ships entered the Park around the same time each day (between 06:00 and 10:30 ADT) and thus passed our focal observation sites around the same time, i.e., within a three-hour window. Thus time of day co-varied with the distance of cruise ships from murrelets. We do not think, however, that time of day was an important factor influencing the probability of flushing because time of day (hour) was not an important factor in explaining variation in our models. We also were able to conduct observations on murrelets during two days when cruise ships were not present in the Park. During those two days 17 focal murrelets were observed in total. While the sample size was small (owing to the few days when no ships entered Glacier Bay during the summer), only 1 of the focal murrelets flushed during the late morning, when cruise ships generally pass that part of the Bay.

Factors influencing flight time

While distance to the nearest cruise ship was inversely related to the probability of a murrelet flushing from the surface of the water, distance was not a good predictor of the amount of time a Kittlitz's murrelet would spend in flight after it flushed. Based on these results, murrelets that failed to fly away from the cruise ship and its 'zone of influence' may have been subjected to repeated flushing events caused by the same ship. If tolerance of cruise ships is individual-specific, each murrelet would only need to fly for a total distance that exceeds the distance to the ship when flushed. Although not directly quantified, murrelets were often observed flying parallel to or in advance of the ship for great distances (TKM, pers. ob.). These results further suggest that murrelets are reacting to cues not solely attributable to the visual presence of the cruise ship.

The duration of flight for Kittlitz's murrelets that had flushed in the presence of cruise ships in Glacier Bay appeared to be more dependent on time of day than distance to the nearest cruise ship. Longer flight times were associated with the morning hours. Time of day has been shown to be a strong predictor of foraging bouts in pelagic seabirds, with most foraging occurring in the early morning and late evening (Ropert-Coudert et al. 2003). Longer duration of flight responses for Kittlitz's murrelets that flushed earlier in the day may be indicative of attempts to find patchily distributed food sources (Weimerskirch 2007).

Results from our study suggest that the samples of birds investigated in previous studies of the effects of vessel disturbance on members of the seabird family Alcidae (the majority of which were of *Brachyramphus* murrelets) may have consisted predominantly of individuals that were more tolerant of ship approaches, as some portion of the population may have previously flushed. In light of our findings, we caution that results from disturbance studies are inherently linked to the scale at which the study is carried out. By not restricting our study to an *a priori* distance from cruise ships, we were able to detect disturbance responses at distances as great as 3.8 km. Our use of GPS and AIS ship tracking technology allowed us to monitor the disturbance regime and the potentially disturbed murrelets independently. By collecting data in this manner, we were able to avoid biasing the study based on pre-conceived notions of what constituted a threshold distance for cruise ships to disturb Kittlitz's murrelets.

The distance from cruise ships at which we were able to detect a change in the behavior of Kittlitz's murrelets, a species of conservation concern, was unexpected. While murrelets in the upper reaches of Glacier Bay National Park appeared to be highly sensitive to the presence of cruise ships, it is beyond the scope of this study to test whether these reactions equate to a reduction in murrelet fitness. Yet the results of our study, along with those of Agness et al. (2013), suggest that cruise ship disturbance increases energy demands and decreases energy intake of Kittlitz's murrelets utilizing the Bay. Agness et al. (2013) suggested that Kittlitz's murrelets in Glacier Bay are "on the edge" energetically during the breeding season, and that murrelets will need to consume between 83% and 107% of their body mass in forage fish each day, depending on breeding status and the frequency of vessel disturbance. Results from this study indicate that Kittlitz's murrelets are more susceptible to disturbance from cruise ships than previously assumed. It is therefore likely that the energetic demands to murrelets of cruise ship disturbance in Glacier Bay have been underestimated. Managers of Glacier Bay National Park should consider the greater than expected impact of cruise ships on the behavior of Kittlitz's murrelets in the Park when developing management plans for cruise ship traffic during the summer months, when the abundance of murrelets in the Park is highest.

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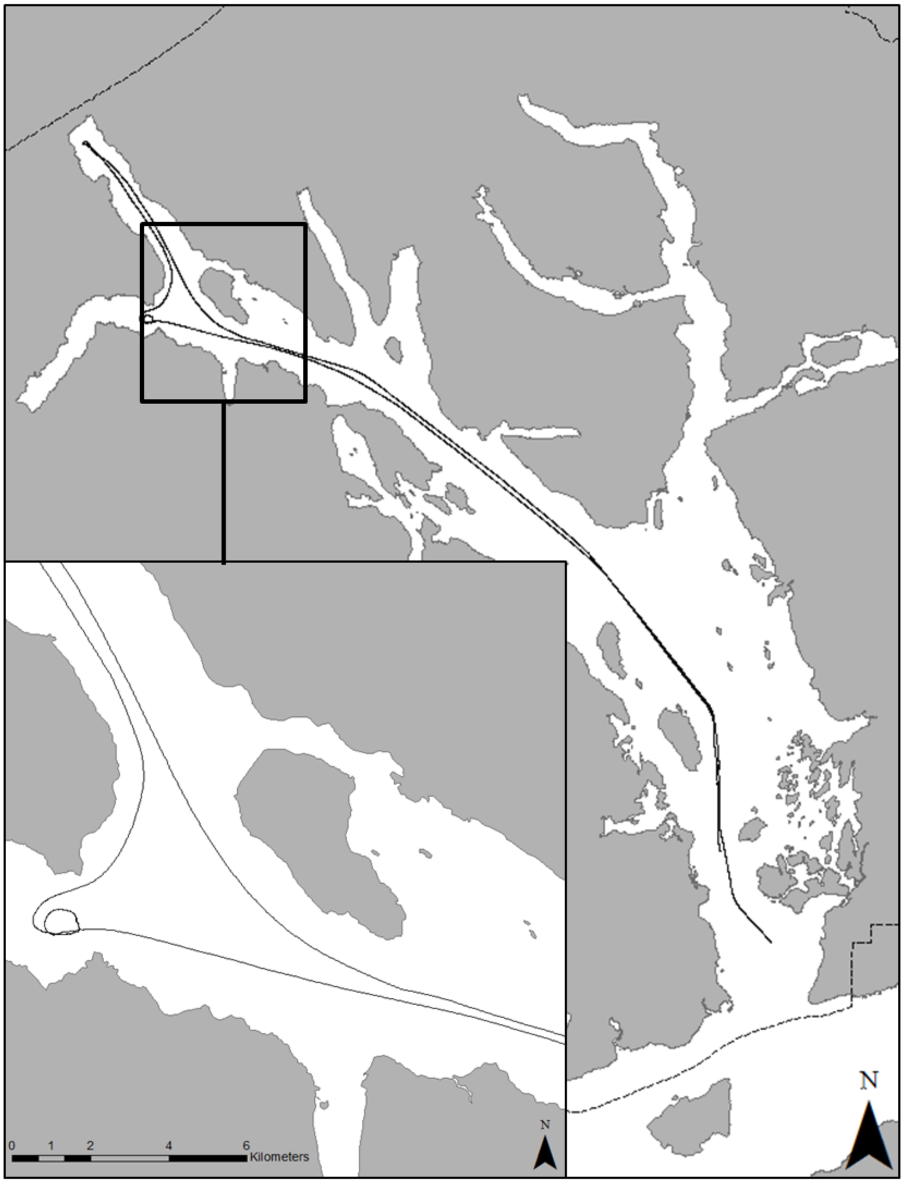

Figure 3.1. Map of Glacier Bay National Park, Alaska. Inset shows the four observation sites (A – D) located in the Upper West Arm of the Park where behavior of focal Kittlitz's murrelets was recorded. The black line indicates the typical route of cruise ships visiting the Park.

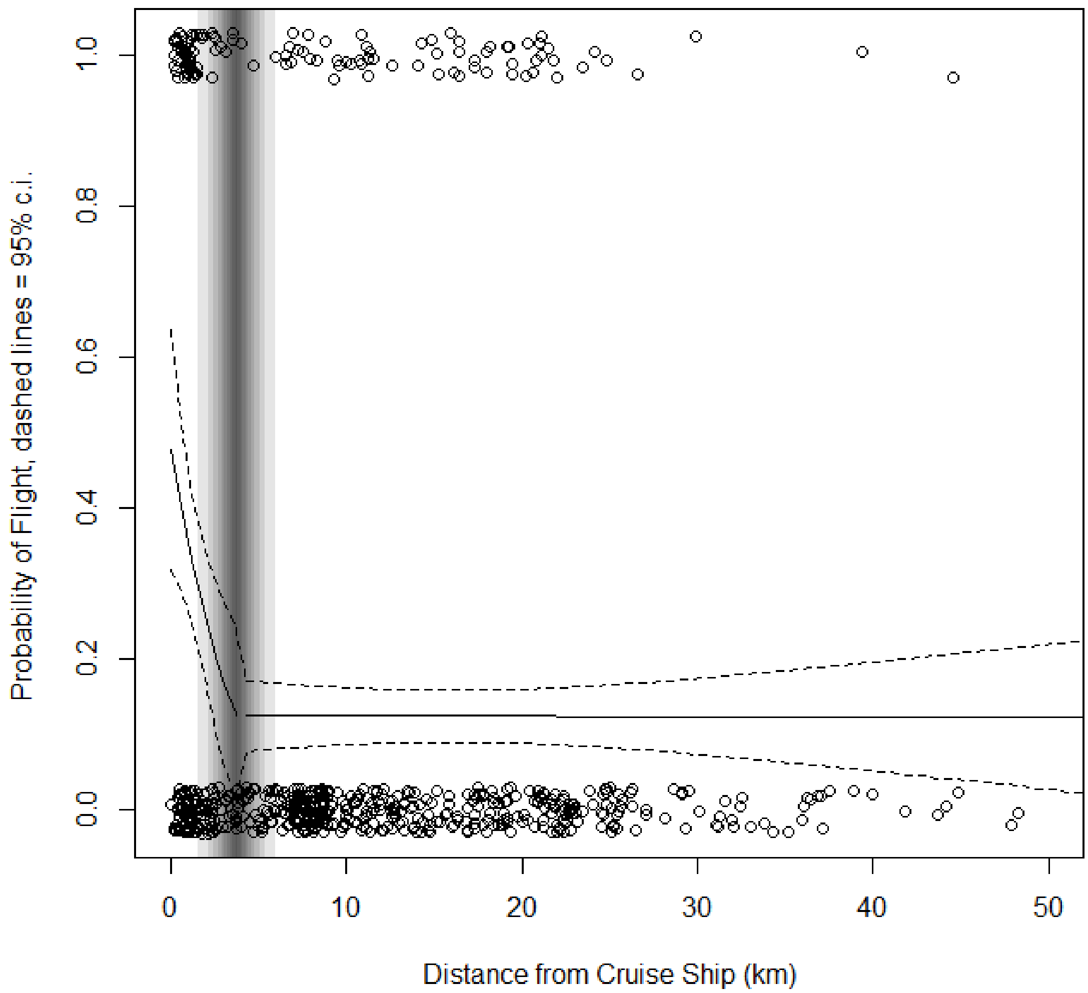

Figure 3.2. Segmented binary logistic regression showing the probability of flushing by Kittlitz's murrelets as a function of distance to the nearest cruise ship in Glacier Bay National Park, Alaska (n = 643 observations). Data points have been jittered for ease of visualization. The transparent vertical grey bar indicates the 95% confidence interval (1.55 – 6.02 km) about the breakpoint of 3.8 km in the probability of flushing as a function of distance to the nearest cruise ship.

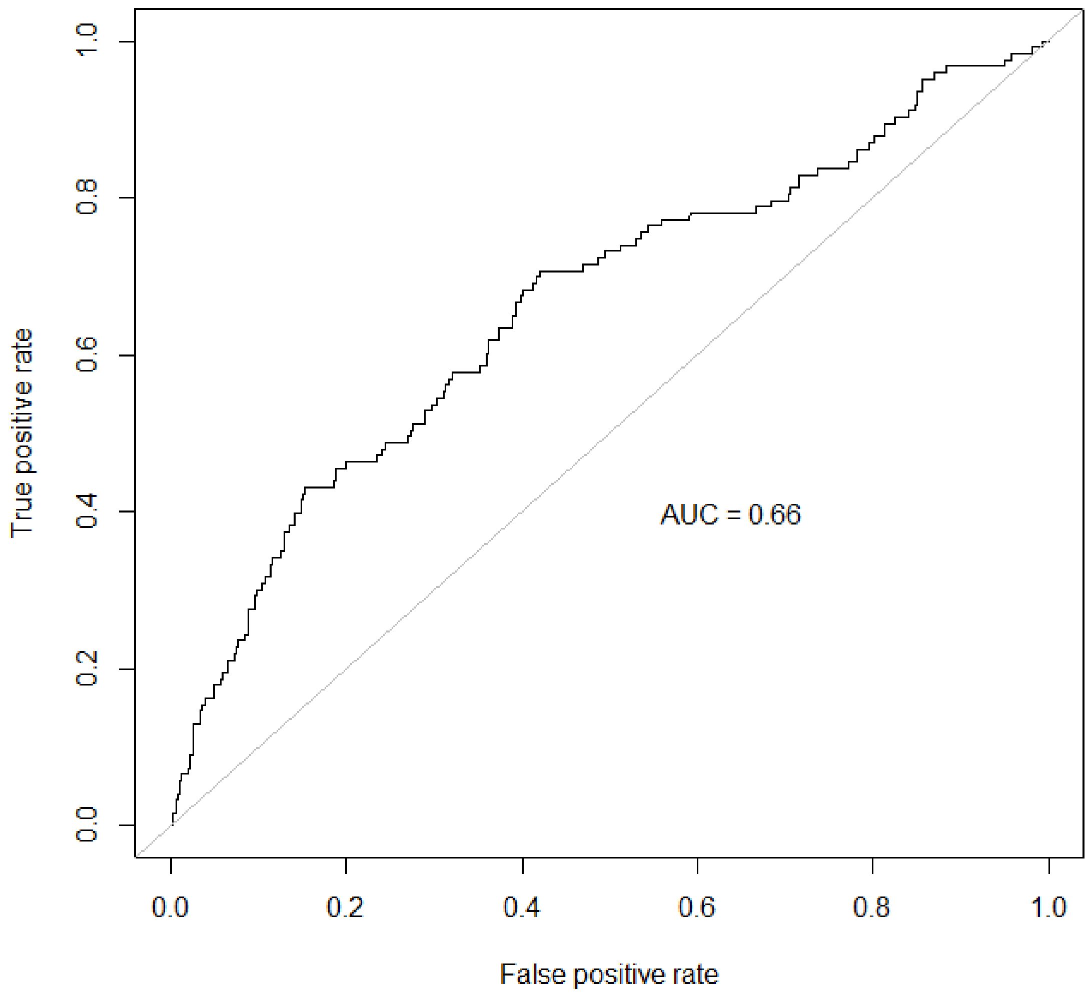

Figure 3.3. Predictive power of the segmented regression logit model estimating the probability of flushing by Kittlitz's murrelets as a function of distance to the nearest cruise ship in Glacier Bay National Park, Alaska, during 2012. Receiver Operating Characteristic (ROC) and the associated area under the curve (AUC = 0.66) suggest that the predictive power of the model is fair.

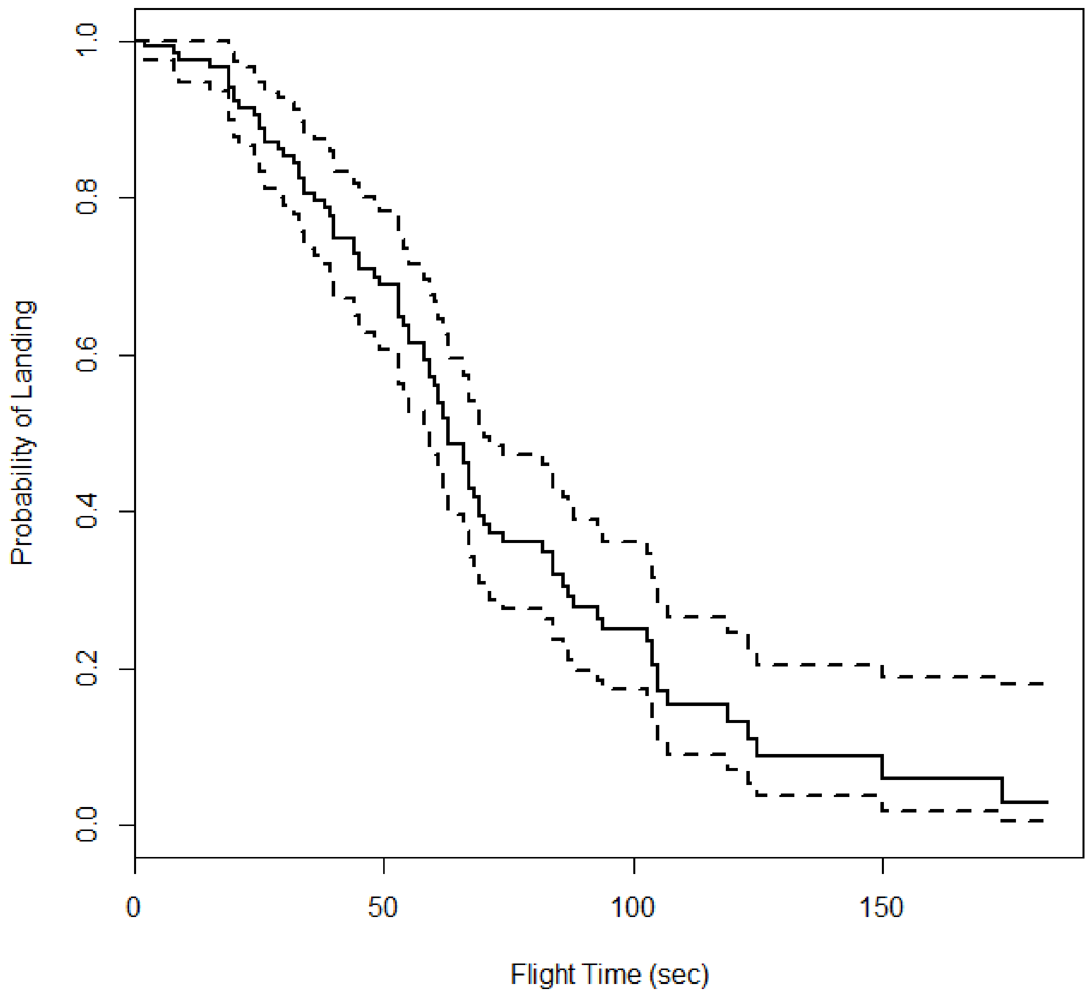

Figure 3.4. Estimated survival function for the Cox regression analysis of the time focal Kittlitz's murrelets remained in flight after flushing from the water, based on mean covariate values retained after model selection. The point-wise 95% c.i. is depicted by dashed lines. Observations were collected at four land-based sites in Glacier Bay National Park, Alaska, during 2012.

Table 3.1. Explanatory variables considered when modeling the probability of flushing (taking flight from the water surface) by Kittlitz's murrelets observed in Glacier Bay National Park, Alaska, during 2012. Sample sizes are included in parentheses.

Variable (sample size)	Classification
Cruise Ship Distance	
continuous	Distance in km from focal murrelet to nearest cruise ship
Stage of Season	
continuous	Days after June 1
Time of Day	
continuous	Hour of the day
Sea State	
Light (n = 399)	0 or 1 on the Beaufort Sea State scale
Moderate (n = 244)	2 or greater on the Beaufort Sea State scale
Murrelet Group Size	
Single (n = 188)	Solitary murrelet
Group (n = 455)	≥ 2 murrelets within 2 meters or acting in concert
Observation Site	
A (n = 189)	Southeastern most observation site
B (n = 197)	Ibach Pt., northeast shore of Reid Inlet
C (n = 163)	Southeast tip of Russell Island
D (n = 94)	Entrance to Tarr Inlet

Table 3.2. Explanatory variables considered when modeling the time spent flying by focal Kittlitz's murrelets after flushing from the water in Glacier Bay National Park, Alaska, during 2012. Sample sizes are included in parentheses.

Variable (sample size)	Classification
Cruise Ship Distance	
continuous	Distance in km from focal murrelet to nearest cruise ship
Stage of Season	
continuous	Julian date
Time of Day	
continuous	Hour of the day
Sea State	
Light (n = 68)	0 or 1 on the Beaufort Sea State scale
Moderate (n = 55)	2 or greater on the Beaufort Sea State scale
Murrelet Group Size	
Single (n = 34)	Solitary murrelet
Group (n = 89)	≥ 2 murrelets within 2 meters or acting in concert
Observation Site	
A (n = 42)	Southeastern most observation site
B (n = 37)	Ibach Pt., northeast shore of Reid Inlet
C (n = 31)	Southeast tip of Russell Island
D (n = 13)	Entrance to Tarr Inlet

Table 3.3. Results from two models predicting the probability of a Kittlitz's murrelet flushing from the water in Glacier Bay National Park, Alaska, during 2012. Single slope binary logit model (a); segmented regression binary logit model (b) with the inclusion of a second slope.

(a)	**β**	**Odds Ratio**	**95% c.i.**	**p – value**
Intercept	-1.156	0.315	0.223 – 0.440	< 0.001
Distance from ship (km)	-0.039	0.962	0.939 – 0.982	< 0.001
Beaufort Sea State				
Light (reference)	1	---	---	---
Moderate	0.345	1.412	0.942 – 2.109	0.093
(b)	**β**	**Odds Ratio**	**95% c.i.**	**p – value**
Distance from ship (km)				
≤ 3.8 km	-0.492	0.611	0.413 – 0.904	0.014
> 3.8 km*	-0.0001	0.9999	NA†	NA†
Beaufort Sea State				
Light (reference)	1	---	---	---
Moderate	0.272	1.312	0.867 – 1.986	0.199

*Additional slope term reduced deviance significantly (-23.715, d.f. = 2, p < 0.001)

† Confidence interval and p-value not generated as standard asymptotics do not apply; significance of the addition of the second slope is tested with the Davie's test (p < 0.001; Muggeo 2008)

Table 3.4. Hazard ratios for explaining the variation in duration of flight following flushing from the water by Kittlitz's murrelets in Glacier Bay National Park, Alaska, during 2012.

Variable		**Hazard (95% c.i.)**	**p**
Distance to cruise ship	km	0.991 (0.970 – 1.013)	0.425
Time of day	hr	1.136 (1.038 – 1.243)	0.005
Murrelet group size	single	1	---
	group	1.461 (0.865 – 2.467)	.156

CHAPTER 4

SYNOPSIS AND CONCLUSIONS

Timothy K. Marcella

This study was initiated by the National Park Service to further investigate cruise ship disturbance within Glacier Bay National Park to Kittlitz's murrelets (*Brachyramphus brevirostris*), a seabird species of conservation concern (National Audubon Society 2006, Birdlife International 2014). In October 2013, the U.S. Fish and Wildlife Service determined that the Kittlitz's murrelet was not warranted for listing under the United States Endangered Species Act (ESA) due to insufficient evidence to conclude a risk of global extinction and uncertainty over what factors were responsible for earlier population declines (Federal Register 2013). When the present study was initiated, however, Kittlitz's murrelets were considered a candidate species for listing as threatened or endangered under the ESA (Federal Register 2007). Nevertheless, as steward of approximately 37% of the global population of the species during the spring and summer breeding season (Federal Register 2013), it is within the mandate of Glacier Bay National Park to limit harm to Kittlitz's murrelets utilizing the Park. Although not the most numerous vessel type operating within Glacier Bay, cruise ships have been previously identified as the vessel type eliciting the greatest disturbance response from Kittlitz's murrelets (Agness et al. 2008), and cruise ships are the means by which more than 95% of Park visitors access the Park (National Park Service 2012).

For this study, I investigated cruise ship disturbance to Kittlitz's murrelets at both fine and broad spatial scales. By deploying observers onboard cruise ships traveling through the Bay, I was able to quantify the probability of murrelet disturbance (defined as flushing or diving) as a function of perpendicular distance to the cruise ship's course, as well as the factors that influence murrelet disturbance response as a function of absolute distance across a range of approach angles within 1 km of an approaching cruise ship (Chapter 2). Additionally, I conducted focal animal observations from on-land observation sites adjacent to waters with high densities of Kittlitz's murrelets, and later appended distance to the nearest cruise ship using GPS and AIS ship-tracking technology (Chapter 3). By not limiting the scope of inference to a distance at which it was feasible to simultaneously monitor both murrelet behavior and distance to the nearest cruise ship, I was able to demonstrate that Kittlitz's murrelets begin to respond to cruise ships at distances far greater than had previously been published for any seabird.

Disturbance responses by wildlife can manifest as (1) purely physiological, with no outward sign of reaction or stress (e.g., increased heart rate; Ellenberg 2013), (2) passively, in the form of alert posturing and orienting towards the disturbance (Chatwin et al. 2013), or (3) actively, as in fleeing from the area of the disturbance (Schwemmer et al. 2011). Furthermore, a disturbed animal may exhibit all three of these responses during the course of one disturbance event. Although flushing is likely the most energetically costly avoidance behavior a murrelet can exhibit when approached by a cruise ship (Pennycuick 1987), by diving in response to a vessel further observation of a focal murrelet is usually precluded. With this in mind, and considering the distances at which observations of potentially disturbed murrelets were conducted, I defined flushing (flying from the surface of the water) as the indicator of the highest magnitude of disturbance in this study, and diving below the surface, when it precluded further observation, as an indicator of a lower magnitude of disturbance in murrelets. I acknowledge that by defining disturbance primarily as flushing, I am under-estimating and ultimately under-representing the actual incidence of disturbance to Kittlitz's murrelets caused by cruise ships in Glacier Bay.

Identification of *Brachyramphus* murrelets to the level of species during at-sea surveys is inherently difficult in areas where Kittlitz's and marbled murrelets (*B. marmoratus*) co-occur (Kuletz et al. 2011, Kirchhoff et al. 2014). This study was also subject to this constraint and, as a result, murrelet species identification rates during shipboard observations were hampered by both the distance at which murrelets responded and how they responded (dive vs. flush) to approaching cruise ships. With this in mind, analysis of the data acquired through shipboard observation of murrelets was conducted at the level of the genus *Brachyramphus*, instead of at the species level. Due to apparent differences in habitat preferences and resource utilization by the two murrelet species in Glacier Bay, Kittlitz's murrelets made up the majority of murrelets identified to species in the upper section of the Bay (Upper Bay), while marbled murrelets made up the majority in the lower section of the Bay (Lower Bay). In order to investigate potential inter-specific differences in response to cruise ships, I included location in the Bay as a dichotomous independent variable (Upper Bay vs. Lower Bay). Within a model selection framework, I also accounted for potential geographical, environmental, and management-based explanatory variables that might differ between the Upper Bay and the Lower Bay. I cautiously inferred that the significant effects of location in the Bay (Upper Bay vs. Lower Bay) represented inter-specific differences in murrelet responses to approach by cruise ships.

Results from the shipboard observations clearly demonstrated that the incidence of disturbance responses by murrelets was inversely related to distance to the cruise ship. In addition to the distance between a focal murrelet and an approaching cruise ship, location in the Bay (a surrogate for murrelet species) was the only other variable that consistently explained a significant proportion of the observed variation in murrelet disturbance response. The strong effect of location in the Bay (Upper Bay vs. Lower Bay) supports the hypothesis that there are inter-specific differences in murrelet sensitivity and response to cruise ships in the Park.

Based on data collected onboard cruise ships, I estimated that as cruise ships travel through the Bay the majority of murrelets within a 1,700-meter wide strip centered on the course of the cruise ship are expected to respond demonstrably (either flush or dive). Murrelets in the Lower Bay, where marbled murrelets predominate, are slightly more responsive to cruise ships than are murrelets in the Upper Bay, where Kittlitz's murrelets predominate. The model that best fit the observed data predicted that 71% of murrelets in the Lower Bay would react within the 1,700-m wide zone of disturbance, while 62% of murrelets in the Upper Bay would react within this zone. The data also suggest that murrelets do not habituate to cruise ships traversing Glacier Bay and, instead, exhibited slightly stronger responses to cruise ships as the season progressed. The data provided no support for the hypothesis that murrelets in Glacier Bay responded differently depending on whether one or two cruise ships entered the Park on a given day (short term habituation).

I was able to further define the response of murrelets to cruise ships in the Park using a multistate modeling framework. Murrelets in Glacier Bay appear to be slightly more sensitive to indirect approaches by cruise ships, compared to direct or head-on approaches. One explanation for this difference could be that the larger profile of the cruise ship displayed to birds not directly on the ship's course may contribute to the perception of speed, size, and advance of the ship (Dill 1974). This difference in response was more pronounced for murrelets in the Lower Bay, which tended to respond at greater distances from the cruise ship and had a tendency to flush more than dive. Murrelets in the Upper Bay, in comparison, responded to cruise ships at smaller distances on average, and responded more often by diving that by flushing. Thus, Kittlitz's murrelets appear to be somewhat less sensitive to cruise ship disturbance than marbled murrelets, and tend to respond to cruise ships more by diving than by flushing.

A reduction in flushing distance is not necessarily an indicator of greater tolerance to a potential disturbance, but may reflect a greater reliance on a particular area for forage, cover, or resources for reproduction, which may also be subject to disturbance (Stankowich and Blumstein 2005). Additionally, adult animals that are defending territories, young, or mates can exhibit reduced response distances compared to the population as a whole (Rodgers and Smith 1997). Kittlitz's murrelets are known to migrate to Glacier Bay for the summer months, where some portion of the population nests in adjacent alpine habitat (Fox and Hall 1982; Day 1996; Marcella et al., unpubl. data). The breeding status of some portion of the Kittlitz's murrelets encountered in the Upper Bay of Glacier Bay, plus the proximity of these murrelets to their nesting habitat, may explain their shorter average response distance to cruise ships, and their propensity to dive rather than flush. In contrast, the large numbers of marbled murrelets found in the Lower Bay of Glacier Bay during summer are thought to be nesting primarily in other areas of Southeast Alaska, and commuting considerable distances to feed near the mouth of the Bay (Whitworth et al. 2000). The transient status of many marbled murrelets using Glacier Bay may be reflected in lower fidelity to particular foraging sites in the Lower Bay and a larger area of core use (Irons 1998), which may in turn result in a greater average response distance to cruise ships. Furthermore, density of murrelets in the Lower Bay is on average greater than in the Upper Bay (Hoekman et al. 2014), which could lead to greater social facilitation when murrelets react to disturbed conspecifics in the area (Lima 1994, Sirot 2006, Fernández-Juricic and Kowalski 2011).

Focal observations of murrelets from the cruise ship were limited to within a 180-degree, 1-km radius arc centered on the ship's bow. This was because of limits to the distance from the ship at which behavioral responses could be observed and the *a priori* assumption that disturbance to murrelets by cruise ships was unlikely at distances greater than 1 km. Both extrapolation of perpendicular disturbance probabilities and anecdotal observations suggested that murrelets in Glacier Bay reacted to cruise ships at distances in excess of 1 km. Furthermore, indirect approaches appeared to elicit greater disturbance responses than direct approaches. These findings suggested that murrelets in Glacier Bay were more susceptible to cruise ship disturbance than formerly thought, and results from Chapter 2 should be viewed as minimum estimates of actual murrelet disturbance rates. The inability to fully document a cruise ship's zone of influence on murrelet behavior based on data collected onboard cruise ships led to the study of Kittlitz's murrelet behavior from land-based observation sites in the Upper West Arm of Glacier Bay, where cruise ship travel routes overlap with high densities of Kittlitz's murrelets.

Kittlitz's murrelets observed from on-land sites in the Upper West Arm of Glacier Bay (Upper Bay) demonstrated the same general trend in response to cruise ships as those observed from onboard: as distance of a focal murrelet from the closest cruise ship declined, the probability of a murrelet disturbance response increased. Focal observations of murrelet behavior were conducted with the aid of spotting scopes, as well as binoculars, allowing for greater rates of murrelet species identification and enhanced ability to continuously follow focal murrelets during diving (foraging) bouts. Consequently, murrelet response to cruise ships as a function of distance to the nearest cruise ship could be more thoroughly evaluated. I was able to estimate the threshold distance from a cruise ship at which the probability of flushing by Kittlitz's murrelets increased significantly.

At distances less than approximately 3.8 km (95% c.i. = 1.6 - 6.0 km) from the nearest cruise ship, I detected an increase in the probability of Kittlitz's murrelets flushing from the surface of the water. When the nearest cruise ship was at greater distances, the baseline probability of a focal murrelet flushing during a 10-min focal observation was not influenced by distance to the nearest cruise ship, and was estimated at 12.5%. This baseline flushing rate included flushing events that apparently were in response to other anthropogenic factors (e.g., tour boats, personal vessels, kayaks), as well as flushing events that were apparently due to natural causes (e.g., movements to nest sites or foraging sites, avoidance of avian predators). At distances less than the threshold distance of 3.8 km, the presence of a cruise ship increased the probability of flushing at rate that approximated a logistic curve. When the cruise ship was as close as a few hundred meters, flushing was expected to occur during 48% of the 10-min focal observation periods. Interestingly, the probability of flushing did not seem to be related to whether the cruise ship was approaching or moving away from the focal murrelet, as a nearly equal number of flushing events were observed when a cruise ship was moving toward vs. away from focal murrelets.

The unexpectedly large distance at which the behavior of Kittlitz's murrelets was altered in the presence of cruise ships (even when the ship was moving away) suggested that murrelets may be reacting to cues other than the visual stimuli associated with an approaching cruise ship. Although cruise ships could potentially be visible to Kittlitz's murrelets on the water surface at distances as great as 3.8 km, it is difficult to imagine that murrelets that flushed at this distance were responding to visual cues alone. Even if a focal murrelet were directly on a cruise ship's course, the ship would not reach the murrelet for another 6 - 7 min. Instead, I propose that Kittlitz's murrelets were responding to the social cues of other murrelets that had flushed in order to avoid approaching cruise ships. Social facilitation from conspecifics in the area that may have already been disturbed by a cruise ship and were flying overhead could be the primary stimulus that caused Kittlitz's murrelets to flush when the nearest cruise ship was well over a kilometer distant (Lima 1994, Sirot 2006, Fernández-Juricic and Kowalski 2011).

The potential for long-distance disturbance of murrelets from cruise ships could limit foraging opportunities to Kittlitz's murrelets across a large portion of available habitat in Glacier Bay. Assuming some fraction of Kittlitz's murrelets on the water in Glacier Bay are disturbed by cruise ships traveling within 3.8 km, then each cruise ship that enters the Park can cause at least some disturbance to murrelets over nearly half the surface area of Glacier Bay (Figure 4.1). This assessment, however, assumes that all aquatic habitat in Glacier Bay is equally suited for Kittlitz's murrelets. In the Upper West Arm of Glacier Bay, an area noted for its high densities of Kittlitz's murrelets (Hoekman et al. 2014), cruise ships visiting the Park have the potential to affect the behavior of a large proportion of the Kittlitz's murrelets that forage and rest in Glacier Bay (Figure 4.1).

Results of studies using both shipboard observations and land-based observations clearly demonstrated that murrelets in Glacier Bay are sensitive to cruise ships. Cruise ships within at least 1.6 km, and more likely within 3.8 km, resulted in murrelets altering their behavior markedly. Although the two studies were carried out over different spatial scales, both demonstrated that Kittlitz's murrelets are responding to cues associated with cruise ships that vary as a function of distance to the ship, instead of the actual threat of being struck by the approaching ship. The discovery that Kittlitz's murrelets are susceptible to disturbance from cruise ships over an extended range of distances, and regardless of whether the ship is advancing or receding, suggests that murrelets are reacting to more than just the visual stimulus of an approaching ship. Although I did not collect data to test the hypothesis that auditory stimuli from cruise ships elicited behavioral responses from murrelets, noise emitted by cruise ships, both surface and subsurface, may be a cause of disturbance to murrelets. In other systems, vessel noise has been shown to disrupt and displace marine mammals (Tyack 2008, Rolland et al. 2012) and other aquatic wildlife (Wysocki et al. 2006, Slabbekoorn et al. 2010), and, consequently, is of considerable concern to managers of Glacier Bay National Park (Kipple and Gabriele 2007). The sensitivity and responsiveness of Kittlitz's murrelets to underwater sounds is, however, not known. Research is needed into the underwater auditory sensory capabilities of murrelets and other pursuit-diving seabirds in order to address the potential effects of cruise ship noise on murrelet behavior.

Numerous studies have demonstrated the negative relationship between distance to vessels and the magnitude of disturbance to waterbirds (e.g., Ronconi and St. Clair 2002, Bright et al. 2003, Agness et al. 2008, Bellefleur et al. 2009, Schwemmer et al. 2011, Velando and Munilla 2011, Chatwin et al. 2013). The magnitude of disturbance varies, however, depending on a number of covariates, some of which include species of waterbird (Schwemmer et al. 2011), type of vessel (Agness et al. 2008, Chatwin et al. 2013), vessel speed (Agness et al. 2008, Ronconi and St. Clair 2002), approach angle (Chapter 2), distance to shore (Ronconi and St. Clair 2002), habituation over daily and seasonal time scales (Bright et al. 2003, Burger et al. 2010, Chatwin et al. 2013), and, importantly, the spatial scale at which the study is conducted (Chapter 3). Although I sought evidence that other covariates could affect the magnitude of cruise ship disturbance on murrelets, factors that might be subject to control by Park managers, I was unable to detect any clear trends. The overwhelming majority of the explained variation in behavioral response by murrelets to cruise ships was attributable to the absolute distance of the murrelet from the ship, which could have helped mask the effects of other covariates. The only covariate that had a significant explanatory effect on murrelet response to cruise ships was the sector of the Bay where murrelet behavioral responses were recorded (Upper Bay vs. Lower Bay), which likely was due to differences in response between the two species of murrelets found in Glacier Bay. The unexpectedly high sensitivity to and avoidance of cruise ships by murrelets, during both direct and tangential approaches, may also be responsible for the lack of other significant explanatory variables among the environmental, biological, and management-related variables explored in this study.

Human disturbance to wildlife can have persistent negative effects on distribution (Lusseau 2005, Velando and Munilla 2011), foraging (Stolen 2003, Burger et al. 2004, Christiansen et al. 2013), resting, and predator avoidance (Pease et al. 2005, Steckenreuter et al. 2011). Although generally non-lethal, these effects can lead to reproductive failure (Ruhlen et al. 2003, Bouton et al. 2005) and, when chronic, may ultimately affect population trends. Within the scope of this study, I was not able to address the demographic effects of cruise ship disturbance on Kittlitz's murrelets in Glacier Bay. Yet the results of my study, along with those of Agness et al. (2013), suggest that cruise ship disturbance increases energy demands and decreases energy intake of Kittlitz's murrelets utilizing the Bay during the breeding season. Agness et al. (2013) suggested that Kittlitz's murrelets in Glacier Bay are "on the edge" energetically during the breeding season, and that murrelets will need to consume between 83% and

107% of their body mass in forage fish each day, depending on breeding status and the frequency of vessel disturbance. As the results from my thesis research indicate, Kittlitz's murrelets are more susceptible to disturbance from cruise ships than previously assumed, and it is therefore likely that the energetic demands to murrelets of cruise ship disturbance in Glacier Bay were underestimated by Agness et al. (2013).

The distribution of murrelets in Glacier Bay, although somewhat predictable, varies by season, year, and species of murrelet, and is not highly aggregated. Unlike other studies of vessel disturbance of seabirds, where the goal was to measure disturbance at either a nesting site (Ronconi and St. Clair 2002) or within core foraging areas (Vellando and Munilla 2011), my study was conducted over larger spatial scales. This makes measuring the impact of cruise ship disturbance on murrelets highly problematic. In the absence of clear and persistent hot spots of murrelet activity within Glacier Bay, it is difficult to identify specific buffer zones where vessel use could be restricted or prohibited, or specific vessel operating restrictions that would reduce disturbance.

Future work should be conducted to couple our results with those from murrelet population surveys in order to estimate the total number of Kittlitz's and marbled murrelets flushed by cruise ships each day. Also, measurements of the energetic costs of flushing in murrelets will help clarify the consequences of cruise ship traffic to the globally important population of Kittlitz's murrelets using Glacier Bay. With a better understanding of the proportion of the overall Kittlitz's murrelet population in Glacier Bay that is disturbed by each cruise ship entry, managers will be able to better assess the trade-offs from increasing cruise ship quotas during the peak tourist season. Nevertheless, I strongly recommend that the murrelet disturbance by cruise ships documented by this study be considered before cruise ship quotas in the Park are adjusted upward.

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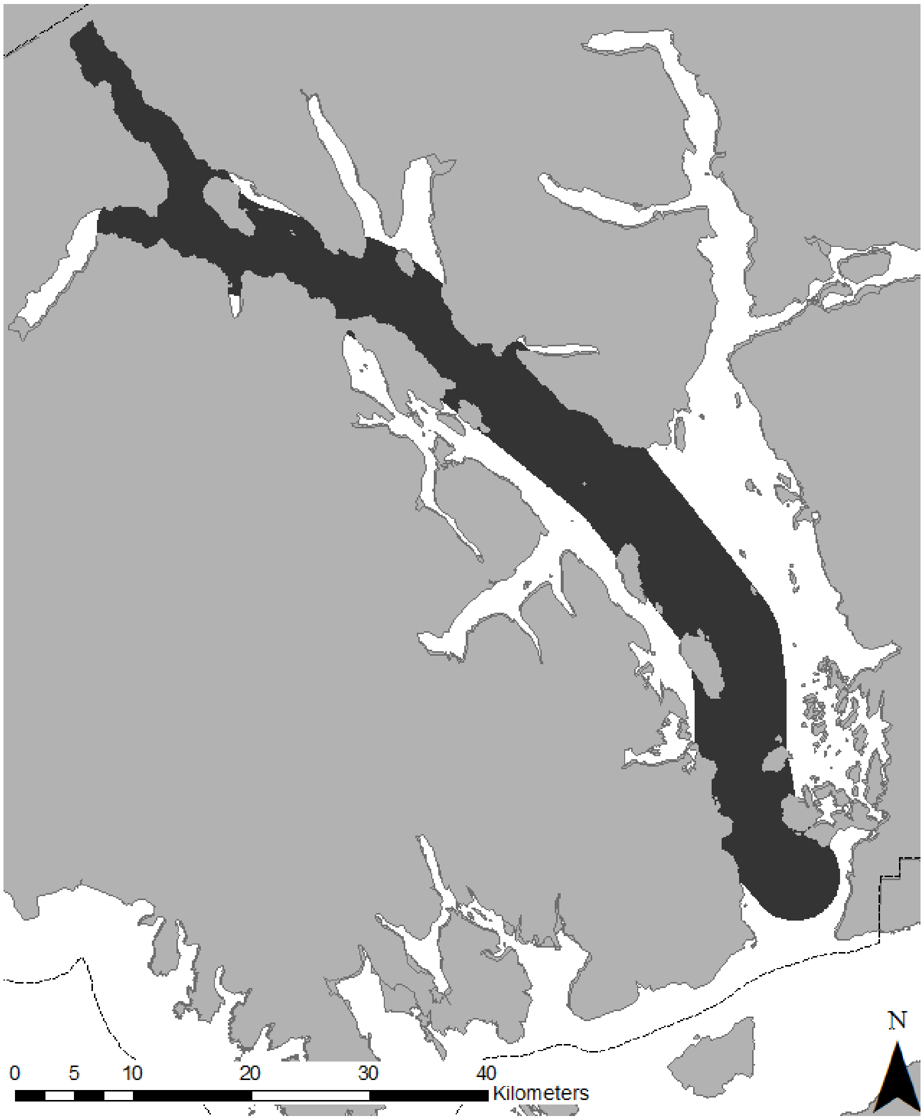

Figure 4.1. Map of Glacier Bay National Park, Alaska. The area shaded in dark grey indicates a 3.8 km buffer around a typical cruise ship travel route in Glacier Bay. Cruise ships traveling the Bay are predicted to disturb (defined as flushing) some portion of Kittlitz's murrelets within this buffer. The buffer encompasses 614 km^2 of the 1,258 km^2 (49%) of the water surface within Glacier Bay.

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