EVALUATING POPULATION TRENDS OF KITTLITZ'S MURRELETS IN ALASKA

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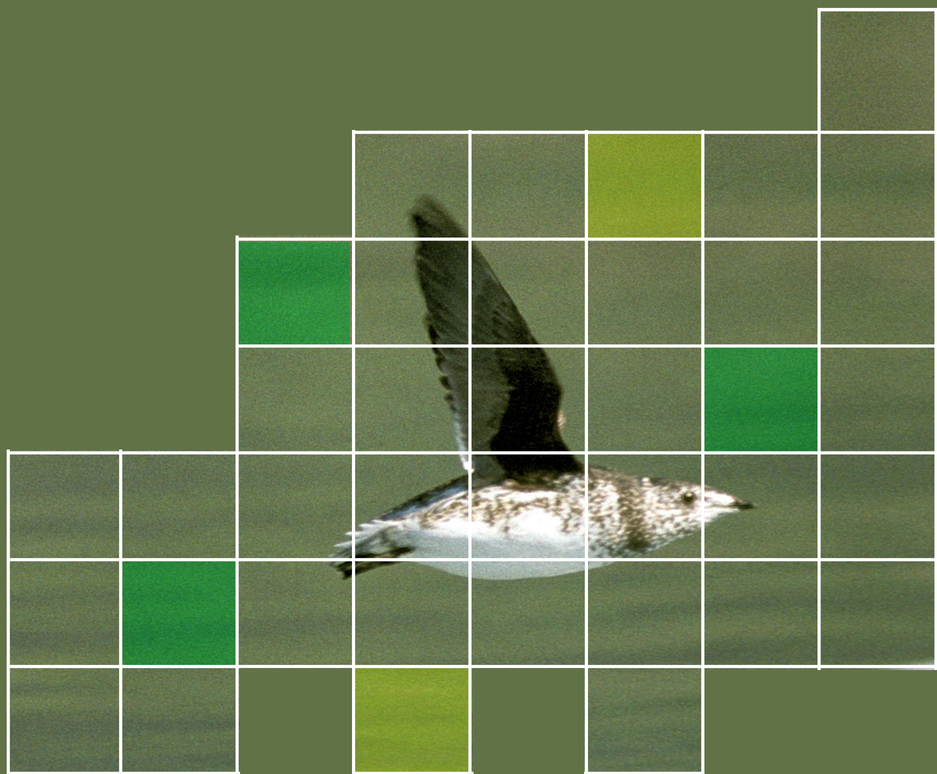

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FINAL REPORT

Prepared for

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EXECUTIVE SUMMARY

- The Kittlitz's Murrelet (*Brachyramphus brevirostris*) has been identified as species of conservation concern by a variety of organizations, primarily because of reports of population declines across much of the northern Gulf of Alaska. However, questions have been raised about both the accuracy of population trends and the methods used to determine those trends.
- I collated and evaluated publications related to Kittlitz's Murrelet populations and density estimates and population trends in Alaska to determine the basis for the reports of population declines. I also reevaluated each publication in terms of weaknesses and strengths and interviewed ten Kittlitz's Murrelet experts about their opinions about population trend and factors affecting/limiting Kittlitz's Murrelet populations.
- Over the past 35 years, numerous methods have been used to survey populations and/or determine the population trend of Kittlitz's Murrelets in Alaska. Within a geographic region, there has been evolution of methodology over time. There also have been dramatic changes among studies and regions in methodology, making comparability of data sets questionable. In addition, many studies suffer from inadequate sampling and/or inconsistent or inappropriate study designs, again reducing the utility of most studies for population estimation and/or trend analysis.
- In spite of these problems, there has been evolution over time toward stronger and more-rigorous study designs that provide insights into useful elements that should be incorporated into a new monitoring study design.
- Essentially every study exhibited one or more weaknesses in either data collection or data analysis, whereas only recent studies had strengths.
- I interviewed ten experts about their perceptions and opinions about whether Kittlitz's Murrelet populations were declining and what factors they believed had strong effects on Kittlitz's murrelet populations. There was great diversity of opinion about whether Kittlitz's Murrelet populations were declining, with equal percentages indicating that there was evidence of declines, that there was no evidence of declines, and that there was so much uncertainty that population trends could not be determined. There was little variability in the respondents' opinions about factors having a major impact on Kittlitz's Murrelet populations, with food limitation and physiological stress of some sort being viewed as the primary factors.
- To some extent, methodology has evolved because of changes in technology that have helped improve sampling methodology in the field (e.g., line-transect sampling methods, the advent of GPS systems), changes in the statistical sophistication of scientists and the statistical tools available to them for analyzing data (e.g., GIS-based analyses of data, strong statistical software), and changes in the objectives of studies as concerns began to be aired about the population trends of Kittlitz's Murrelets (e.g., the use of single-species surveys or *Brachyramphus* surveys, rather than multi-species surveys).
- In every case examined here, the older data that are being used as baseline data sets suffer from a variety of problems that are so severe that they really are unusable as baseline data. These earlier studies suffer from problems with sampling methodology, study design, layout of sampling effort, insufficient sampling intensity, incorrect approach to stratification, excessive rates of unidentified birds, possible misidentification, and/or a variety of other problems.
- Although I have indicated that the baseline data are not adequate for concluding that Kittlitz's Murrelets have undergone dramatic, catastrophic declines across large parts of their range, I emphasize that this conclusion does not mean that the species has not undergone smaller declines in parts or all of its range; it also is possible that there has been a population shift of this species.

- I recommend the development of a coordinated and statistically-rigorous monitoring scheme focused on monitoring Kittlitz's Murrelet populations as a whole, across the state.
- Before a new monitoring program can be developed, several issues related to population monitoring should be considered and/or evaluated when designing a new monitoring program. I provide a list of recommendations, questions that need to be answered, and issues that need to be considered in designing such a program.

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ACKNOWLEDGMENTS

This study was funded by the Alaska Department of Fish and Game; I also thank Sadie Wright, Karen Blejwas, and Mary Rabe of that organization for their assistance. I am greatly indebted to the Principal Investigators on the various studies and other scientists for graciously allowing me to interview them about their thoughts on Kittlitz's Murrelets. At ABR, I thank Alexander Prichard and Tawna Morgan for statistical advice; Pamela Odom for assistance with reporting; and Thomas DeLong for help with contracting. This report has been improved by the reviews of Sadie Wright, Karen Blejwas, Mary Rabe, and Kim Titus.

INTRODUCTION

The Kittlitz's Murrelet (*Brachyramphus brevirostris*) is featured in Alaska Wildlife Action Plan (formerly known as Alaska's Comprehensive Wildlife Conservation Strategy; ADFG 2006), a federally-approved plan that outlines conservation actions for Alaska's "species of greatest conservation need." The species is a Candidate Species for listing under the federal Endangered Species Act (ESA; USFWS 2008), and, in 2009, the Center for Biological Diversity requested that the Alaska Department of Fish and Game evaluate this species to determine whether it should be listed as "endangered" under the State's endangered species statutes (CBD 2009). It also is considered a species of high conservation concern by various organizations, including Audubon Alaska (Kirchhoff and Padula 2010), the North American Waterbird Conservation Plan (Kushlan et al. 2002), and others.

Surveys for Kittlitz's Murrelets have been conducted in the mainland fjords of Southeastern Alaska, Glacier Bay and Icy Strait, Yakutat Bay and the Malaspina Forelands, Icy Bay, Prince William Sound, Kenai Fjords, Kachemak Bay, Cook Inlet, and portions of the Alaska Peninsula and Aleutian Islands. The conservation concerns for this species, and an impetus for many of the recent surveys, center on reported declines of 60–90% occurring over the last 20 years in a number of population concentrations, including Glacier Bay and Prince William Sound (Kuletz et al. 2003, Piatt et al. 2007). However, recent surveys in Glacier Bay, where a large number of Kittlitz's Murrelets occur, found evidence of steady or increasing Kittlitz's Murrelet populations (Kirchhoff 2008, Kirchhoff et al. 2010; Hoekman et al. 2011a, 2011b), raising questions about both the accuracy of earlier analyses of population trends and the comparability of methods used to determine those trends. Determination of population trends within a particular area is influenced by a variety of factors, so there is a need to evaluate all of the data that are being used to determine trends.

Uncertainty about population trends of Kittlitz's Murrelets is resulting in questions about the need for protection of that species under the ESA. For example, uncertainty about the trend data is one factor that led the State of Alaska to deny the Center for Biological Diversity's recent request to list the Kittlitz's Murrelet as a State endangered species, although it should be noted that the standards for listing under the State of Alaska's statute differ from, and are more narrow than, standards for the federal ESA. Hence, there is a need for a better understanding of the studies on which population trends have been based.

OBJECTIVES

This study has the following objectives:

- Examine reports and publications that discuss population surveys, density estimates, and/or trend analyses of Kittlitz's Murrelets in Alaska.
- Describe surveys discussed in each report, including study objectives, overall study design, sampling methodology, sampling protocol, study assumptions, and data analysis; evaluate population trend estimates in these studies and determine whether they are reliable.
- Identify those areas in Alaska where there is reliable evidence for a population decline, areas where the population appears to be stable or increasing, and areas where more data are needed to estimate a population trend; and, if surveys from the same areas suggest different population trends, suggest possible explanations for the differences.
- Use data from those surveys (if any) that are found appropriate for estimating the population size of Kittlitz's Murrelet in Alaska.
- Interview a series of Kittlitz's Murrelet experts about their views on population trends and factors that may be affecting Kittlitz's Murrelet populations in Alaska.

BACKGROUND

Kittlitz's Murrelets are small, inconspicuous seabirds that are endemic to Beringia—the former area that occurred from the Verkhoyansk range of northeastern Russia to the Rocky Mountains just east of the Alaska–Yukon border during the Pleistocene glaciation. Because they are endemic to this area, they have a strong association with glaciated and formerly-glaciated habitats (Day et al. 1999, Piatt et al. 1999), ranging in Alaska from southeastern Alaska to the Chukchi Sea.

Kittlitz's Murrelets, and their closely-related congener Marbled Murrelets (*Brachyramphus marmoratus*), are unusual for seabirds in that they are solitary nesters; they also nest in inaccessible places (Day et al. 1983, 1999), generally making locating nests (and, hence, monitoring population size and breeding effort) extremely difficult. Consequently, studying population size and monitoring population trends in this species are impossible to do on the breeding grounds, in contrast to colony-based studies that are used for most seabird species. However, these birds sit on the ocean and forage at sea in the vicinity of nesting areas, making that the logical location for monitoring. In these marine areas, birds occur in both nearshore (i.e., ≤200 m from shore) and offshore (i.e., >200 m from shore) areas; most birds occur in offshore areas, usually because those are much larger than nearshore zones (e.g., Kirchhoff 2008).

METHODS

I collated and evaluated both unpublished reports and white-literature papers (hereafter, both are collectively referred to as "publications") related to Kittlitz's Murrelet populations and density estimates and population trends in Alaska. Because these publications varied from unpublished reports to published scientific papers, they had varying degrees of scientific rigor, completeness of information, and statistical analysis. I assembled the publications and evaluated them in chronological order within a region; regions used here included Glacier Bay, Icy Bay and miscellaneous Southeastern Alaska, Prince William Sound, Kenai Fjords, Cook Inlet and Kachemak Bay, and Alaska Peninsula/Aleutian Islands (Figure 1). It was informative to evaluate the publications within a region because different methodologies often were used in different regions. I then summarized for each publication in a matrix table how the data were collected and recorded by observers, survey design, survey protocol, data analysis, and population counts or estimates. I also summarized what I thought were biases or problems in the numbers or population trends presented what I thought were other types of biases or problems, and what strengths I thought each study had. I attempted to fill in each cell of information in the matrix, but that was not always possible.

After assembling the matrix, I reevaluated each publication in terms of weaknesses and strengths. I classified four main types of weaknesses in data collection and two main types of weaknesses in data analysis (Table 1), then summarized what I believed to be the main weaknesses of studies in each region. I classified four main types of strengths in data collection and two main types of strengths in data analysis (Table 2), then summarized what I believed to be the main strengths of studies in each region.

I also interviewed ten Kittlitz's Murrelet experts about two issues: population trend and factors affecting/limiting Kittlitz's Murrelet populations. These experts are employed at state and federal agencies, private companies, and non-governmental organizations. I first asked the experts whether they thought that Kittlitz's murrelets were undergoing or had undergone a population change—either a decrease or an increase—and why. I also asked them what factors they thought had the strongest effect on Kittlitz's Murrelet populations.

After evaluating the evidence, I addressed the overall questions whether or not there is sufficient information to determine (a) the population size of Kittlitz's Murrelets in Alaska and (b) the population trend of Kittlitz's Murrelets in Alaska. Finally, I used the results of this study to recommend important attributes and issues that needed to be incorporated or considered for incorporation into a monitoring program for Kittlitz's Murrelets in Alaska.

In this report, I use the generic terms "nearshore" and "offshore" survey to represent the terminology used in the various publications. For example, nearshore surveys, which generally represent a small-boat survey of the nearshore zone (usually, but not always, ≤200 m from shore), have variously been called nearshore, coastal, shoreline, and shoreline/coastal surveys, and possibly more. Similarly, offshore surveys, which represent a broad range of survey types conducted from larger boats at various distances from shore (but at least

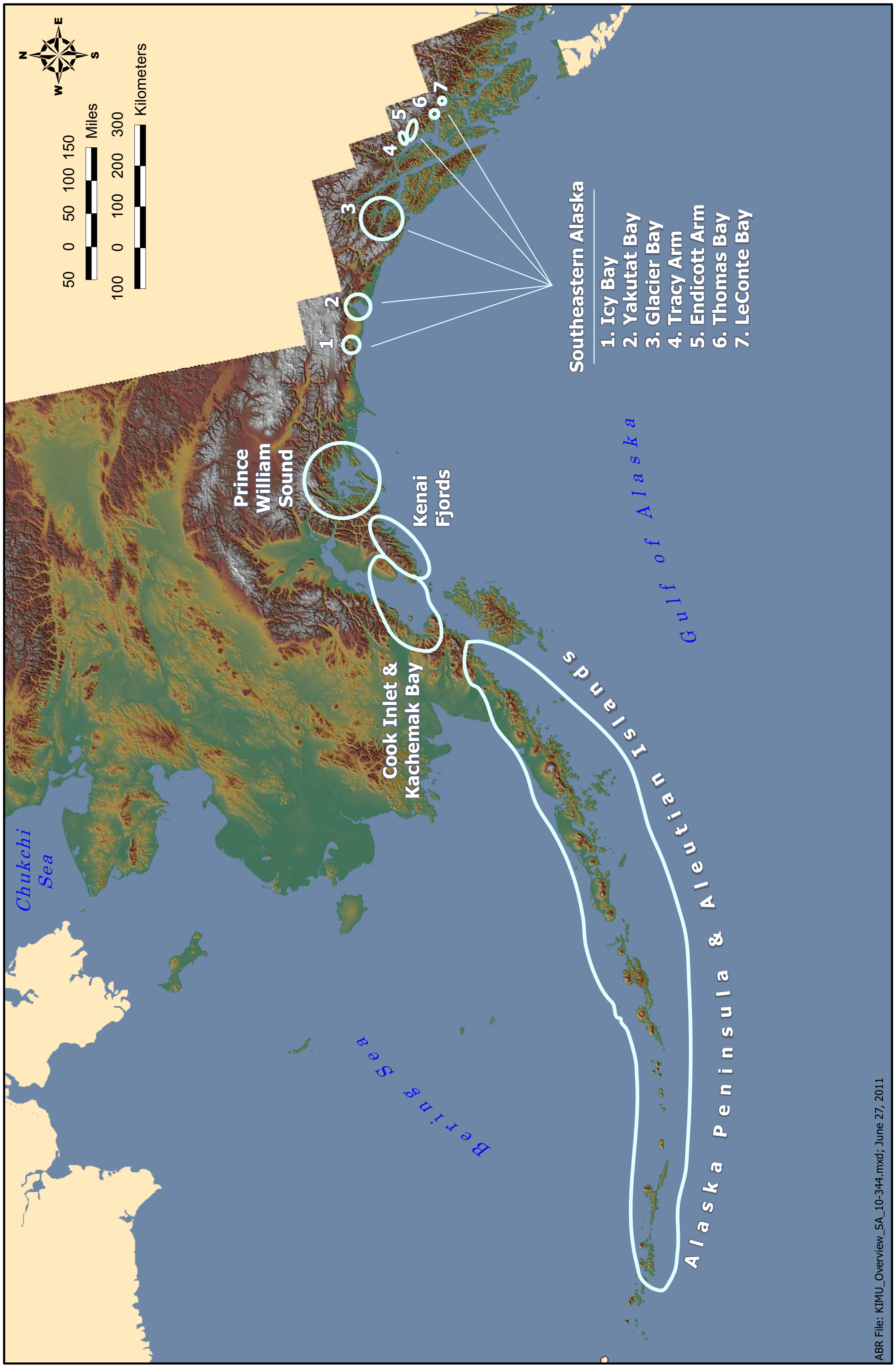

Figure 1. Study area showing geographic regions discussed in text.

Table 1. Weaknesses in studies of the abundance and/or population trends of Kittlitz's Murrelets in Alaska.

Weakness	Definition
DATA COLLECTION	
Inappropriate study design or sampling methodology for quantifying population numbers	Study design and/or sampling methodology make study inappropriate for accurately quantifying abundance (e.g., only nearshore sampling, oversampling of nearshore, large number of unidentified birds, random sampling design for clumped species, insufficient sampling of habitat that species concentrates in, ignoring inshore-offshore density gradient that results in inaccurate population estimate, not identifying birds to species, continuous count of flying birds).
Inappropriate study design or sampling methodology for monitoring population trend	Problems with study design and/or sampling methodology make accurately quantifying trend in abundance doubtful or impossible (e.g., random sampling design for clumped species, insufficient sampling of habitat that species concentrates in, inconsistency in timing of sampling that increases variability, no quantification of variability, continuous count of flying birds).
Insufficient sampling intensity	Methodology may or may not be appropriate, but intensity of sampling clearly is insufficient for accurately quantifying abundance so that data can be used for population monitoring (e.g., sampling effort insufficient to generate accurate population estimates or monitoring numbers, lack of replication).
Sampling methodology is such that comparisons with other data sets is difficult or impossible	Methodology may or may not be appropriate, but methodology is so different from other studies that comparisons with other data sets are invalid (e.g., multiple methods used in the same study, land-based surveys, flyway counts, aerial surveys).
DATA ANALYSIS	
Inappropriate analytical methodology for quantifying population numbers or population trend	Problems with data analysis makes accurately quantifying abundance or accurately conducting trend analyses impossible (e.g., errors in data analysis, ignoring data, inappropriate statistical comparisons, incorrect stratification or correction of estimates based on attributes that are not significantly different, not apportioning unidentified birds to species).
Inappropriate method for apportioning unidentified birds to species	Method of apportioning unidentified birds to species is inappropriate (e.g., using KIMU:MAMU ratios throughout an entire bay or large area for apportionment if KIMUs occupy only a small part of that study area)

Table 2. Strengths in studies of the abundance and/or population trends of Kittlitz's Murrelets in Alaska.

Strength	Definition
DATA COLLECTION	
Strong study design or sampling methodology for quantifying population numbers	Study design and/or sampling methodology make study appropriate for accurately quantifying abundance (e.g., mix of nearshore and offshore sampling, emphasis of sampling offshore zone, few unidentified birds, adaptive and/or stratified sampling design for clumped species, emphasis on sampling of habitat that species concentrates in, accounting for inshore-offshore density gradient, snapshot count of flying birds).
Appropriate study design or sampling methodology for monitoring population trend	Study design and/or sampling methodology make study appropriate for accurately quantifying trend in abundance (e.g., adaptive and/or stratified sampling design for clumped species, emphasis on sampling of habitat that species concentrates in, consistency in timing of sampling among years, quantifying variability, snapshot count of flying birds).
Sufficient sampling intensity	Methodology may or may not be appropriate, but intensity of sampling is sufficient for accurately quantifying abundance so that data can be used for population monitoring (e.g., sampling effort sufficient to generate accurate population estimates or monitoring numbers, use of replication).
Sampling methodology is comparable with other data sets	Methodology may or may not be appropriate, but methodology is similar to that of other studies that are deemed to be useful (e.g., similar sampling methods, similar timing of surveys).
DATA ANALYSIS	
Appropriate analytical methodology for quantifying population numbers or population trend	Data analysis accurately quantifies abundance and/or trend analyses (e.g., appropriate statistical comparisons, correct stratification or correction of estimates based on attributes that are not significantly different).
Appropriate method for apportioning unidentified birds to species	Method of apportioning unidentified birds to species is appropriate (e.g., using KIMU:MAMU ratios for part of a bay, given that most KIMUs occupy a small part of bay)

200 m offshore), have variously been called offshore, pelagic, and coastal-pelagic surveys, and possibly more.

In this report, I also use the term "population" in a general sense. The term "population" can represent a breeding population, a total population, a non-breeding population, or a mixture. In none of the studies discussed here did the authors define exactly what population they were referring to. Hence, I will follow suit and use the term "population" generically.

RESULTS

STUDY METHODOLOGIES

Over the past 36 years, numerous methods have been used to survey populations of Kittlitz's Murrelets in Alaska during the ~35 studies examined here (Tables 3–7). Several of these attributes discussed in Tables 3–7 have important implications for the study of Kittlitz's Murrelets. Although a large amount of detail is shown in Tables 3–7, I discuss here what I consider to be the attributes of greatest importance in the context of this study.

Most studies have included various amounts of both nearshore and offshore boat-based sampling in their methodology (Table 3), primarily because the best place to monitor populations is on the water. However, a few studies have used only nearshore surveys or very few offshore surveys (e.g., Bailey 1976, Nishimoto and Rice 1987, Meehan 1995; Piatt et al., undated), reducing their utility in population estimation and monitoring. Studies that use only nearshore data or few offshore data are of limited utility because the great majority of a Kittlitz's Murrelet population that is at sea occurs in offshore waters.

Most studies have conducted multi-species surveys (with sometimes >50 species being recorded) that included data on murrelets, but only a few studies have focused exclusively on murrelets (e.g., Day and Nigro 1999; Kissling et al. 2007a, 2007b; Kirchhoff et al. 2010; Arimitsu and Piatt, undated; Table 3). Studies that focus exclusively on murrelets presumably are more accurate than ones in which observers have to count all species, although this hypothesis has not been tested, to my knowledge. In reality, however, resource-management agencies generally are unwilling to fund single-species surveys and generally do so only when a species becomes high profile because of management or conservation concerns.

Study designs have consisted of a few categories (Table 4). The simplest is a continuous nearshore survey that usually is 200 m wide and includes the assumption of a complete census (i.e., that all murrelets within the nearshore survey zone are detected and counted). More-common (and more-complicated) surveys include nearshore censuses (or inclusion of data in overall density calculations) with offshore strip-transect surveys that are either random, stratified random (e.g., Agler et al. 1995, McKnight et al. 2008), or systematic in layout (e.g., Kissling et al. 2007c, Drew et al. 2008). For population estimation, these surveys generally have treated the nearshore survey as a census and the offshore survey as a sampled estimate of density that then is converted to an estimate of population (with associated measures of variation) based on the area of the offshore zone; this estimation technique usually has been done as ratio estimation (e.g., McKnight et al. 2008). Recent variations of these techniques include line-transect methodology (e.g., Kissling et al. 2007a, 2007b, 2007c; Kirchhoff 2008), rather than strip transects, and adaptive sampling (e.g., Kissling et al. 2007a).

The methodology for counting flying birds has varied a great deal among studies (Table 4). Many of these at-sea studies of birds have followed Gould and Forsell (1989), who advocated the use of a "snapshot method" for counting flying birds. This method basically consists of sampling a zone 300 m wide and ahead of the moving ship; birds on the water are counted continuously, whereas flying birds are counted as a "snapshot" of birds in the air 300 m ahead of the ship. Hence, a new snapshot should be taken every time the ship advances 300 m (or however far ahead of the ship one is looking), so that flying birds in "new" airspace can be counted. Unfortunately, many studies indicated that they followed Gould and Forsell (1989), then counted flying birds continuously. To some extent, this approach probably reflected in most cases a desire to follow data-collection methods used in earlier studies, which were conducted (incorrectly) before the methodology of Gould and Forsell (1989) was published. By following earlier

Table 3. Characteristics of studies that have surveyed the abundance or population trend of Kittlitz's Murrelets in Alaska—Part A.

Region/citation	Objective(s)	Year(s)	Dates	Habitat	Location	Survey type (single species, multi-species)
GLACIER BAY						
Piatt et al. (undated)	assess KIMU and MAMU distributions	1991	13 JN–15 JL	all nearshore and a small amount of offshore area	Glacier Bay National Park	multi-species
Lindell (2005)	assess baseline murrelet distribution and abundance in Icy Strait and nearby areas	1993–1999	JN–AU	nearshore (rarely) and offshore	Icy Strait and nearby bays (including Glacier Bay)	single species (murrelets)
Robards et al. (2003)	inventory marine-fish predators (including seabirds)	1999–2000	10–23 JN 1999, 17–22 JN 2000	nearshore (shoreline) and offshore (pelagic)	Glacier Bay National Park	multi-species
Drew and Piatt (2008)	analyze population trends in Glacier Bay	1991, 1999–2000	JN	nearshore (1991, 1991–2000), offshore (1999–2000)	Glacier Bay National Park	multi-species
Drew et al. (2008)	determine distribution and abundance of marine predators and forage fishes in relation to oceanography; assess survey methodologies	1999–2003	10–26 JN 1999, 17–23 JN 2000, 16–21 JN 2001, 7–13 JN 2002, 9–14 JN 2003	nearshore and offshore (pelagic)	Glacier Bay National Park and nearby Icy Strait	multi-species
Romano et al. (2004)	describe at-sea distribution and abundance of KIMU and MAMU ast a variety of scales	2003	9–14 JN, 12–19 JL, 5–11 AU	nearshore and offshore	Glacier Bay National Park	multi-species
Kirchhoff (2008)	identify methods for murrelet monitoring in Glacier Bay	2007	9–15 JL	nearshore and offshore	Glacier Bay National Park	single species (murrelets)
Arimitsu and Piatt (undated)	estimate size of murrelet breeding population in Glacier Bay	2008	23–26 JN	nearshore and offshore	Glacier Bay National Park	single species (murrelets)
Hoekman et al. (2011a)	testing survey and analytical methodologies: (1) implement line-transect surveys for KIMU and MAMU; (2) test assumption of 100% detection near transect centerline; (3) compare line transects and strip transects; (4) assess performance of 1 and 2 observers; (5) evaluate analytical methods to account for incomplete detection and unidentified birds.	2009	8–15 JL	nearshore and offshore	Glacier Bay National Park	single species (murrelets)
Hoekman et al. (2011b)	refine survey and analytical methods based on the 2009 surveys	2010	8–16 JL	nearshore and offshore	Glacier Bay National Park	single species (murrelets)

Table 3. Continued.

Region/citation	Objective(s)	Year(s)	Dates	Habitat	Location	Survey type (single species, multi-species)
Kirchhoff et al. (2010)	analyze KIMU population trends based on past and current surveys	1993, 2009	1 JN–15 JL [24 JN?] 1993; 3–9 JL 2009	nearshore and offshore	Glacier Bay National Park	single species (murrelets)
ICY BAY, OUTER COAST & MISCELLANEOUS LOCATIONS						
Stephensen and Andrus (2001)	determine summer abundance of marine birds and mammals; also surveyed some areas for nesting Black Oystercatchers and counted birds at previously-known seabird colonies	2000	16–19 JN	nearshore (shoreline) and offshore (pelagic)	Yakutat Bay, including Disenchantment bay and Russell and nunatak fjords	multi-species
Kissling et al. (2007a)	describe distribution and abundance in a previously unsurveyed area	2003–2004	3–11 JL 2003, 6–16 JL 2004	primarily exposed coast; nearshore (shoreline) and offshore	Pt. Carolus-Yakutat	single-species (murrelets only)
Kissling et al. (2007b)	assess distribution and abundance of murrelets in specific parts of SE Alaska	2002–2004	7–14 JL 2002, 3–11 JL 2003, 6–16 JL 2004	fjords, exposed coast	Icy Bay to LeConte Bay (scattered locations)	single-species (murrelets only)
Kissling et al. (2007c)	collect data to help develop long-term monitoring plan for KIMU that would result in reliable trend estimates	2005	2 JL–5 AU	nearshore and offshore (pelagic) zones of fjord	Icy Bay	unspecified, presumably single-species (murrelets only)
PRINCE WILLIAM SOUND						
Day and Nigro (1999)	determine population size in four fjords; estimate KIMU population; determine habitat associations	1996–1998	late MY–early AU, primarily early JN–late JL	nearshore and offshore	Unakwik Inlet, College Fjord, Harriman Fjord, Blackstone Bay	single-species (murrelets)
Kuletz et al. (2003a)	determine distribution and population size in 17 fjords where the species may occur	2001	22 MY–3 AU	nearshore (shoreline/coastal) and offshore (pelagic)	17 fjords where the species had been recorded	multi-species
Kuletz et al. (2003b)	assess population changes in relation to glacier characteristics	1989–2000, 2001	late JN–late JL	nearshore (shoreline) and offshore (pelagic)	Sound-wide surveys, 17 fjords where the species had been recorded	multi-species
McKnight et al. (2003)	assess distribution and population size	2003	13–16 JN, 12–15 JL, 9–12 AU (associated with spring tides)	nearshore (shoreline/coastal) and offshore (pelagic)	College and Harriman fjords	single-species (murrelets only)
Kuletz et al. (2007)	describe KIMU population trends in PWS	1972, 1989–2004	JL	nearshore (shoreline/coastal) and offshore (pelagic)	throughout PWS	multi-species
McKnight et al. (2008)	assess population trends in oiled and unoiled areas	1989–2007	MR, JL	nearshore (shoreline/coastal) and offshore (pelagic)	throughout PWS	multi-species

Table 3. Continued.

Region/citation	Objective(s)	Year(s)	Dates	Habitat	Location	Survey type (single species, multi-species)
KENAI FJORDS						
Bailey (1976)	basic reconnaissance of marine birds breeding in the region; determine species composition, distribution, and abundance of marine birds and mammals	1976	19 JN–14 JL	protected bays, open coastline	Gore Point–Callisto Head, Cape Resurrection, and islands at mouth of Resurrection Bay	multi-species
Nishimoto and Rice (1987)	detect gross changes in coastal seabird and marine mammal distribution and abundance as opposed to a 1976 survey	1986	25 JN–12 JL	protected bays, open coastline	Gore Point–Callisto Head, Cape Resurrection, and islands at mouth of Resurrection Bay	multi-species
Bailey and Rice (1989)	assess injury to seabird and marine mammal populations along the south coast of the Kenai Peninsula as a result of the oil spill from the T/V *Exxon Valdez*; collection of dead and live wildlife specimens	1989	27 JN–7 JL, 24 JL–4 AU (replicate surveys)	protected bays, open coastline	Gore Point–Callisto Head, Cape Resurrection, and islands at mouth of Resurrection Bay	multi-species
Van Pelt and Piatt (2003)	develop accurate population estimates of Kittlitz's Murrelets to assess the true status of the species; conduct broad-scale surveys in areas where the species is known to occur but has not been monitored in the past; replication of surveys in core areas to produce more precise information on population trends; emphasize spatial scale and accuracy of population estimates over the precision of those estimates	2002	3–13 JL	protected bays, open coastline	Gore Point–Cape Resurrection	multi-species
Romano et al. (2006)	examine the variability in the at-sea distribution, abundance, and habitat use of KIMU and MAMU during the breeding season (May–August) in the nearshore waters adjacent to Kenai Fjords National Park	2006	25 JN–5 JL	protected bays, open coastline	Gore Point–Callisto Head	multi-species
Arimitsu et al. (2010)	examine variability in the at-sea distribution, abundance, and habitat use of KIMU and MAMU during the breeding season (June–August) in the nearshore waters adjacent to Kenai Fjords National Park	2006–2008	late JN to mid-JL	protected bays, open coastline	Gore Point–Callisto Head	multi-species
KACHEMAK BAY & COOK INLET						
Agler et al. (1995)	baseline data on abundance and distribution of marine bird populations during summer and winter	1993–1994	7–23 JN (1993), 6 FE–10 MR (1994; sporadically)	protected bays, open coastline; both nearshore (shoreline) and offshore (coastal, pelagic)	southern Cook Inlet (in summer, from Cape Douglas to Point Adam on the south and from Harriet Point to Cape Kasilof on the north; in winter, from Ninilchik south to ~20 NM north of Barren Islands and west to 152°28'longitude line)	multi-species

Table 3. Continued.

Region/citation	Objective(s)	Year(s)	Dates	Habitat	Location	Survey type (single species, multi-species)
Kuletz et al. (2008)	current population estimates and decadal trends of KIMU and MAMU	1984–2004 (irregularly)	JN, JL, and AU 2004–2007 for field surveys; also used historical data from	primarily protected bay; both nearshore and offshore	Kachemak Bay	multi-species
ALASKA PENINSULA & ALEUTIAN ISLANDS						
Meehan (1996)	identify murrelet abundance and distribution	1993–1995	year-round	nearshore, offshore (in places), pelagic	Adak Island	single species (murrelets)
Romano et al. (2005a)	identify murrelet abundance and distribution	2005	15–19 JN	nearshore and offshore waters	Unalaska Island	multi-species
Van Pelt and Piatt (2005)	determine population status of KIMU along southern coast of the Alaska Peninsula	2003	8 JN–12 JL	both bays and exposed coasts	southern side of Alaska Peninsula, from Cape Douglas to Isanotski Strait	multi-species
Romano et al. (2005b)	describe at-sea density and distribution of KIMU and MAMU around Atka Island and provide a population estimate for each species	2004	11-13 JN	nearshore and offshore waters	eastern ~75% of Atka Island	multi-species
OTHER/MULTIPLE LOCATIONS						
Agler et al. (1998)	estimate murrelet abundance and distribution in three parts of Alaska	1989–1991, 1993–1994	FE–MR 1994/JN (CI), MR/JL 1989–1991, 1993 (PWS), JN/JL 1994 (SE)	nearshore and offshore (bay, pelagic)	throughout lower Cook Inlet, Prince William Sound, and Southeastern Alaska	multi-species
Kendall and Agler (1998)	determine distribution and abundance of birds in three parts of Alaska	1989–1991, 1993–1994, 1996	FE-MR 1994/JN (CI), MR/JL 1989–1991, 1993, 1996 (PWS), JN/JL 1994 (SE)	nearshore and offshore	throughout lower Cook Inlet, Prince William Sound, and Southeastern Alaska	multi-species

Table 4. Characteristics of studies that have surveyed the abundance or population trend of Kittlitz's Murrelets in Alaska—Part B.

Region/citation	Sampling design	Sampling unit	Overall sampling methodology	Flying birds counted?	Replicate samples collected?	Sampling platform
GLACIER BAY						
Piatt et al. (undated)	continuous nearshore census; offshore sampling unclear and only mentioned in passing	continuous census	census	counted (continuously); included in density estimates	no	5-m skiff
Lindell (2005)	systematic and opportunistic strip transects of varying methodology	transect	strip transects running diagonally (zigzag), perpendicular, and parallel to shore	counted (unclear methodology) but not included in density estimates	no	20-m boat
Robards et al. (2003)	systematic strip transects	transect	nearshore census and offshore sample with systematically placed strip transects ~2.5 km apart	counted (continuously); included in density estimates	no	8–22 m boats
Drew and Piatt (2008)	systematic strip transects	transect extrapolated to nearshore area	compare densities estimated from overlapping area of nearshore zone	counted (continuously); included in density estimates	no	<6-m skiff (1991), 16–22-m boats (1999–2000)
Drew et al. (2008)	continuous nearshore census and systematic strip transects	transect	nearly-continuous nearshore survey and systematic strip-transect offshore survey	counted (continuously); included in density estimates	no	8–22-m boats
Romano et al. (2004)	continuous nearshore and systematic offshore strip transects	transect	strip transects established in 1999 on monthly, weekly, and daily bases to describe variation in density patterns	counted (continuously); included in density estimates	some (to examine daily patterns in variation)	8–15-m boats
Kirchhoff (2008)	strip and line transects and flyway counts	transect	tested differences between strip and line transects run simultaneously; also evaluated flyway counts as measure of trend analysis and population variability	unspecified	no	9-m boat
Arimitsu and Piatt (undated)	stratified random nearshore and offshore historical transects	transect	used strip transects to sample nearshore and offshore areas; transects were repeats from historical studies	counted (continuously) but analyzed separately	no	7.7-m boat
Hoekman et al. (2011a)	stratified random offshore transects; in effect, only the small ends of those lines fell within nearshore waters, but the data were not stratified into nearshore and offshore zones	transect	stratified the bay into 3 regions of historically high densities and a large area of historically low densities, with high-density strata receiving twice the sampling intensity as the low-intensity stratum; line-transect sampling	unclear whether counted or, if so, used in population estimate	no	unclear size
Hoekman et al. (2011b)	stratified random offshore transects; in effect, only the small ends of those lines fell within nearshore waters, but the data were not stratified into nearshore and offshore zones; additional sampling in narrow, enclosed arms	transect	stratified the bay into 3 regions of historically high densities, a large area of historically low densities, and a stratum of narrow, enclosed arms, with high-density strata receiving twice the sampling intensity as the low-intensity stratum; line-transect sampling	yes, to 200 m to sides and ahead of boat; however, numbers not used in population estimate	no	unclear size
Kirchhoff et al. (2010)	systematic transects to cover mostly offshore waters	transect	zigzag transects along shoreline, extending to middle bay; same lines as 1993	no [Note: However, they later indicate that they used counts of flying birds in population estimates to make them comparable to earlier methods.]	yes	10.7- and 15.9-m boats

Table 4. Continued.

Region/citation	Sampling design	Sampling unit	Overall sampling methodology	Flying birds counted?	Replicate samples collected?	Sampling platform
ICY BAY, OUTER COAST & MISCELLANEOUS LOCATIONS						
Stephensen and Andrus (2001)	nearshore census and systematic sampling in offshore	transect	fixed-width strip-transects in nearshore; fixed-width systematic line transects in offshore	unspecified, but appears to be yes because they counted birds up to 100 m above them; methodology unspecified	no	4.3- and 6.7-m vessels
Kissling et al. (2007a)	systematic sampling with adaptive cluster sampling in areas with high densities	transect	fixed-width systematic line transect with 25-m distance bins	counted (method unspecified)	no	5.5-m skiff (nearshore); 20-m boat (offshore)
Kissling et al. (2007b)	nearshore census and systematic sampling in offshore	transect	strip-transect (2002); fixed-width systematic line transect with 25-m distance bins (2003–2004)	counted (method unspecified)	some (only along Outer Coast in 2003)	5.5-m skiff on nearshore surveys and in protected waters; 20-m boat on offshore surveys and in exposed waters
Kissling et al. (2007c)	nearshore census and systematic strip transects offshore	transect	unlimited-distance line transect in both habitats, even though width of sampling zone differed between the two survey types; later binned offshore data into 50-m bins for analyses	counted (method unspecified)	no, but 5 weekly samples collected consecutively	5.5-m skiff
PRINCE WILLIAM SOUND						
Day and Nigro (1999)	nearshore census, random strip transects; also pelagic strip transects in Eaglek Bay and Port Wells to see if birds left the bays	transect	census and stratified random sampling of transects in 3 strata (2 focal strata) in four bays	counted (continuously); included in density estimates	no	primarily 4-m skiff (nearshore and most offshore); ~17-m seiner (late summer offshore and pelagic)
Kuletz et al. (2003a)	nearshore census and systematic strip transects offshore	transect	census and systematic random sampling in 3 strata	unspecified, but counted continuously in other surveys that were said to be similar	no	8-m boat
Kuletz et al. (2003b)	random stratified (1989–2000); continuous nearshore and systematic offshore (2001)	transect (1989–2000); continuous nearshore census and offshore transect (2001)	census and systematic random sampling in 3 strata	counted continuously (1989–2000); unspecified, but counted continuously in other surveys that were similar	no	8-m boat
McKnight et al. (2003)	nearshore census and systematic strip transects approximately replicating previous surveys in 2001	continuous nearshore census and offshore transect	census and systematic random sampling in 2 strata	unspecified, but counted continuously in other surveys that were said to be similar	no	8-m boat
Kuletz et al. (2007)	random (1972); stratified random strip transects (1989–2004)	transect	census and systematic random sampling in 3 strata	counted (continuously)	no	8-m boat; similar size for 1972
McKnight et al. (2008)	stratified random strip transects	transect	census and systematic sampling in 3 strata	counted (continuously)	no	8-m boat

Table 4. Continued.

Region/citation	Sampling design	Sampling unit	Overall sampling methodology	Flying birds counted?	Replicate samples collected?	Sampling platform
KENAI FJORDS						
Bailey (1976)	nearshore survey with unlimited survey width; occasional censusing of seabird colonies on shore	entire shoreline (nearshore only); data summarized by geographic parts of study area	continuous nearshore survey with unlimited survey width and mapping of observations; large groups were aggregated to stretches of shoreline, and sizes of large groups were estimated; counting of nests	unspecified, but presumably counted continuously	no	flying bridge of 12.8-m boat (most surveys); 4.5-m skiff (shallow or unmapped areas; extensive use in some areas)
Nishimoto and Rice (1987)	nearshore survey with unknown, but presumably unlimited, survey width (Methods stated that they tried to duplicate survey dates and counting units used by Bailey but said nothing about survey width); occasional censusing of seabird colonies from skiff	entire shoreline (nearshore only); data summarized by geographic parts of study area	continuous nearshore survey with unknown, but presumably unlimited, survey width; shoreline broken into ~150 smaller sampling units; sizes of large groups were estimated; counting of nests	unspecified, but presumably counted continuously	no	4.5-m skiff for shallow or unmapped areas (760 km); flying bridge of 9.6-m boat (278 km)
Bailey and Rice (1989)	nearshore survey with 200-m survey width; occasional censusing of seabird colonies, but exact location not specified	entire shoreline (nearshore only), although only ~25% of total shoreline was surveyed [Note: Van Pelt and Piatt (2003) stated that this study surveyed 31% of the shoreline, rather than the 25% stated in this report.]	continuous nearshore survey with 200-m survey width; shoreline broken into ~150 smaller sampling units; random subsample of 25% of shoreline (based on these ~150 smaller units); counting of nests	unspecified, but presumably counted continuously	no	flying bridge of 9.6-m boat (most surveys); inflatable skiff of unknown length, presumably ~4.5 m (shallow or rocky areas; extensive use in some areas)
Van Pelt and Piatt (2003)	stratified systematic sampling without replication; FWS strip survey with 300-m strip width (150 m each side and ahead of ship)	transect	continuous survey with 300-m survey width (150 m on each side of ship); shoreline broken into ~150 smaller sampling units; somewhat-random subsample of 31% of shoreline (based on these ~150 smaller units), with an emphasis on glaciated fjords	counted (continuously)	no	flying bridge of 12.8-m boat (seiner)
Romano et al. (2006)	systematic sampling with nearshore (≤200 m) and offshore (>200 m) surveys; nearshore surveys had segment length 4 km assigned with GIS; one of every three nearshore segments selected after randomly selecting starting point; with lines selected randomly, although upper Aiailik Bay and Northwestern Bay surveyed with lines 1 NM apart; strip transects 200 m wide and 200 m ahead of vessel.	transect	continuous survey with 200-m survey width (100 m on each side of ship and 200 m ahead of ship); three surveys, with only mid-summer survey being used for population comparison.	counted (continuously)	no	4.8-m inflatable boat

Table 4. Continued.

Region/citation	Sampling design	Sampling unit	Overall sampling methodology	Flying birds counted?	Replicate samples collected?	Sampling platform
Arimitsu et al. (2010)	systematic sampling with nearshore (≤200 m) and offshore (>200 m) surveys; nearshore surveys had segment length 4 km assigned with GIS; one of every three nearshore segments selected after randomly selecting starting point; E-W offshore survey lines spaced 1 NM apart, with lines selected randomly, although upper Aialik Bay and Northwestern Bay surveyed with lines 0.5 NM apart; strip transects 200 m wide and 200 m ahead of vessel (in 2006–2007) and increased to 300 m wide [unstated but presumably 300 m ahead of the vessel] in 2008. [Note: the width between offshore survey lines in outer bays and head of Aialik and northwestern bays appear to have been reversed accidentally.]	transect	continuous survey with 200-m survey width (100 m on each side of ship and 200 m ahead of ship) in 2006–2007, expanding to 300 m total width in 2008; distance surveyed ahead of the ship in 2008 not stated but presumably 300 m; three surveys, with only mid-summer survey being used for population comparison.	counted (continuously)	no	4.8-m inflatable boat in all areas (2006); 4.8-m inflatable in protected waters and 15.6-m ship in exposed waters (2007–2008)
KACHEMAK BAY & COOK INLET						
Agler et al. (1995)	stratified random sampling with nearshore and offshore surveys in summer and with shoreline, bay (= Kachemak Bay), and pelagic surveys in winter; offshore zone divided into coastal (out to 3 NM offshore from nearshore stratum) and pelagic (beyond coastal) strata	transect	continuous strip-transect survey with 200-m survey width (100 m on each side of ship and 100 m ahead of ship	counted (continuously)	no	in summer, 7.5-m boats; in winter, 7.5-m boats for shoreline and bay strata and 22-m boat for pelagic stratum
Kuletz et al. (2008)	sampling of fixed sampling lines in four strata (Southern Shore, Inner Bay, Yukon Island, and Outer Bay); randomly selected strip-transect surveys with variable widths among years (200–1,000 m offshore)	unclear---individual transect line? stratum?	continuous strip-transect survey with variable transect widths among years (200–1,000 m); however, report later states that birds were tallied in 25-m distance categories, so that information presumably was not used in density calculations; did not use a shoreline stratum but recorded those data separately so that they could be stratified later, if needed	counted (continuously)	no (but multiple samples over a summer in some years)	7.5-m boats
ALASKA PENINSULA & ALEUTIAN ISLANDS						
Meehan (1996)	road-based counts, shoreline surveys	transects?	murrelets were counted from land and from boat traveling 100 m offshore, plus on pelagic transects running perpendicular to shore	unspecified	no	inflatable skiff, 8-m boat
Romano et al. (2005a)	randomized-stratified design with strip transects	transects	nearshore—nearly continuous strip transect 200 m wide, even though skiff's distance from shore varied up to 500 m offshore (i.e., did not appear to be consistent); offshore—pelagic survey transects 300 m wide	counted (continuously)	no	nearshore—4.5-m skiff; offshore—36.5-m ship (*Tiglax*)

Table 4. Continued.

Region/citation	Sampling design	Sampling unit	Overall sampling methodology	Flying birds counted?	Replicate samples collected?	Sampling platform
Van Pelt and Piatt (2005)	stratified systematic (outer nearshore stratum) and random (other four strata) sampling without replication	transects	strip transect 300 m wide	counted (continuously)	no	12.8-m boat
Romano et al. (2005b)	sampling of fixed lines in two strata (nearshore zone and offshore surveys)	transect	nearshore—nearly continuous strip transect 200 m wide, even though skiff's distance from shore varied up to 500 m offshore (i.e., did not appear to be consistent); offshore—pelagic survey transects 300 m wide	counted (continuously)	no	nearshore—4.5-m skiff; offshore—36.5-m ship (*Tiglax*)
OTHER/MULTIPLE LOCATIONS						
Agler et al. (1998)	stratified random strip transects	transect	census and systematic random sampling in 3 strata	unspecified, but counted continuously in other surveys as part of same study	no	7.6-m boat (most surveys); 22-m boat (winter surveys in CI)
Kendall and Agler (1998)	stratified random strip transects	transect	census and systematic random sampling in 2 strata	unspecified, but counted continuously in other surveys as part of same study	no	7.6-m boat (most surveys); 22-m boat (winter surveys in CI)

Table 5. Characteristics of studies that have surveyed the abundance or population trend of Kittlitz's Murrelets in Alaska—Part C.

Region/citation	Viewing height of observers above water (m)	Number of observers; assignments	Transect width	Ship's speed (km/h)	Ship's trackline	Orientation of ship's trackline	Criteria for stopping surveys	Strata
GLACIER BAY								
Piatt et al. (undated)	unspecified, probably ~1.25 m	2; unspecified	400 m (200 m on each side of boat) [Note: Drew and Piatt 2008 state 100 m on each side and 200 m ahead of boat.]	unspecified	200 m from shore [Note: Drew and Piatt 2008 say 100 m from shore.]	parallel to shore	unspecified	1
Lindell (2005)	5 m	2, unspecified; a third was added if large numbers of birds were encountered	150 m on each side and 300 m ahead of boat	18	generally >200 m from shore	diagonal (zigzag), parallel, and perpendicular to shore	seas >1.0 m	1
Robards et al. (2003)	~2.5–4 m	2–3; 1 data-entry person and 1–2 observers, depending on the boat	smaller boats: 100 m on either side [and ahead of?] boat; larger boats: 150 m on each side and 300 m ahead of boat	11–15	nearshore surveys: 100 m offshore; pelagic surveys: at various distances	nearshore surveys parallel to shore; pelagic surveys perpendicular to shore	ability to detect small seabirds at 150-300 m	2
Drew and Piatt (2008)	unspecified, probably ~1.5 m (1991); unspecified, probably ~4 m (1999–2000)	unspecified, presumably 2; assignments unspecified	smaller boats: 100 m on either side and ahead of skiff [Note: 1991 report says 400 m transect but this publication now says 200 m transect.]; larger boats: 150 m on each side and 300 m ahead of boat	unspecified (1991); 11–15 (1999–2000)	nearshore surveys 100 m offshore [Note: 1991 report says sampling width was 400 m but did not specify distance from shore]; offshore surveys at various distances	nearshore surveys parallel to shore; offshore surveys perpendicular to shore	unspecified (1991); ability to detect small seabirds at 150–300 m (1999–2000)	1
Drew et al. (2008)	~1.5–3.7 m, depending on ship used	3; 1 data-entry person and 2 observers	100 m on either side and 200 m ahead of boat; or 150 m on each side and 300 m ahead of boat, depending on size of ship	11–15	nearshore surveys 100 m offshore; offshore surveys at various distances	nearshore surveys parallel to shore; offshore surveys perpendicular to shore	unspecified	11
Romano et al. (2004)	unspecified (smaller boat), probably ~2.5 m; ~5 m (larger boat)	unspecified number, but, based on previous surveys, 2 observers were used	smaller boats: 100 m on either side [and ahead of?] boat; larger boats: 150 m on each side and 300 m ahead of boat	13–22	nearshore surveys 100 m offshore; offshore surveys at various distances	nearshore surveys parallel to shore; offshore surveys perpendicular to shore	inability to detect small seabirds at 200 m (small boat) or 300 m (large boat) or wave height >0.3 m	1 in analysis, although discussion about nearshore and offshore
Kirchhoff (2008)	~2.5 m	3; 1 for line transect, 1 for strip transect, and 1 to determine distance of each bird from shore	strip transects 100 m on each side of boat, distance ahead not specified; for line transects, all birds on centerline and all others farther out as time permitted (unlimited distance)	10	straight lines perpendicular to shore	perpendicular to shore	unspecified	2

Table 5. Continued.

Region/citation	Viewing height of observers above water (m)	Number of observers; assignments	Transect width	Ship's speed (km/h)	Ship's trackline	Orientation of ship's trackline	Criteria for stopping surveys	Strata
Kirchhoff (2008)	~2.5 m	3; 1 for line transect, 1 for strip transect, and 1 to determine distance of each bird from shore	strip transects 100 m on each side of boat, distance ahead not specified; for line transects, all birds on centerline and all others farther out as time permitted (unlimited distance)	10	straight lines perpendicular to shore	perpendicular to shore	unspecified	2
Arimitsu and Piatt (undated)	unspecified, probably ~2.5 m	2	200 m (100 m on each side of boat); however, later states that distances were estimated out to 300 m perpendicular to boat, so exact transect width unclear	unspecified	nearshore surveys 100 m offshore; pelagic (offshore) surveys at various distances	nearshore surveys parallel to shore; pelagic (offshore) surveys perpendicular to shore	unspecified	2
Hoekman et al. (2011a)	~2.5 m	1–3, including independent observer who measured missed birds; plus recorder	unspecified, presumably unlimited; however, detections are shown only out to ~225 m perpendicular to the ship	maximal speed 10, slowing when large numbers of murrelets seen	offshore surveys at various distances from shore	offshore surveys perpendicular to shore	Beaufort state >3 or visibility <100 m	2
Hoekman et al. (2011b)	~2.5 m	2; unclear whether there was additional recorder, but no independent observer was used	unspecified, presumably unlimited; however, detections are shown only out to ~225 m perpendicular to the ship	maximal speed 10, slowing when large numbers of murrelets seen	offshore surveys at various distances from shore	offshore surveys perpendicular to shore	Beaufort state >2 or visibility <100 m	5
Kirchhoff et al. (2010)	3 m (smaller boat), 4.5 m (larger boat	3; 1 recording and 2 surveying	300 m (150 m on each side of boat); distance surveyed ahead of ship unspecified	11–13 (smaller boat), 15–17 (larger boat)	>200 m from shore	zigzag, approximately perpendicular to shore	visibility "poor" or wave action "greater than small waves"	1
ICY BAY, OUTER COAST & MISCELLANEOUS LOCATIONS								
Stephensen and Andrus (2001)	unspecified, presumably ~1-1.5 m	2 plus boat operator; assignments unspecified	200 m (100 m on each side, ahead of, and above boat and within 100 m of shore on land)	unspecified	nearshore surveys unspecified but presumably 100 m offshore; offshore surveys at various distances	nearshore parallel to shore; offshore parallel lines approximately perpendicular to shore	wave height >0.9 m	2

Table 5. Continued.

Region/citation	Viewing height of observers above water (m)	Number of observers; assignments	Transect width	Ship's speed (km/h)	Ship's trackline	Orientation of ship's trackline	Criteria for stopping surveys	Strata
Kissling et al. (2007a)	nearshore unspecified, probably ~1.5 m; offshore unspecified, probably ~5 m	nearshore 2 plus boat operator; offshore 2 at bow of boat, plus boat operator	100 m on either side of boat and 100 m ahead of boat for nearshore; 150 m on either side and ahead of boat for offshore	unspecified	nearshore parallel to shore; offshore zig-zag trackline between nearshore areas and areas farther offshore	nearshore surveys parallel to shore; offshore surveys perpendicular to shore, sawtooth zigzag, or parallel to shore (depending on water depth)	unspecified	7
Kissling et al. (2007b)	nearshore unspecified, probably ~1.5 m; offshore unspecified, probably ~5 m	nearshore 2 plus boat operator; offshore 2 at bow of boat, plus boat operator	100 m on either side of boat and 100 m ahead of boat for nearshore; 150 m on either side and ahead of boat for offshore	unspecified	nearshore parallel to shore; offshore zig-zag or perpendicular trackline between nearshore areas and areas farther offshore	nearshore surveys parallel to shore; offshore surveys perpendicular to shore, sawtooth zigzag, or parallel to shore (depending on water depth)	unspecified	12
Kissling et al. (2007c)	unspecified, probably ~1.5 m	2 plus boat operator	200 m for nearshore, 300 m for offshore; however, observers recorded birds out to unlimited distance in both surveys	~10	nearshore surveys unspecified but presumably 100 m offshore; offshore surveys at various distances	nearshore parallel to shore; offshore parallel lines approximately perpendicular to shore	Beaufort sea scale >2 (>0.15 m)	4
PRINCE WILLIAM SOUND								
Day and Nigro (1999)	~1.25 m (small boat); ~6 m (large boat)	2; assignments unspecified	200–300 m (100 m on each side and 300 m ahead) for nearshore; 200-300 m (150 m off each side and 300 m ahead) for pelagic	mean ~10 (nearshore and offshore); unspecified (~16; pelagic)	nearshore surveys 100 m offshore; offshore and pelagic surveys at various distances	nearshore surveys parallel to shore; offshore surveys diagonal (zigzag) to shore; pelagic surveys perpendicular to shore	unspecified [ability to detect small birds at 150–300 m]	3
Kuletz et al. (2003a)	unspecified, probably ~3 m (A. E. Gall, pers. comm.)	2; assignments unspecified	200 m (100 m on either side of and ahead of boat)	10–20	nearshore surveys 100 m offshore; offshore surveys at various distances	nearshore surveys parallel to shore; offshore surveys approximately perpendicular to shore	wave height >0.6 m	3
Kuletz et al. (2003b)	unspecified, probably ~3 m (A. E. Gall, pers. comm.)	2; assignments unspecified	200 m (100 m on either side of and ahead of boat)	10–20	nearshore surveys 100 m offshore, offshore surveys N–S lines (1989–2000); nearshore surveys 100 m offshore, offshore surveys at various distances (2001)	nearshore surveys parallel to shore; offshore surveys N–S lines (1989–2000) or approximately perpendicular to shore (2001)	wave height >0.6 m	2

Table 5. Continued.

Region/citation	Viewing height of observers above water (m)	Number of observers; assignments	Transect width	Ship's speed (km/h)	Ship's trackline	Orientation of ship's trackline	Criteria for stopping surveys	Strata
McKnight et al. (2003)	unspecified, probably ~3 m (A. E. Gall, pers. comm.)	2 sampling plus driver; one observer also was recorder	200 m (100 m on either side of and ahead of boat)	10–20	nearshore surveys 100 m offshore; offshore surveys at various distances	nearshore surveys parallel to shore; offshore surveys approximately perpendicular to shore	unspecified	2
Kuletz et al. (2007)	unspecified in 1989-2004, probably ~3 m (A. E. Gall, pers. comm.); unspecified in 1972 but presumably about same	unspecified in 1972; 2 sampling plus driver, with one observer also recorder in 1989–2004	unspecified in 1972 [allegedly 200 m but greater sampling width at times; M. E. Isleib, pers. comm.]; 200 m (100 m on either side of and ahead of boat) in 1989–2004	unspecified (1972); 10–20 (1989–2004)	nearshore surveys 100 m offshore, offshore surveys N–S lines (1989–2004); allegedly similar in 1972	unspecified (1972); nearshore surveys parallel to shore and offshore surveys N–S lines (1989–2004)	unspecified (1972); wave height >0.6 m (1989–2004)	3 in each period but different layout
McKnight et al. (2008)	unspecified, probably ~3 m (A. E. Gall, pers. comm.)	2 sampling plus driver; one observer also was recorder	200 m (100 m on either side of and ahead of boat)	10–20	nearshore surveys 100 m offshore, offshore surveys N-S lines	(1) nearshore surveys parallel to shore; (2) offshore surveys N-S lines	wave height >0.6 m	3
KENAI FJORDS								
Bailey (1976)	Large boat unspecified; small boat unspecified, probably ~1–1.25 m	4–5? (not clear, but authors and this many people were in Acknowledgments); assignments unknown	unlimited	mean ~11; highly variable, depending on the number of birds	<100 m from shore (when possible)	parallel to shore	unknown	14
Nishimoto and Rice (1987)	unspecified, probably ~1–1.25 m (skiff); unspecified (ship)	2 for nearshore; one drove and counted and one recorded and counted; unspecified for offshore	unspecified, but presumably unlimited (Methods stated that they tried to duplicate survey dates and counting units used by Bailey but said nothing about exact survey width)	highly variable, depending on the number of birds, but maximum ~22	<100 m from shore (when possible)	parallel to shore	heavy precipitation, fog, or seas >1 m	11
Bailey and Rice (1989)	unspecified (ship); unspecified, probably ~1–1.25 m (skiff)	unspecified for nearshore; 2 for offshore, with activities unspecified, but presumably one drove and counted and one recorded and counted	200 m [Note: Authors stated that they recorded wildlife up to 200 m from shore to make them comparable to previous surveys, but those previous surveys had unlimited survey width.]	~11 or less	<100 m from shore (when possible)	parallel to shore	unknown	11

Table 5. Continued.

Region/citation	Viewing height of observers above water (m)	Number of observers; assignments	Transect width	Ship's speed (km/h)	Ship's trackline	Orientation of ship's trackline	Criteria for stopping surveys	Strata
Van Pelt and Piatt (2003)	unspecified	4–5? (not clear, but authors and this many people were in Acknowledgments); assignments unknown	300 m (150 m on each side and ahead of ship)	11–15	unspecified, but presumably ~150 m from shore (nearshore surveys); highly variable (offshore surveys)	parallel to shore (nearshore surveys); approximately perpendicular to shore or down the central axis of fjords (offshore surveys); offshore surveys followed Loran lines	heavy precipitation, fog, glare, or seas >0.6 m	3
Romano et al. (2006)	unspecified, probably ~1.5 m	unspecified; assignments unknown	200 m (100 m on each side and 200 m ahead of ship)	~13–22	unspecified, but presumably ~100 m from shore (nearshore surveys); east–west tracklines (offshore surveys)	parallel to shore (nearshore surveys); east–west direction (offshore surveys)	observation conditions for detecting birds and mammals at outer edge of survey zone; seas >0.5 m	4
Arimitsu et al. (2010)	unspecified, probably ~1.5 m (inflatable); unspecified (ship)	2; assignments unknown, but each presumably surveyed one side of boat	200 m (100 m on each side and 200 m ahead of ship) in 2006–2007; 300 m (150 m on each side and unspecified, but presumably 300 m, ahead of ship) in 2008	~9–22 for most surveys; ~9–11 during hydroacoustic surveys	unspecified, but presumably ~100 m from shore (nearshore surveys); east–west tracklines (offshore surveys)	parallel to shore (nearshore surveys); east–west direction (offshore surveys)	unknown	4
KACHEMAK BAY & COOK INLET								
Agler et al. (1995)	unspecified, probably ~3 m, for 7.5-m boats (A. E. Gall, pers. comm.); unspecified for 22-m boat	2; assignments unknown	200 m (100 m on each side and 100 m ahead of ship)	~9–18	100 m from shore for shoreline segments; north–south lines for offshore segments	parallel to shore (nearshore surveys); north–south direction (offshore surveys)	seas >0.5 m in summer, >1.8 m in winter; ice and heavy seas prevented sampling of some pelagic surveys in winter	3 (although they differed between summer and winter)
Kuletz et al. (2008)	unspecified, probably ~3 m (A. E. Gall, pers. comm.)	2; assignments unknown	200–1,000 m, depending on the year; recorded "all birds and mammals observed within 100 m of the boat"	~10–20	highly variable, depending on stratum and year; detailed tracklines provided by stratum and year are shown in Speckman et al. (2005) but are pooled in this report	parallel to shore in some strata, zigzag and at an angle to shore in other strata	unspecified	4 (during data collection); 2 (during analyses)

Table 5. Continued.

Region/citation	Viewing height of observers above water (m)	Number of observers; assignments	Transect width	Ship's speed (km/h)	Ship's trackline	Orientation of ship's trackline	Criteria for stopping surveys	Strata
ALASKA PENINSULA & ALEUTIAN ISLANDS								
Meehan (1996)	unspecified, probably ~1.25 m for skiff; unspecified, probably ~3 m for 8-m boat (A. E. Gall, pers. comm.)	unspecified	unspecified for shoreline surveys; unspecified for boat-based surveys, but probably 200 m	unspecified	100 m from shore (some surveys; unclear in others), perpendicular in pelagic surveys	parallel for shoreline and nearshore, perpendicular for pelagic	unspecified	4?
Romano et al. (2005a)	small skiff ~1 m; large boat unspecified	2, with each surveying one side of the boat	nearshore 200 m wide and 200 m ahead of skiff, with each observer surveying 100 m on each side; offshore 300 m wide and 300 m ahead of the ship, with each observer surveying 150 m on each side	13–22	nearshore up to 500 m from coastline; offshore variable distances	nearshore parallel to coast; offshore mostly perpendicular to coast, but highly variable	wave height >0.5 m nearshore, >1 m offshore	3
Van Pelt and Piatt (2005)	~4.25 m	2, with each surveying one side of the boat	300 m wide, with each observer surveying 150 m on each side and 300 m ahead of the boat	11–14	highly variable: all three nearshore strata generally up to 500 m, but occasionally up to 1,000 m, from coast and generally parallel to it; offshore strata generally greater than 500 m from coast	nearshore parallel to coast; offshore mostly perpendicular to coast	heavy precipitation, fog, glare, or seas with chop >0.6 m	5 (outer nearshore, bay nearshore, bay offshore, fjord nearshore, fjord offshore
Romano et al. (2005b)	small skiff ~1 m; large boat unspecified	2, with each surveying one side of the boat	nearshore 200 m wide and 200 m ahead of skiff, with each observer surveying 100 m on each side; offshore 300 m wide and 300 m ahead of the ship, with each observer surveying 150 m on each side	13-22	nearshore parallel to and along most coastline of eastern ~75% of island, up to 500 m off coast; offshore 0.3–10 km from shore	nearshore parallel to shore; offshore mostly perpendicular to coast	wave height >0.5 m nearshore, >1 m offshore	2 during data collection; 3 during analyses (offshore stratum split with GIS into 2 strata)
OTHER/MULTIPLE LOCATIONS								
Agler et al. (1998)	unspecified, probably ~3 m for small boat (A. E. Gall, pers. comm.); unspecified, probably ~3 m (larger boat)	2; assignments unspecified	200 m (100 m on either side of and ahead of boat)	unspecified, but 10-15 in other surveys as part of same study	nearshore surveys 100 m offshore, offshore surveys N–S lines	nearshore surveys parallel to shore; offshore surveys N–S lines	wave height >0.6 m	3
Kendall and Agler (1998)	unspecified, probably ~3 m for small boat (A. E. Gall, pers. comm.); unspecified, probably ~3 m (larger boat)	unspecified number, 2 observers in other surveys as part of same study; assignments unspecified	200 m (100 m on either side of and ahead of boat)	10-15	nearshore surveys 100 m offshore, offshore surveys N–S lines	nearshore surveys parallel to shore; offshore surveys N–S lines	wave height >0.6 m	2

Table 6. Characteristics of studies that have surveyed the abundance or population trend of Kittlitz's Murrelets in Alaska—Part D.

Region/citation	Basis for stratification	Number Kittlitz's Murrelets (C = count; E = estimate; P = population estimate)	Number Marbled Murrelets (C = count; E = Estimate; P = population estimate)	Number unidentified murrelets (C = count; E = estimate; P = population estimate)	Percentage unidentified murrelets	How unidentified murrelets were incorporated into population estimates and/or population trends of Kittlitz's Murrelets	Data analysis
GLACIER BAY							
Piatt et al. (undated)		C 1,019	C 4,489	C 3,587	39	unspecified	none
Lindell (2005)		C 322; P 6,995	P 25,975	Total BRMU C 36,995	unspecified	combined all murrelets but calculated densities separately for KIMU and MAMU	calculated mean density by area and population based on total area and average density
Robards et al. (2003)	nearshore and offshore	C 506 (1999); C 402 (2000)	C 4,094 (1999); C 1,322 (2000)	C 1,951 (1999); C 2,864 (2000)	~30-62	analyzed in trends of total murrelets	raw densities calculated; compared 1991 nearshore with 1999, 2000 nearshore
Drew and Piatt (2008)	only nearshore was sampled in 1991				unspecified	not incorporated	compare direct densities across approximately same areas
Drew et al. (2008)	depth and geographic section of the bay	C 2,180 (all 5 years combined); P 3,042-3,271 (summer; all 5 years combined; depending on stratification method)	C 11,930 (all 5 years combined); P 10,529-10,875 (summer; all 5 years combined; depending on stratification method)	C 6,979 (all 5 years combined); P8,310-8,557 (summer; all 5 years combined; depending on stratification method)	~10 (all 5 years combined)	not incorporated	Monte Carlo simulations of population estimates using varying number of transects and transect locations
Romano et al. (2004)	historical (Piatt et al. nearshore zone and Robards et al. tracklines)	C 411 (JN)	C 2,843 (JN)	unspecified	unspecified	analyzed separately	non-parametric Kruskal-Wallis test to compare densities across time periods
Kirchhoff (2008)	nearshore, offshore	P 3,692 (strip transects); P 4,299 (line transects)	P 23,029 (strip transects); P 31,318 (line transects)		unspecified (strip transects); 4 (line transects)	allocated in proportion to KIMU proportion of total murrelet numbers	comparison of methods
Arimitsu and Piatt (undated)	nearshore, offshore	C 116; P 4,981	C 421; P 12,195	C 64; numbers included in estimate of Total Brachyramphus	11	included only in Total Murrelets population estimate	used DISTANCE to calculate density and estimate population size; compared with historical data using densities calculated from strip transects
Hoekman et al. (2011a)	areas of historical high density and low density; data appear to be pooled among areas for the 3 high-density areas	C 151 groups; P = 13,124	C 348 groups; P = 28,978	C 565 groups	53 (of groups, not birds)	allocated in proportion to KIMU:MAMU proportion of identified murrelet	used DISTANCE to calculate density and estimate population size; compared with historical data using densities calculated from strip transects

Table 6. Continued.

Region/citation	Basis for stratification	Number Kittlitz's Murrelets (C = count; E = estimate; P = population estimate)	Number Marbled Murrelets (C = count; E = Estimate; P = population estimate)	Number unidentified murrelets (C = count; E = estimate; P = population estimate)	Percentage unidentified murrelets	How unidentified murrelets were incorporated into population estimates and/or population trends of Kittlitz's Murrelets	Data analysis
Hoekman et al. (2011b)	areas of historical high density and low density; data appear to be pooled among areas for the 3 high-density areas	C 225 groups; P 14,503	C 725 groups; P 67,259	C 308 groups	24 (of groups, not birds)	allocated in proportion to KIMU:MAMU proportion of identified murrelet	used DISTANCE to calculate density and estimate population size; compared with historical data using densities from strip transects adjusted for probability of detection and probability of identification to species
Kirchhoff et al. (2010)		P 5,317	P 27,266		~1-9	allocated in proportion to KIMU proportion of total murrelet numbers	density extrapolation to entire bay population; comparison of density and CI between 1993 and 2009
ICY BAY, OUTER COAST & MISCELLANEOUS LOCATIONS							
Stephensen and Andrus (2001)	geographic location (Yakutat and Disenchantment bays; Russell and Nunatak fjords)	C 120; P 982	C 760; P 8,344	C 107	12	unclear	ratio estimator; multiplied mean density in offshore by area of offshore, then added to census in nearshore to estimate population in total study area
Kissling et al. (2007a)	geographic location and bathymetry	P 578			unspecified	unclear	DISTANCE for density and population estimates; density estimates by stratum extrapolated to greater area
Kissling et al. (2007b)	geographic location, management boundaries, bathymetry, and exposure (exposed, protected)	C 452 (2002); C 472 (2003); C 115 (2004); P 4,236	C 2,558 (2002); C 5,979 (2003); C 1,870 (2004); P 37,788	C 104 (2002); C 391 (2003); C 120 (2004)	3 (2002); 6 (2003); 6 (2004)	analyzed separately	DISTANCE for density and population estimates; density estimates by stratum extrapolated to greater area
Kissling et al. (2007c)	geographic location and survey lines (Main Bay shoreline, Main Bay pelagic, Taan Bay shoreline, Taan Bay pelagic)	C 794; peak P 1,317	C 16	C 70	7–12, depending on survey	not incorporated	DISTANCE for density and population estimates after correction of weather-caused effects on detectability; density estimates by stratum extrapolated to greater area

Table 6. Continued.

Region/citation	Basis for stratification	Number Kittlitz's Murrelets (C = count; E = estimate; P = population estimate)	Number Marbled Murrelets (C = count; E = Estimate; P = population estimate)	Number unidentified murrelets (C = count; E = estimate; P = population estimate)	Percentage unidentified murrelets	How unidentified murrelets were incorporated into population estimates and/or population trends of Kittlitz's Murrelets	Data analysis
PRINCE WILLIAM SOUND							
Day and Nigro (1999)	nearshore and offshore	C 630 and P ~1,400 (1996); C408 and P ~1,275 (1997); C854 and P ~1,275 (1998)			<1 (Day and Nigro, unpubl. data)	not incorporated	multiplied mean density in offshore by area of offshore, then added to census in nearshore to estimate population in total bay
Kuletz et al. (2003a)	nearshore (shoreline), pelagic-coastal, and offshore (pelagic)	C 716, P 2,020	C 6,088		~4	not incorporated	ratio estimator; multiplied mean density in offshore by area of offshore, then added to census in nearshore to estimate population in total bay
Kuletz et al. (2003b)	nearshore and offshore	P 1969 (2001)	unspecified	unspecified	~4 (2001 only; much higher in earlier years)	excluded; assumed MAMU and KIMU were equally unidentified, so identified portions accurately reflected entire population [Note: This does not really make sense.]	(1) ratio estimator for stratified random sample (1989–2000); (2) multiplied mean density in offshore by area of offshore, then added to census in nearshore to estimate population in total bay
McKnight et al. (2003)	nearshore and offshore	P 1,042 (JL estimate)	P 4,130 (JL estimate)	unspecified	~3–10	unspecified, but assumed to be excluded like Kuletz et al. 2003a)	ratio estimator; multiplied mean density in offshore by area of offshore, then added to census in nearshore to estimate population in total bay; no real analysis
Kuletz et al. (2007)	shoreline, bay, and pelagic (1972); nearshore (shoreline), pelagic-coastal, and offshore (pelagic) in 1989–2004	JL P 279 (1998) to P 63,229 (1972)	JL P 14,177 (1993) to P 236,633 (1972)	JL P 840 (2004) to P 142,546 (1993)	~2–89	created a model to estimate populations that incorporated unidentified birds in estimates of each species	linear regression on population estimates; homogeneity of slopes for (1) all years; (2) no 1972; (3) no 1972 and 1993
McKnight et al. (2008)	nearshore (shoreline), pelagic-coastal, and offshore (pelagic)	JL P 279 (1998) to P 6,436 (1989)	JL P 14,177 (1993) to P 63,455 (1996)	JL P 836 (2004) to P 142,546 (1993)	varied; up to 80%	grouped into MAMU because suspected most (95%) were MAMU	ratio estimator to produce population estimates; regression of population estimates over time

Table 6. Continued.

Region/citation	Basis for stratification	Number Kittlitz's Murrelets (C = count; E = estimate; P = population estimate)	Number Marbled Murrelets (C = count; E = Estimate; P = population estimate)	Number unidentified murrelets (C = count; E = estimate; P = population estimate)	Percentage unidentified murrelets	How unidentified murrelets were incorporated into population estimates and/or population trends of Kittlitz's Murrelets	Data analysis
KENAI FJORDS							
Bailey (1976)	geographic location (stretches of shoreline)	162 (C)	3,095 (C)	0	0	NA	summary of counts of birds and counts/estimates of colony sizes by geographic stratum
Nishimoto and Rice (1987)	geographic location (stretches of shoreline)	86 (C)	1,534 (C) [Note: This report reduced the 1976 count to just those birds seen within the reduced survey area (2,970 birds).]	300 (C)	~16	not incorporated	summary of counts of birds and counts/estimates of colony sizes by geographic stratum
Bailey and Rice (1989)	geographic location (stretches of shoreline)	26 (C) in JN–JL [Note: This report reduced the 1986 count to just those birds seen within the 25% subsample (= 31 birds).]; 59 (C) in JL–AU	336 (C) in JN–JL [Note: This report reduced the 1986 count to just those birds seen within the 25% subsample (= 442 birds).]; 489 (C) in JL–AU	369 (C) in JN–JL [Note: This report reduced the 1986 count to just those birds seen within the 25% subsample (= 152 birds).]; 1,745 (C) in JL–AU	~50	not incorporated	summary of counts of birds and counts/estimates of colony sizes by geographic stratum
Van Pelt and Piatt (2003)	pre-existing shoreline (i.e., the same nearshore samples as those surveyed by Bailey and Rice 1989); new shoreline (i.e., new nearshore samples added in 2002); new pelagic (i.e., new offshore samples added in 2002)	total 81 (C) in all strata, including 8 (C) on existing nearshore transects, 24 (C) on new nearshore transects, 34 (C) on new offshore transects, and 15 on new offshore transects used for distribution mapping; 509 (E) in nearshore and offshore areas combined (65 in nearshore and 444 in offshore)	total 3,350 (C) in all strata, including 1,690 (C) on existing nearshore transects, 1,312 (C) on new nearshore transects, 297 (C) on new offshore transects, and 51 on new offshore transects used for distribution mapping; 9,554 (E) in nearshore and offshore areas combined (5,676 in nearshore and 3,879 in offshore)	total 323 (C) in all strata, including 228 (C) on existing nearshore transects, 56 (C) on new nearshore transects, 27 (C) on new offshore transects, and 12 on new offshore transects used for distribution mapping; total population estimate of unidentified murrelets not generated	~12	ignored; however, they stated that they assumed that most or all unidentified Brachyramphus were Marbled Murrelets because they were seen in areas where Kittlitz's Murrelets were not found	calculation of density estimate by each of 3 strata (existing nearshore, new nearshore, new offshore), then converting density estimates to population estimates by correcting area sampled in each stratum by total area of each stratum

Table 6. Continued.

Region/citation	Basis for stratification	Number Kittlitz's Murrelets (C = count; E = estimate; P = population estimate)	Number Marbled Murrelets (C = count; E = Estimate; P = population estimate)	Number unidentified murrelets (C = count; E = estimate; P = population estimate)	Percentage unidentified murrelets	How unidentified murrelets were incorporated into population estimates and/or population trends of Kittlitz's Murrelets	Data analysis
Romano et al. (2006)	coastline (= nearshore) stratum (nearshore zone of lower parts of bays and outer, exposed coasts); fjords nearshore stratum (nearshore zone of upper Nuka, Northwestern, and Aialik bays); bays offshore stratum (offshore zone of lower bays); fjords offshore stratum (offshore zone of upper bays)	total 82 (C) in all strata, including 79 (C) on fjords offshore stratum, 2 (C) on coastline stratum, and 1 (C) on fjords coastal stratum during mid-summer population survey; 845 (E) in nearshore and offshore areas combined (12 in nearshore and 834 in offshore, specifically fjords offshore)	total 936 (C) in all strata during mid-summer population survey, but breakdown of counts by stratum unclear; 5,264 (E) in nearshore and offshore areas combined (2,476 in nearshore and 2,787 in offshore)	total 27 (C) in all strata during mid-summer population survey, but breakdown of counts by stratum unclear	~3 (during mid-summer population survey)	not incorporated	calculation of density estimate by each of 4 strata (coastline, fjords coastal, bays offshore, fjords offshore), then converting density estimates to population estimates by correcting area sampled in each stratum by total area of each stratum (ratio estimation)
Arimitsu et al. (2010)	coastline (= nearshore) stratum (nearshore zone of lower parts of bays and outer, exposed coasts); fjords nearshore stratum (nearshore zone of upper Nuka, Northwestern, and Aialik bays); bays offshore stratum (offshore zone of lower bays); fjords offshore stratum (offshore zone of upper bays)	in nearshore and offshore areas combined, estimates of 925 (E) in 2006, 423 (E) in 2007, and 664 (E) in 2008; in all cases, 95% CI's overlapped	in nearshore and offshore areas combined, estimates of 6,418 (E) in 2006, 3,619 (E) in 2007, and 7,529 (E) in 2008; in all cases, 95% CI's overlapped		~4 across all surveys and years combined	allocated unidentified birds into KIMU and MAMU based on proportions seen on each transect	calculation of density estimate by each of 4 strata (coastline, fjords coastal, bays offshore, fjords offshore), then converting density estimates to population estimates by correcting area sampled in each stratum by total area of each stratum (ratio estimation)
KACHEMAK BAY & COOK INLET							
Agler et al. (1995)	in summer, used shoreline (nearshore), coastal (offshore area with some land in sampling block), and pelagic strata; in winter, used shoreline, bay (Kachemak Bay), and pelagic strata	P 3,353 (summer), 0 (winter; partial survey coverage)	P 7,782 (summer), 7,449 (winter; partial survey coverage)	P 47,092 (summer), 4,178 (winter; partial survey coverage)	~81 (summer), ~36 (winter)	analyzed separately and as a "total murrelet" group	ratio estimator by analytical stratum that calculated the density within that stratum, then calculated the overall area of the stratum and converted the densities to overall population estimate

Table 6. Continued.

Region/citation	Basis for stratification	Number Kittlitz's Murrelets (C = count; E = estimate; P = population estimate)	Number Marbled Murrelets (C = count; E = Estimate; P = population estimate)	Number unidentified murrelets (C = count; E = estimate; P = population estimate)	Percentage unidentified murrelets	How unidentified murrelets were incorporated into population estimates and/or population trends of Kittlitz's Murrelets	Data analysis
Kuletz et al. (2008)	during data collection, places where historical surveys were conducted?; during analyses, nearshore and offshore strata	numbers in all of Kachemak Bay combined in June—E 328 (1993), E 0 (2005), E 319 (2006); numbers [including flying birds] in July—E 2,015 (2005), E 3,294 (2006), E 1,141 (2007)	numbers in all of Kachemak Bay combined in June—E 984 (1993), E 3,651 (2005), E 7,312 (2006); numbers [including flying birds] in July—E 12,092 (2005), E 11,437 (2006), E 9,912 (2007)	numbers in all of Kachemak Bay combined in June—E 4,354 (1993), E 0 (2005), E 7365 (2006); numbers [including flying birds] in July—E 1,842 (2005), E 829 (2006), E 1,141 (2007)	in June, 0 (2005) to ~77 (1993); in July, ~5 (2006) to ~12 (2005)	analyzed separately and as a "total murrelet" group	ratio estimator by analytical stratum that calculated the density within that stratum, then calculated the overall area of the stratum to and converted the densities to overall estimate
ALASKA PENINSULA & ALEUTIAN ISLANDS							
Meehan (1996)	geographic				mean 65	not incorporated into population estimates	plotted seasonal distribution from shore-based surveys
Romano et al. (2005a)	bays and fjords, nearshore (all waters ≤500 m from shore but not in bay/fjord stratum), offshore (>500 m from shore but not in bay/fjord stratum)	C 184; P 1,594	C 2,020; P 7,486	C 272	10	not incorporated into population estimates	ratio estimator by analytical stratum that calculated mean density within each stratum and the area of each stratum, then multiplied the two numbers together to estimate overall population in each estimate; summed estimates for each stratum as total population estimate; assumed 100% detection of murrelets within sampling zone
Van Pelt and Piatt (2005)	(1) outer exposed coastlines; (2) embayments stratified into 2 types—bays (wide) and fjords (narrow)—which then were stratified into nearshore and offshore strata	C 123; P 2,265	C 722; P 7,389	C 65; no estimate generated, but authors indicated that, because numbers of UNBR were about 7% of the total, their total populations based on these unidentified birds would be slightly higher	~7	not incorporated into population estimates	ratio estimator by stratum density and area, the, pooled estimates across strata; assumed 100% detection of murrelets within sampling zone
Romano et al. (2005b)	during analyses: 0–1 km from shore, 1–3 km from shore, 3–10 km from shore	C 184; P 749	C 173; P 724	C 89; no estimate generated, but authors indicated that, because numbers of KIMU and MAMU were about equal, their total populations based on these unidentified birds would be ~10% higher	20	not incorporated into population estimates	ratio estimator by analytical stratum that calculated mean density within each stratum and the area of each stratum, then multiplied the two numbers together to estimate overall population in each estimate; summed estimates for each stratum as total population estimate; assumed 100% detection of murrelets within sampling zone

Table 6. Continued.

Region/citation	Basis for stratification	Number Kittlitz's Murrelets (C = count; E = estimate; P = population estimate)	Number Marbled Murrelets (C = count; E = Estimate; P = population estimate)	Number unidentified murrelets (C = count; E = estimate; P = population estimate)	Percentage unidentified murrelets	How unidentified murrelets were incorporated into population estimates and/or population trends of Kittlitz's Murrelets	Data analysis
OTHER/MULTIPLE LOCATIONS							
Agler et al. (1998)	nearshore, bay or pelagic-coastal, and offshore (pelagic)	C 347 (summer)	C 5,999 (summer)	C 7,726 (summer)	average 55	analyzed with Total Brachyramphus murrelets	ratio estimator to produce population estimates by stratum and area, then summed to produce total population estimate by area
Kendall and Agler (1998)	nearshore and offshore	max P 23,603 (CI; summer), max P 8,185 (PWS; summer), max P 7,883 (SE; summer)			~81 (CI), ~8 (PWS), unspecified (SE)	apportioned unidentified birds to species based on percentage of birds within a region that were identified as KIMU	ratio estimator to produce population estimates by stratum and area, then summed to produce total population estimate by area

Table 7. Characteristics of studies that have surveyed the abundance or population trend of Kittlitz's Murrelets in Alaska—Part E.

Region/citation	Corrections of population or density estimates of murrelets for time of day, tidal stage, etc.	Biases in numbers	Biases in analysis of population trends	Errors/problems/comments
GLACIER BAY				
Piatt et al. (undated)	none	(1) Sampling primarily nearshore zone would decrease counts and increase variability. (2) Use of 400-m sampling zone makes comparison with other surveys difficult, if not impossible. (3) The little sampling in offshore zone happened to occur in areas of higher KIMU densities, biasing populations upward.	Did not analyze.	Present numbers of birds counted both on and off transect; therefore, density cannot be calculated.
Lindell (2005)	none	(1) Survey methods differed between areas, creating a bias of unknown strength and direction. (2) Unclear whether author considers KIMU population in Icy Strait to be part of Glacier Bay population.	Did not analyze.	(1) Varied effort in nearshore zone, variation in timing of surveys, and variation in study designs make valid comparisons among areas difficult. (2) Densities in Icy Strait seem as high or higher in August as in mid-July; if this result indicates that KIMU move out of Glacier Bay and into Icy Strait as the season progresses, it would change the ideal time of sampling for this area compared with Glacier Bay.
Robards et al. (2003)	none	Changing densities with increasing distance from shore suggests that a third stratum (near-coast offshore) probably needed.	Compares nearshore data only, comparing a region with low counts and high variability--probably not reflective of entire population in the bay.	Only looks at nearshore densities, which are not reflective of of the bay.
Drew and Piatt (2008)	none	By sampling nearshore only, there will be fewer birds and higher variability.	(1) What they are calling approximately the same areas are not actually the same areas, in that a slight variation in parallel trackline 100 m from shore could result in very different density estimates; they used an 800-m selection buffer, meaning that they could be comparing lines that were up to 800 m offshore with lines that are much closer to shore. There is a very strong KIMU density gradient over this range, so it is doubtful that these estimates can be compared.	This is not a GIS innovative study--this is using a digital map to identify transects that are in the "same" area; however, the area identified as comparable between years is not actually comparable--a line run 100 m from shore vs. one run even 300 m from shore will likely result in very different density estimates
Drew et al. (2008)	none	(1) Uncertainty about how some data were collected, so difficult to evaluate. (2) Modeling exercise suggests that nearshore effort has been oversampled.	(1) Changing densities with increasing distance from shore suggests that a third stratum (near-coast offshore) probably needed.	Suggest ~4% effort in nearshore zone and ~96% effort in offshore zone for more precise KIMU estimates; reasonable idea.
Romano et al. (2004)	none	Oversampled nearshore zone, increasing variability in counts and decreasing total count.	Did not analyze. Density estimates probably are biased low because nearshore stratum was oversampled and no strata were used when estimating densities for areas.	(1) Oversampled nearshore zone and did not include strata in density estimates. (2) Counts are provided for June—a low-density month. (3) They report a greater number of KIMU in nearshore, but it is unclear if this is just a greater number detected there because more nearshore survey area was covered or if densities actually were higher. If densities were higher in nearshore zone, this result would contradict other studies and also would require that variability should be looked at, given that it is expected to be higher in nearshore zone. (4) Peak densities occurred in July survey; however, peak daily variability occurred in June.

Table 7. Continued.

Region/citation	Corrections of population or density estimates of murrelets for time of day, tidal stage, etc.	Biases in numbers	Biases in analysis of population trends	Errors/problems/comments
Kirchhoff (2008)	detected a tidal influence; however, there may be a confounding effect between time of day and tide, in that the sampling for tidal stage occurred over 4.5 consecutive days	Counted only birds on the water but then used estimate of 13% flying birds to inflate estimate.		Dramatic differences in densities among small inlets that were censused suggest more factors at play affecting distribution in time and space than indicated here. In particular, studies of movements into and out of bay and relationships to tides are confounded by the narrow sampling window.
Arimitsu and Piatt (undated)	none	Oversampled nearshore zone, increasing variability in counts and decreasing total count.	Did not do an analysis, but 2000-2008 comparison shows no change; however, 1991 survey not comparable, and 1993 data are not comparable because most of the area covered then was offshore.	The 1991 population estimate appears to have come from nowhere because one cannot estimate a total bay population from essentially only nearshore data; given the focus on nearshore zone in that survey, it seems unbelievably high and does not appear to be possible to calculate with the data and sampling design presented in Piatt et al. (1991).
Hoekman et al. (2011a)	probability of being near the ship's centerline and probability of identification to species	Correction for unidentified birds overestimates KIMU population.	(1) Problems created by high numbers in low-density stratum. (2) Some transects are so short that large numbers of birds inflate density estimate (and variance) wildly. (3) Sampling intensity appears to be too low for clumped species.	Did not analyze, but comparison of corrected (from line-transects) vs. uncorrected data (from strip-transects) shows that strip-transects badly underestimate population size.
Hoekman et al. (2011b)	probability of being near the ship's centerline and probability of identification to species	Correction for unidentified birds overestimates KIMU population.	(1) Suddenly mixed high-density and low-density areas into one estimate, rather than calculating each stratum separately. (2) Some transects are so short that large numbers of birds inflate density estimate (and variance) wildly. (3) Sampling intensity appears to be too low for clumped species. (4) Disquieting that the year with poor visibility 25% of the time yielded the highest population estimates—is there a relationship between the two?	Comparison of corrected (from line-transects) vs. uncorrected data (from strip-transects) shows that strip-transects badly underestimate population size.
Kirchhoff et al. (2010)	none	Numbers will be higher and less variable for offshore surveys than for nearshore surveys. (2) Probably a need for third stratum (near-coast offshore) to encompass zone of high densities.	Compared directly between identical survey methods and areas; no bias detected.	Interannual variability in distance from shore at which KIMU concentrate [contrast these plots with those of Kirchhoff 2008] makes development of a third stratum complicated.
ICY BAY, OUTER COAST & MISCELLANEOUS LOCATIONS				
Stephensen and Andrus (2001)	none		Undersampled offshore area, especially in Yakutat Bay.	Did not analyze.
Kissling et al. (2007a)	none	(1) Stratifying densities by water depth, even though it was shown that they did not differ significantly by depth (Fig. 4), probably leads to biased estimates. (2) Unclear whether flying birds were counted continuously or with snapshot method, so effect on numbers difficult to judge.	Did not analyze.	Differences among strata in survey effort would bias estimates low if nearshore stratum was oversampled.

Table 7. Continued.

Region/citation	Corrections of population or density estimates of murrelets for time of day, tidal stage, etc.	Biases in numbers	Biases in analysis of population trends	Errors/problems/comments
Kissling et al. (2007b)	none	Numbers will be different among years dependent on stratum covered--which varied among years.	(1) Large short-term variation in abundance (Fig. 16) would indicate that single surveys in single years should not be compared to produce accurate trend estimates.	(1) Large variety of methods used, making comparability impossible; however, useful for identifying suitable survey methods. (2) Consistently higher densities in pelagic waters--more evidence of habitat selection against nearshore zone. (3) Also, p. 69 graph had huge variation among days, providing more evidence of high spatial and temporal variability.
Kissling et al. (2007c)	corrected for weather-related effects on detectability; also examined effects of water depth, ice, tide type, and tidal-current strength on abundance of KIMU but did not correct population estimates with resulting information	Did not survey some parts of Icy Bay, so some variation in numbers, and utility of data as baseline data set for population monitoring, are compromised by possibility that birds are simply moving into/out of unsampled areas at various times.	(1) Reducing target CVs to 10% required an 800% increase in sampling effort over a target CV of 30%; however, not enough km of sampling tracklines are possible within the bay to achieve a CV of 10%—you reach a complete census of the bay at a ~670% increase (at which point, the CV should become 0 because it is a census).	Unclear how authors sampled unlimited distance, then truncated offshore surveys into 300-m-wide strips, then later created a matrix of 200- x 200-m cells for spatial analyses; where did the other 100 m of (truncated) transect width go?
PRINCE WILLIAM SOUND				
Day and Nigro (1999)	examined abundance trends in relation do diurnal cycles; data showed unclear patterns	(1) Nearshore data exhibit high variability. (2) Intensity of offshore sampling was not high enough to yield estimates with reasonable precision.	(1) Trends are representative of the areas sampled but are not necessarily reflective of entire population. (2) High variability in seasonal and interannual counts would make it extremely difficult to detect a trend during a 3-year time frame.	Lack of GPS made layout of offshore surveys difficult and reduced sampling intensity because visible landmarks had to be used to lay out lines.
Kuletz et al. (2003a)	none	The estimate here of >2,000 KIMU in PWS at the same time that the broad-scale surveys estimate ~1,000 illustrates the inaccuracy of the latter survey and monitoring technique for this species.	Did not analyze.	
Kuletz et al. (2003b)	none	(1) Stratified random survey design does not accurately sample clumped species if stratification is not based on factors associated with clumping. (2) Continuous shoreline survey does not accurately sample clumped species.	(1) 1989–1991 survey design does not adequately sample clumped species like KIMU because of strict habitat requirements; hence, trend analysis appears to be simply showing the retreat of birds into habitat that is more and more restricted in distribution. (2) Assuming that identified KIMU represent the entire KIMU population biases estimate in an unknown direction, given that the proportion on KIMU identified varied from year to year. (3) Low counts do not justify pooling across years in Fig. 6 because it decreases the actual variability in the dataset, permitting identification of a trend when in fact there is not one.	(1) Why are there 6 maps but 7 years in graph? What happened to 1994? (2) Is it really useful to analyze a trend for a species in a habitat that it doesn't really use?

Table 7. Continued.

Region/citation	Corrections of population or density estimates of murrelets for time of day, tidal stage, etc.	Biases in numbers	Biases in analysis of population trends	Errors/problems/comments
McKnight et al. (2003)	none	Continuous shoreline survey does not accurately sample clumped species. Incomprehensible why surveys were timed to coincide with spring tides, since date has strongest effect on numbers.	(1) Confidence intervals for 2001 and 2003 overlap; however, authors did not run any tests and just assumed that estimates were absolute population size and report a decline. (2) Seasonal differences are greater than between-year differences, requiring you to correct for variability caused by differences in date of survey. (3) Comparing only one survey in each year, taken during different time periods, is as equally likely to reflect seasonal differences as between-year differences.	(1) Sampled offshore one day and nearshore the next; given daily patterns of habitat use, this would decrease the likelihood that the assumption of nearshore birds not being the same birds as pelagic is true. (2) Cannot actually compare densities of nearshore and offshore without an estimate of variance for nearshore.
Kuletz et al. (2007)	none	(1) Biases in 1972 numbers difficult to ascertain given 1972 survey methods are not presented. (2) Model assumes that the probability of being identified is the same for both species; is incorrect because KIMU are much more difficult to identify to species than are MAMU, resulting in underestimated proportion of KIMU+MAMU population. (3) See additional criticisms in column for McKnight et al. (2008).	(1) Excluded 1993 because it is an outlier, but it is within range of other values for KIMU—but extremely high for unidentified murrelets. (2) Assumption of equal probability of misidentification does not seem right—should be that probability of misidentification is proportional to probability of encounter, biasing trends in the rarer species.	(1) Paper makes little sense because model estimates do not add to our understanding of KIMU population trends, there is no way to evaluate the accuracy of the model, no need to produce a complicated model to take into account unidentified KIMU, and their estimates of decline are based on a model with no way to evaluate its accuracy to predict a decline in an area where the species is not very numerous to begin with. (2) Results of actual regression with and without 1972 and 1993 are not presented. (3) Why try to create population predictions based on unidentified murrelets instead of just correcting for them based on overall proportion in identified murrelet population?
McKnight et al. (2008)	none	(1) Stratified random survey design does not accurately sample clumped species if stratification is not based on factors associated with clumping. (2) Continuous shoreline survey does not accurately sample clumped species. (3) Undersampling KIMU-specific habitat would result in underestimate of KIMU population; this problem is illustrated by the fact that Day and Nigro counted more birds in 4 bays in 1998 than this study estimated for all of PWS. (4) Large percentage of unidentified birds and unusual distributions in some years suggests problems with observers' identification abilities and results in questionable population estimates for KIMU. (5) Rarity of KIMUs vs. MAMUs suggests that misidentification of MAMUs also may skew KIMU estimates. (6) Large interannual variability in population estimates for both KIMU and MAMU suggests questionable accuracy in population estimation—population cannot change that rapidly under natural conditions.	(1) Combining UNMU with MAMU underestimates KIMU population by an unknown amount. (2) because so little KIMU-specific habitat is being surveyed, it is highly probable that this sampling technique actually is documenting retreat of birds into preferred habitat rather than population decline. (3) No change in population is assumed to represent no recovery from oil spill, rather than quick recovery.	(1) No change in population trend is taken as an indication of no recovery, which does not make sense, particularly if you do not have a good pre-spill baseline for comparison—could just as easily be a stable population. (2) Given the extreme variability in KIMU counts among years, you probably cannot detect a trend, even if there was a significant one. (3) Determining a population trend in an area that does not contain most of the KIMU is of questionable value.
KENAI FJORDS				
Bailey (1976)	none	(1) Underestimated population because did not sample offshore area at all, and that is where most birds occur. (2) Bias of unknown direction because sample-area width was unlimited	NA	Lack of defined survey width makes these data worthless for later comparisons of population trends.

Table 7. Continued.

Region/citation	Corrections of population or density estimates of murrelets for time of day, tidal stage, etc.	Biases in numbers	Biases in analysis of population trends	Errors/problems/comments
Nishimoto and Rice (1987)	none	(1) Underestimated population because did not sample offshore area at all, and that is where most birds occur. (2) Bias of unknown direction because sample-area width was unlimited		Lack of defined survey width makes these data worthless for later comparisons of population trends.
Bailey and Rice (1989)	none	Underestimated population because did not sample offshore area at all.		
Van Pelt and Piatt (2003)	none	(1) Overestimated population because additional survey lines were added only in area of known concentration. (2) Bias of unknown direction because they presumably avoided areas with ice (not stated whether they sampled areas with ice and, if so, amount of ice cover that excluded them) and because the representativeness of offshore areas selected for surveys is unknown	(1) Used data from nearshore segments sampled only in 1986, 1989, and 2002 in analysis of trends; however, only 2 of ~100 segments sampled in all 3 years were in the vicinity of glaciers, so the analysis simply documents that KIMU's were becoming more and more concentrated away from these non-glacial segments, rather than that the population was declining; sample sizes also were smaller than another possible analysis (see next). (2) A better analysis would be to use the larger set of nearshore segments sampled in 1986 and 2002 in a comparison, since the 2002 "new transects" were concentrated near glaciers. (3) The only data used for analysis of population trends were nearshore data, but that area represents only a small part of the total population, so it is not a good baseline to use for monitoring.	(1) Used data from nearshore segments sampled only in 1986, 1989, and 2002 in trend analysis; however, only 2 of ~100 segments sampled in all 3 years were in vicinity of glaciers, so analysis simply shows that KIMU's were becoming more and more concentrated away from these non-glacial segments; sample sizes also were smaller than another possible analysis (see #2 left). (2) Cannot use 1986 data in any analyses because width of count area was unlimited, so no correct density estimates can de made. (3) Claim that Ralph and Miller's (1995) paper proves that murrelets cannot be seen >100 m away is refuted by Speckman et al. (2000) and personal observations of Day, Nigro, and many others; net result of this low width estimate is to inflate population estimates in the earlier years by several hundred percent. (4) Authors did not account for increasing proportion of unidentified murrelets over successive surveys; net result is to underestimate KIMU population in later years, although the fact that much of the habitat in the segments used for comparison was not particularly great KIMU habitat suggests that the underestimate is possibly by only a few birds. (5) Because densities differ by distance from shore, different survey width for nearshore surveys (300 m) here makes comparison impossible with 1989 survey (survey width 200 m).
Romano et al. (2006)	none	Did not conduct surveys along exposed coast for accurately estimating population size; there probably are a few birds at sea in that area (e.g., they nest in the Pye Islands, and I have seen them at sea near the Chiswell and Pye islands in the spring), but the underestimation probably is small.	Simply cited the faulty Van Pelt and Piatt (2003) report as evidence of a widespread, large-scale decline, even though this population estimate was ~66% higher than the 2003 population estimate.	Appears to be approaching a good study design, except for not sampling outer coast-offshore well.
Arimitsu et al. (2010)		(1) Strip transects and continuously counting flying birds bias numbers in different direction (underestimate and overestimate, respectively), making actual population size unclear. (2) Did not conduct surveys along exposed coast for accurately estimating population size, although effect may be small.		Appears to be approaching a good study design, except for not sampling outer coast-offshore well. Approaching a good method for apportioning unidentified murrelets to species

Table 7. Continued.

Region/citation	Corrections of population or density estimates of murrelets for time of day, tidal stage, etc.	Biases in numbers	Biases in analysis of population trends	Errors/problems/comments
KACHEMAK BAY & COOK INLET				
Agler et al. (1995)	none, but information was recorded	(1) Nearshore-offshore gradient in densities not accounted for in sampling scheme; even the post-survey re-stratification of the offshore stratum into a coastal stratum (0.1–3 km) and a pelagic stratum was compromised and crude. (2) Continuous count of flying bird overestimates abundance. (3) No detection functions calculated.	Did not analyze population trends, However, MAMU and KIMU (particularly MAMU) population estimates probably are extremely low, given that the unidentified murrelet estimate is nearly 8 times as high as the MAMU estimate; most of these unidentified birds probably were MAMU.	(1) Sampling within a stratum requires that all points within the stratum have an equal probability of being sampled; if that assumption is true, you get an unbiased estimate of populations. However, if there are gradients of abundance within a stratum (specifically, the coastal stratum), your gradient will increase the variability (= uncertainty) of those estimates.
Kuletz et al. (2008)	none	(1) Nearshore-offshore gradient in densities not accounted for in sampling scheme; even the post-survey re-stratification of the survey data into a nearshore stratum and a pelagic stratum was questionable and crude. (2) Historical surveys used in later trends analysis were not designed for such an analysis and should not be used in such an analysis. (3) Historical surveys consisted of minimal sampling effort and provide biased estimates of numbers; in fact, estimate for Southern Shore stratum in one year (1984) was discarded (see Speckman et al. 2005). As a result, the abnormally high "baseline" year of 1988 was used, even though the area sampled that year was the least ever sampled.	(1) Estimate for Southern Shore stratum in one year (1984) was discarded (see Speckman et al. 2005). As a result, the equally abnormally high "baseline" year of 1988 was used, even though the area sampled that year was the least ever sampled. (2) No critical description and analysis of early baseline data were provided, making a complete understanding of the important early data impossible. (3) Unclear why some densities in Figure 7 were insufficient to test for trends, whereas others were deemed sufficient. (4) Although current estimates may be a more accurate comparison, historical data are not very reliable, particularly with a limited number of years included in the analysis; could this be approached using some sort of bootstrap analysis to allow estimates to vary over a range of values within 95% CI? (5) Early surveys with limited replicates will have large confidence intervals.	(1) Sampling effort in early years was so minimal that there cannot be confidence in the accuracy or precision of the estimate, which is used as the baseline estimate; unfortunately, Figure 5A pools among years, whereas Figures 2-6 in Speckman et al. (2005) shows survey effort by year, clarifying just how minimal the sampling effort was in the early years that are being used as baseline data. (2) A 32% decline in June KIMU numbers is reported between 1993 and 2005 (P. 20); however, this estimate is based on a regression of two points, and 0 KIMU were detected in 2005 (Table 2); when 2006 data were included in the analysis, there is no change in KIMU numbers; this difference alone should be enough to indicate that a two-year comparison is not valid, particularly when there is not standardization across surveys. (3) On P. 21, they report late-season declines in KIMU numbers, but it is not significant (Fig. 7); however, they then go on to use that reported decline throughout the rest of the report as a fact. (4) Density values in the various strata reported here are not matched by densities for the same years reported in Speckman et al. (2005); in addition, some years of data shown in Speckman et al. are missing from this report.
Meehan (1996)	none	(1) Surveys reflect areas suitable to survey in the future, not estimate populations or density. (2) Lack of delineation of area sampled in some cases makes calculation of densities impossible.	did not analyze	(1) Sampling design needs much more work. (2) Poor ability to identify murrelets to species makes utility of data questionable.
Romano et al. (2005a)	none	(1) Nearshore survey appeared to occur at variable distances from shore, making accurate estimation of density questionable. (2) Part of island that contained most birds was sampled, but not clear how that information was derived. (3) The offshore stratum is the largest stratum and, hence, has the greatest effect on the total population estimate, but the sampling effort there was the least of all three strata; hence, estimates may be biased in an unknown direction. (4) Reason for not sampling western part of island unclear; also, makes accurate population estimate for entire island impossible to generate.	did not analyze	(1) Needs greater sampling intensity in offshore stratum and additional sampling in rest of island before an accurate population estimate can be generated. (2) Reasons for laying out particular survey tracklines not explained.

Table 7. Continued.

Region/citation	Corrections of population or density estimates of murrelets for time of day, tidal stage, etc.	Biases in numbers	Biases in analysis of population trends	Errors/problems/comments
Van Pelt and Piatt (2005)	none	(1) Nearshore survey appeared to occur at variable distances from shore, making accurate estimation of density in that stratum (actually 3 of 5 strata) questionable. (2) As indicated by the authors, surveys were associated strongly with the mainland, so no surveys occurred farther offshore, where at least some KIMU's occur; as a result, estimates will be biased downward. (3) The highest densities occurred in stratum with lowest sampling intensity and largest area; hence, estimates may be biased in an unknown direction.	did not analyze	(1) Stratified random survey design does not accurately sample clumped species if stratification is not based on factors associated with clumping. (2) Lack of inclusion of nearby islands and island-groups where the species nests (e.g., Shumagin Islands) underestimates population in this region.
Romano et al. (2005b)	none	(1) Nearshore survey appeared to occur at variable distances from shore, making accurate estimation of density questionable. (2) Western ~1/3 of island was not sampled, yet density estimates from eastern ~2/3 of island were applied to that unsampled area; this approach is useful for developing a rough estimate of about how many birds may be in a particular area, but it is not appropriate for developing estimates that will be used in the future. (3) In addition, the large, protected bays that the species concentrates in the eastern part of the island are nearly absent from the western part of it, making the inclusion of the western part in the population estimate even more questionable. (4) The 3–10-km zone is the largest stratum and, hence, has the greatest effect on the total population estimate, but the sampling effort there was the least of all three strata; hence, estimates may be biased in an unknown direction.	Did not analyze.	(1) Needs greater sampling intensity in 3–10-km zone and additional sampling in western ~1/3 of island before an accurate population estimate can be generated. (2) Reasons for sampling some areas and ignoring others and for laying out particular survey tracklines not explained.
OTHER/MULTIPLE LOCATIONS				
Agler et al. (1998)	none	(1) High proportion of nearshore sampling increases variability in counts, particularly if distance from shore was not constant. (2) Low species identification rate will underestimate counts and species-specific density estimates. (3) Inclusion of continuously counted data on flying birds will overestimate population size. (4) Random sampling is inappropriate sampling method for a clumped species. (4) Random sampling undersamples the specific habitat type that KIMU prefers, underestimating population size.	Did not analyze-—pooled across years.	(1) Do not provide information by year or variance among years. (2) Lumping of all BRMU makes it very difficult to compare these estimates with other studies. (3) Very low identification rate makes the data for KIMU unreliable for comparison.
Kendall and Agler (1998)	none	(1) High proportion of nearshore sampling increases variability in counts, particularly if distance from shore was not constant. (2) Low species identification rate will underestimate counts and species-specific density estimates. (3) Inclusion of continuously counted data on flying birds will overestimate population size. (4) Random sampling is inappropriate sampling method for a clumped species. (4) Random sampling undersamples the specific habitat type that KIMU prefers, underestimating population size (acknowledged by authors).	Did not analyze—pooled across years.	(1) Do not provide information by year or variance among years. (2) Very low identification rate makes the data for KIMU unreliable for comparison. (3) The method for apportioning unidentified birds to species could be improved

methodology, these later studies were able to compare their results with those of the earlier studies, even though the continuous-counting method overestimates densities.

Very little effort has been expended in conducting replicate sampling, which is defined here as sampling the same area multiple times over a short time period (Table 4). The few studies with replicate samples include Romano et al. (2004), Kirchhoff et al. (2010), and Kissling et al. (2007b). A few other studies (e.g., Day and Nigro 1999, Kissling et al. 2007c) conducted surveys spaced 7–10 days apart that may have been construed as replicates, but this length of time showed much variation in numbers that indicated a seasonal pattern of abundance, so much variation that it probably makes these samples unusable as replicates. Some of the variation also may be caused by among-sample differences in the location and density of calved glacial ice (e.g., Kissling et al. 2007c; Day, pers. obs.), but there also is a strong seasonal pattern in abundance of this species.

There has been substantial variation among studies in sampling platforms, viewing height of observers above the water, and the number and assignments of observers (Tables 4–5). In general, small skiffs (usually inflatables less than ~6 m long) have been the primary vehicle used for nearshore surveys. On exposed coastlines and in many locations in recent years, ~8–25-m vessels have been used. Large vessels, such as the 36-m *Tiglax*, are used only in dangerous, exposed waters such as the Aleutian Islands (Romano et al. 2005a, 2005b). Most surveys have used 2 observers, although a few have used 2 observers and a recorder who enters data directly into a computer that has data-collection software installed and is connected to a GPS unit. In earlier, pre-GPS surveys (e.g., Day et al. 1999), one observer drove the boat, surveyed a smaller part of the survey zone, and recorded data, whereas the other observer surveyed a larger part of the survey zone and mapped locations.

Transect sampling width and layout have varied extensively among surveys (Table 5). Nearshore surveys have tended to be 200 m wide and up to 200 m ahead of the skiff; however, some studies searched nearshore zones up to 500 m wide, others searched between 100 m and 300 m ahead of the boat, and two (Bailey 1976, Nishimoto and Rice 1987) used an unlimited sampling width. Offshore surveys have been far more varied, although most have used a sampling zone 300 m wide and 300 m ahead of the ship; again, however, some surveys searched for birds 150 m or 200 m ahead of the boat, and one study recorded birds out to 1,000 m from the boat in some years (Kuletz et al. 2008).

Ship's speed for sampling has varied considerably among studies (Table 5). In most cases, vessel speed has ranged between 10 and 20 km/h, with a few at ~10 km/h (e.g., Bailey 1976, Bailey and Rice 1989, Day and Nigro 1999, Kissling et al. 2007c, Kirchhoff 2008) and some >20 km/h (e.g., Romano et al. 2005a, 2005b; Arimitsu et al. 2010). Ship's speed has implications for data quality in terms of the distance at which birds become disturbed and fly away (greater distance with greater ship's speed), rather than sitting on the water, thus decreasing the identification rate. High speeds also increase the chances of missing birds that happen to be diving as the ship nears.

The layout of sampling lines has varied dramatically among studies (Table 5). Nearshore surveys have tended to be conducted parallel to shore and encompass a zone out to 200 m (e.g., Day and Nigro 1999); in some locations, however, the nearshore zone has been considered to be 400 m wide (e.g., Piatt et al., undated), variable width up to 500 m wide to deal with large shallow areas (e.g., Romano et al. 2005b), up to 800 m wide (e.g., Drew and Piatt 2008), or even of unlimited width (e.g., Bailey 1976, Nishimoto and Rice 1987). Likewise, offshore surveys generally have been laid out orthogonal to shorelines (e.g., Robards et al. 2003, Kissling et al. 2007c, Drew et al. 2008) or in a zigzag pattern out from shorelines (e.g., Day and Nigro 1999, Lindell 2005), but other layouts have been used in some cases (e.g., Romano et al. 2005a, 2005b; Van Pelt and Piatt 2005, Kuletz et al. 2008, McKnight et al. 2008). In general, it is best to lay out lines orthogonal to or zigzagging out from shorelines because of changing densities of Kittlitz's Murrelets with increasing distance from shore (Kirchhoff 2008, Kirchhoff et al. 2010). Offshore surveys also have had variable widths, ranging in most cases from 200 m wide and ahead of the boat to 300 m wide and ahead of the boat;

however, studies that use line-transect sampling generally have used unlimited sampling width but later truncated the sampling zone after looking at detection curves (e.g., Kissling et al. 2007c).

Criteria for stopping surveys often have been unspecified, but studies that do specify them generally have used sea height of ~0.5–1 m as the primary cutoff criterion (Table 5). Other criteria have reflected the point at which one cannot see small birds on the water at 200–300 m (depending on the size of the boat and the width of the sampling zone); sea height >0.3 m; Beaufort sea scale >2; poor visibility; and/or heavy precipitation, glare, or fog. One study varied criteria seasonally, ranging from seas >0.5 m in summer to >1.8 m in winter (Agler et al. 1995), and 2 varied criteria spatially, with the cutoffs >0.5 m in the nearshore zone (where smaller boats generally are used) and >1 m in the offshore zone (Romano et al. 2005a, 2005b).

The degree of stratification and the reasons for stratification has varied dramatically among studies (Tables 5–6). The number of strata within a restricted area (e.g., Glacier Bay) has ranged from 1 (several studies) to 11 (Drew et al. 2008), whereas studies that have covered a larger geographic area have had even more strata. For example, one study that covered a large part of Southeastern Alaska used 12 strata based on geography (Kissling et al. 2007b), and 3 studies that covered most or all of the Kenai Fjords ranged between 11 and 14 geographic strata that were used for summarizing data (Bailey 1976, Nishimoto and Rice 1987, Bailey and Rice 1989). Stratification generally consisted of a nearshore stratum and one or more offshore strata, with nearshore and offshore strata often divided further by geographic area (e.g., the survey type/geographic strata that subdivided Glacier Bay into 11 strata (Drew and Piatt 2008).

The percentage of unidentified murrelets has varied dramatically among surveys (Table 6). Although many studies did not specify the percentage of unidentified murrelets, numbers that were reported ranged from 0% for a study with unlimited sampling width (Bailey 1976) to ~89% in some years for surveys in Prince William Sound (Kuletz et al. 2007). In fact, at least 18 studies had at least 10% unidentified murrelets at one time or another, and at least 10 studies had at least 50% unidentified murrelets at one time or another.

Most studies did not allocate unidentified murrelets into estimates of density and/or population size, perhaps because of the extensive variation in the percentage of unidentified murrelets (Table 6). Instead, most of these studies simply used the unidentified birds in an estimate of all *Brachyramphus* murrelets combined. However, Kirchhoff (2008), Kirchhoff et al. (2010), and Hoekman et al. (2011b) allocated unidentified birds in proportion to the percentage of identified birds that were Kittlitz's Murrelets. In addition, Kuletz et al. (2007) created a model that allocated unidentified murrelets to species; however, the methodology for this technique is unclear. Arimitsu et al. (2010) allocated unidentified murrelets in proportion to the percentage of identified birds on a given transect line that were Kittlitz's Murrelets. Kendall and Agler (1998) apportioned unidentified murrelets in proportion to the percentage of identified birds within a region (Cook Inlet, Prince William Sound, Southeastern Alaska) that were Kittlitz's Murrelets.

The primary data-analysis methodology has been to calculate standardized mean densities (birds/km^2) by sampling method (nearshore, offshore, and/or any other stratum such as this) and geographic stratum (Table 6). If another objective is to estimate population size, most authors have multiplied estimated densities (and their associated measures of variation) by the area of the method-geographic stratum with a ratio estimator (which is designed to improve stratified sampling by incorporating covariates in the estimation), then summing across strata to generate a total population estimate for the area of interest. Some studies, especially the recent ones (e.g., Kissling et al. 2007a, 2007b, 2007c; Arimitsu and Piatt, undated), have used the software DISTANCE to generate detection functions that can be used to generate corrected density and population estimates. Studies that examine population trends generally have used linear regression on densities and/or population size (e.g., Kuletz et al. 2007).

Very few of the studies have corrected estimates of density and/or population size by extrinsic factors that Kittlitz's Murrelets might respond to, such as tidal stage, tidal current strength, and time of day (Table 7). Kirchhoff et al. (2010) found a tidal pattern to movements of Kittlitz's Murrelets at Glacier Bay; unfortunately, the 4.5 days of sampling were consecutive days, so time of day and tide were confounded, making the analyses of the effects of tide on movements of murrelets of questionable validity. Kissling et al. (2007c) used weather as a covariate in detectability functions at Icy Bay and examined effects of water depth, ice cover, tide type, and tidal-current strength on the abundance of Kittlitz's Murrelets, but those environmental factors did not have a significant effect on the detection of those birds. Otherwise, the issue of correction factors for detectability of Kittlitz's Murrelets has been unexplored.

STUDY WEAKNESSES AND STRENGTHS FOR ABUNDANCE AND TREND ESTIMATION

Determination of population size and population trends also requires an evaluation of the various studies that have been conducted, including examining them for weaknesses and strengths that may affect confidence in their results (Tables 7, 8, and 9). To simplify presentation, the information is presented by geographic region (Figure 1), similar to the presentation of information in Tables 3–7. When reading this section, it is important to keep in mind that some of these studies were fine by themselves but that they were not designed for long-term monitoring, making them weak in the context of this study.

GLACIER BAY

Examination of the various studies in chronological order makes clear that few of them are of a quality useful for long-term monitoring (Tables 7 and 8). The 1991 survey (Piatt et al., undated) is unusable as a baseline data set because it consists almost entirely of nearshore data; further, the small amount of offshore sampling that they did conduct occurred primarily in areas with generally-high Kittlitz's Murrelet densities, resulting in an inflated baseline population estimate. Various historical studies also used different sampling methodology with varying degrees of coverage of the nearshore area. The 1993 survey of Lindell (2005) can be repeated and used to estimate trends, but it cannot be used to estimate population size accurately (Kirchhoff et al. 2010). The work of Robards et al. (2003), Lindell (2005), Drew et al. (2008), and Kirchhoff (2008) shows that large number of birds move in and out of Glacier Bay on a daily basis, raising questions about exactly what the "Glacier Bay population" of murrelets actually represents. The intensive broad-scale surveys of Robards et al. (2003), Romano et al. (2004), and Drew et al. (2008) have attributes that approach a study design good for both population estimation and population monitoring; however, it is clear that they oversample the nearshore zone (Drew et al. 2008), and they could be improved by stratifying the offshore zone into two or more strata that better reflect the nearshore–offshore density gradient that occurs in the bay (Kirchhoff 2008). The 2008 surveys of Arimitsu and Piatt (undated) appear to have too low a sampling intensity of the offshore area for adequate estimation of densities or population. The methodology of Drew and Piatt (2008) appears to have some deficiencies that make at least some of its conclusions questionable.

Several studies have strengths that make parts of them useful for monitoring Kittlitz's murrelet populations; these attributes are concentrated primarily in surveys conducted in the period 2000–2010 (Table 9). In particular, the surveys of Robards et al. (2003), Romano et al. (2004), and Drew et al. (20008) provide extensive sampling intensity of the offshore zone of Glacier Bay, an attribute that is important for a clumped species such as Kittlitz's Murrelet. The surveys of Kirchhoff et al. (2010) and Hoekman et al. (2011a, 2011b) all incorporate line-transect sampling, which is needed for generating corrected densities of birds at sea. Finally, several of the recent studies have elements that are desired for monitoring populations or population trends, including quantifying sources of variability, an emphasis of sampling the offshore zone and areas where the species concentrates, and accounting for the inshore–offshore density gradient.

ICY BAY AND OTHER SOUTHEASTERN ALASKA

The surveys of Icy Bay by Kissling et al. (2007c) have minor problems that may compromise the quality of the population estimates, but the overall design is strong (Tables 7

Table 8. Weaknesses of individual studies of the abundance and/or population trends of Kittlitz's Murrelets in Alaska.

	Data collection				Data analysis	
Region/citation	Inappropriate study design or sampling methodology for quantifying population numbers	Inappropriate study design or sampling methodology for monitoring population trend	Insufficient sampling intensity	Sampling methodology is such that comparisons with other data sets is difficult or impossible	Inappropriate analytical methodology for quantifying population numbers or population trend	Inappropriate method for apportioning unidentified birds to species
GLACIER BAY						
Piatt et al. (undated)	X	X	X		NA	NA
Lindell (2005)	X	X	?	X	X	NA
Robards et al. (2003)	X	X	X		X	NA
Drew and Piatt (2008)	X	X			X	NA
Drew et al. (2008)	X	X			X	NA
Romano et al. (2004)	X		X		X	NA
Kirchhoff (2008)	X	X	X	X	X	X
Arimitsu and Piatt (undated)	X	X	X			NA
Kirchhoff et al. (2010)	X	?	?		?	X
Hoekman et al. (2011a)	X		X		X	X
Hoekman et al. (2011b)	X		X		X	X
ICY BAY, OUTER COAST & MISCELLANEOUS LOCATIONS						
Stephensen and Andres (2001)	X		X		X	
Kissling et al. (2007a)	X				X	NA?
Kissling et al. (2007b)			X	X		NA
Kissling et al. (2007c)	?	?				NA

Table 8. Continued.

Region/citation	Data collection: Inappropriate study design or sampling methodology for quantifying population numbers	Data collection: Inappropriate study design or sampling methodology for monitoring population trend	Data collection: Insufficient sampling intensity	Data collection: Sampling methodology is such that comparisons with other data sets is difficult or impossible	Data analysis: Inappropriate analytical methodology for quantifying population numbers or population trend	Data analysis: Inappropriate method for apportioning unidentified birds to species
PRINCE WILLIAM SOUND						
Day and Nigro (1999)	X		X			NA
Kuletz et al. (2003a)						NA
Kuletz et al. (2003b)	X	X	X		X	NA
McKnight et al. (2003)		X			X	NA?
Kuletz et al. (2007)	X	X	X		X	NA
McKnight et al. (2008)	X	X	X		X	NA
KENAI FJORDS						
Bailey (1976)	X	X	X	X		NA[a]
Nishimoto and Rice (1987)	X	X	X		X	
Bailey and Rice (1989)	X	X	X			NA
Van Pelt and Piatt (2003)	X	X	?		X	NA
Romano et al. (2006)		X			X	
Arimitsu et al. (2010)		X				
KACHEMAK BAY & COOK INLET						
Agler et al. (1995)	X	X		X	X	NA
Kuletz et al. (2008)	X	X	X	X	X	NA

Table 8. Continued.

Region/citation	Data collection: Inappropriate study design or sampling methodology for quantifying population numbers	Data collection: Inappropriate study design or sampling methodology for monitoring population trend	Data collection: Insufficient sampling intensity	Data collection: Sampling methodology is such that comparisons with other data sets is difficult or impossible	Data analysis: Inappropriate analytical methodology for quantifying population numbers or population trend	Data analysis: Inappropriate method for apportioning unidentified birds to species
ALASKA PENINSULA & ALEUTIAN ISLANDS						
Meehan (1996)	X	X	X	X		NA
Romano et al. (2005a)	X	X	X		X	NA
Van Pelt and Piatt (2005)	X	X	X			NA
Romano et al. (2005b)	X	X	X		X	NA
OTHER/MULTIPLE LOCATIONS						
Agler et al. (1998)	X	X			X	NA
Kendall and Agler (1998)	X	X			X	

[a] No unidentified birds.

Table 9. Strengths of individual studies of the abundance and/or population trends of Kittlitz's Murrelets in Alaska.

Region/citation	Data collection				Data analysis	
	Appropriate study design or sampling methodology for quantifying population numbers	Appropriate study design or sampling methodology for monitoring population trend	Sufficient sampling intensity	Sampling methodology is comparable with other data sets	Appropriate analytical methodology for quantifying population numbers or population trend	Appropriate method for apportioning unidentified birds to species
GLACIER BAY						
Piatt et al. (undated)						NA
Lindell (2005)	(X)[a]					NA
Robards et al. (2003)	(X)	(X)	X		(X)	NA
Drew and Piatt (2008)						NA
Drew et al. (2008)	(X)	(X)	X		X	NA
Romano et al. (2004)	(X)	(X)	X		(X)	NA
Kirchhoff (2008)	(X)	(X)				
Arimitsu and Piatt (undated)	(X)					NA
Kirchhoff et al. (2010)	(X)			(X)		
Hoekman et al. (2011a)	(X)	(X)		X		
Hoekman et al. (2011b)	(X)	(X)		X		
ICY BAY, OUTER COAST & MISCELLANEOUS LOCATIONS						
Stephensen and Andres (2001)				X		NA
Kissling et al. (2007a)	(X)	(X)	X		X	NA?
Kissling et al. (2007b)	(X)	(X)	X		X	NA
Kissling et al. (2007c)	X	X	X	X	X	NA

Table 9. Continued.

Region/citation	Data collection: Appropriate study design or sampling methodology for quantifying population numbers	Data collection: Appropriate study design or sampling methodology for monitoring population trend	Data collection: Sufficient sampling intensity	Data collection: Sampling methodology is comparable with other data sets	Data analysis: Appropriate analytical methodology for quantifying population numbers or population trend	Data analysis: Appropriate method for apportioning unidentified birds to species
PRINCE WILLIAM SOUND						
Day and Nigro (1999)				X		NA
Kuletz et al. (2003a)	(X)	(X)	(X)			NA
Kuletz et al. (2003b)				X		NA
McKnight et al. (2003)				X		NA?
Kuletz et al. (2007)				X		NA
McKnight et al. (2008)				X		NA
KENAI FJORDS						
Bailey (1976)						NA[b]
Nishimoto and Rice (1987)						
Bailey and Rice (1989)						NA
Van Pelt and Piatt (2003)						NA
Romano et al. (2006)	(X)	(X)		X	(X)	NA
Arimitsu et al. (2010)	(X)	(X)		X	(X)	
KACHEMAK BAY & COOK INLET						
Agler et al. (1995)	(X)	(X)	(X)			NA
Kuletz et al. (2008)						NA

Table 9. Continued.

Region/citation	Data collection: Appropriate study design or sampling methodology for quantifying population numbers	Data collection: Appropriate study design or sampling methodology for monitoring population trend	Data collection: Sufficient sampling intensity	Data collection: Sampling methodology is comparable with other data sets	Data analysis: Appropriate analytical methodology for quantifying population numbers or population trend	Data analysis: Appropriate method for apportioning unidentified birds to species
ALASKA PENINSULA & ALEUTIAN ISLANDS						
Meehan (1996)						NA
Romano et al. (2005a)	(X)	(X)			(X)	NA
Van Pelt and Piatt (2005)	(X)	(X)				NA
Romano et al. (2005b)	(X)	(X)			(X)	NA
OTHER/MULTIPLE LOCATIONS						
Agler et al. (1998)	(X)	(X)				NA
Kendall and Agler (1998)	(X)	(X)				

[a] (X) = contains some elements that are desired.
[b] No unidentified birds.

and 8). The biggest concern is that not all areas within the bay were surveyed, meaning that some birds may have moved into/out of the unsampled areas; however, heavy ice prevented sampling those areas in most cases, and the authors did not believe that murrelets occupied areas with heavy ice cover (a pattern similar to that seen by Day and Nigro 1999). Nevertheless, this is a strong study design overall and should be considered a model for other studies. The maps of weekly changes in distribution and abundance illustrate some of the problems that one faces in designing a study for determining the abundance of a clumped, mobile species such as Kittlitz's Murrelet with precision.

The surveys of the outer coast by Kissling et al. (2007a) and of various locations in southeastern Alaska by Kissling et al. (2007b) are good overall but have some problems (Tables 7 and 8). Effects of variation in study designs among locations need to be evaluated, and the irregular timing of surveys has resulted in only sporadic data for several locations. Further, the large variation in density estimates along the Outer Coast over a 2-day span in 2003 (see Figure 16 in Kissling et al. 2007b) indicate that single surveys should not be compared for population-trend analyses. However, the overall study design within the various bays generally consists of intensive systematic survey lines, approaching a study design that is good for both population estimation and population monitoring.

Most of the studies in Icy Bay and elsewhere in southeastern Alaska have several strengths, primarily because they were conducted by the same research group (Table 9). These studies generally have high sampling intensity, emphasize sampling the offshore zone and areas that Kittlitz's murrelets concentrate in, use line-transect sampling methodology, and account for the inshore–offshore density gradient.

PRINCE WILLIAM SOUND

Examination of the various studies in chronological order makes clear that few of them, especially the baseline studies, are of a quality useful for long-term monitoring (Tables 7 and 8). The work of Day and Nigro (1999) resulted in oversampling of the nearshore zone, primarily because of a lack of GPS capability that could have helped to increase sampling effort in the offshore zone. The broad-scale surveys of Kuletz et al. (2003b, 2007) and McKnight et al. (2008) suffer from use of a stratified random sampling methodology not based on factors associated with the clumped distribution of Kittlitz's Murrelets and, hence, result in inaccurate population estimates and inaccurate estimates of population trends. In addition, these studies are plagued by some years with large numbers of unidentified murrelets (up to 89%, which makes the data essentially useless for population trends) and by questionable identification accuracy in some years (see maps showing dramatic interannual changes in distribution and abundance in Figure 5 of Kuletz et al. 2003b). Moreover, the pooling of data among years by Kuletz et al. (2003b: Figure 6) reduces among-year variation in estimates, making patterns appear stronger than they may actually be. The stratification issue is a common problem associated with multi-species surveys, which are designed to be as generic as possible because of the large number of species being surveyed. The intensive surveys of the glaciated fjords by Kuletz et al. (2003a) and McKnight et al. (2003) are approaching a study design that is good for both population estimation and population monitoring.

Few of the studies that have been conducted in Prince William Sound have strengths that make them useful for long-term monitoring (Table 9). The work of Kuletz et al. (2003a), however, has stratified on factors that affect the distribution of Kittlitz's Murrelets, are designed with high sampling intensity in those areas, account for the inshore–offshore density gradient, and extensively sample the offshore zone. Unfortunately, they do not use line-transect sampling methodology, so they could be improved by that modification.

KENAI FJORDS

Examination of the studies in chronological order makes clear that very few studies, especially the baseline studies, are of a quality that they can be used for long-term monitoring (Tables 7 and 8). All of the older studies (Bailey 1976, Nishimoto and Rice 1987, Bailey and Rice 1989) emphasize nearshore surveys, which are unsuitable for long-term population monitoring because most of the population occurs in the offshore zone and because variability in the nearshore zone is high. In addition, the earlier surveys used unlimited width of the sampling zone (the first two of these earlier studies) and varying degrees of species identification, making those data unusable for comparative purposes. The study by Van Pelt and Piatt (2003) also is compromised by the incorrect comparisons being made and by the use of the older data; hence, it cannot be used for trend analysis.

The intensive surveys of the glaciated fjords by Romano et al. (2006) and Arimitsu et al. (2010) are approaching a study design that is useful for both population estimation and population monitoring (Table 9). Those studies stratified on factors affecting Kittlitz's Murrelet distribution, accounted for the inshore–offshore density gradient, and collected data with line-transect methodology, but they still used techniques such as continuous counts of flying birds and multispecies surveys.

COOK INLET/KACHEMAK BAY

There is little here that will be of use for long term population monitoring and for baseline data sets (Tables 7 and 8). The surveys of Agler et al. (1995) include such a high proportion of unidentified birds that the data are unusable for tracking *Brachyramphus* species separately. (Agler [pers. comm.] indicated that the USFWS did not emphasize identification at that time, so most observers did not identify murrelets to species.) The work of Kuletz et al. (2008) suffers from a variety of problems: inadequate sampling effort that makes the baseline data of doubtful value in population monitoring (e.g., compare the maps of overall sampling effort in Figure 5 of Kuletz et al. 2008 with the year-by-year presentation of sampling effort in Figures 2–6 in Speckman et al. 2005), inconsistency of sampling effort and methodology, and problems with data analysis. However, the intensive surveys of the entire bay conducted in July 2005–2007 (Figures 16–17 in Kuletz et al. 2008) are approaching a study design that is good for both population estimation and population monitoring.

The only study for Cook Inlet/Kachemak Bay that has strengths is the original extensive sampling design laid out by Agler et al. (1995; Table 9). The best attribute is that this study has fairly substantial sampling effort, although it could be improved further.

KODIAK ISLAND

No information was available for evaluation. This lack of information points out a major data gap in population monitoring for this species in the northern Gulf of Alaska. Further, although the island has many large fjords where monitoring could occur, none are glaciated. Hence, monitoring on this island would provide a good comparison with the glaciated fjords that are being monitored elsewhere in the northern Gulf.

ALASKA PENINSULA/ALEUTIAN ISLANDS

Examination of the suite of reports makes it clear that only a few surveys may be of value for long-term monitoring (Tables 7 and 8). The baseline data of Meehan (1996) at Adak are not adequate for monitoring for a variety of reasons, especially incomplete sampling effort, inadequate study design, and methodology that is incompatible with monitoring(e.g., road-based surveys). The surveys of Unalaska (Romano et al. 2005a) and Atka (2005b) show promise in overall approach (especially the part about strata based on differing densities with increasing distance from shore) but need additional effort to develop a stronger study design and clearly need greater sampling effort: the stratum that contributed the most to the overall population size also had high variability and the least sampling effort. Finally, the broad-scale surveys of the Alaska Peninsula (Van Pelt and Piatt 2005) helped to identify areas where the most Kittlitz's Murrelets may occur, but additional effort needs to be expended to develop a stronger sampling design in those areas of concentration; in addition, sampling also needs to be conducted in offshore island-groups where the species also occurs in numbers (e.g., the Shumagin Islands).

Three recent studies from this region have some strengths, although none is a perfect study (Table 9). The sampling design of Romano et al. (2005a, 2005b) is a reasonable overall design for estimating populations around islands, although more sampling effort clearly needs to be expended in the outermost stratum because it is where most of the population appears to lie. The work by Van Pelt and Piatt (2005) has fairly substantial sampling effort, although this reconnaissance-level survey could be improved by laying out a systematic set of survey lines. All of these studies, however, could be improved by the use of line-transect sampling methodology, the snapshot method of counting flying birds, and more-intensive sampling effort.

NORTHERN BERING SEA

No information was available for evaluation. This lack of information points out a data gap in population estimation and monitoring for this species in the Bering Sea north of the Aleutian Islands. In reality, monitoring in this area should be combined with a monitoring program for the Chukchi Sea, since most of the birds in the northern Bering Sea probably are associated with the Seward Peninsula.

CHUKCHI SEA

No information was available for evaluation. However, an unpublished manuscript (Day et al., in press) discusses population estimates and presents evidence that there has been no population change in the American part of that vast region over the past 40 years.

RESULTS OF INTERVIEWS

I interviewed ten experts about (1) their perceptions and opinions about whether Kittlitz's Murrelet populations were declining or had declined and their reasons for thinking so and (2) what factors they believed significantly affected Kittlitz's Murrelet populations. The identities of these respondents have been kept anonymous here.

There was great diversity of opinion about whether Kittlitz's Murrelet populations were declining or had declined (Table 10). Three respondents said yes, three said no, three said that they were uncertain about whether there was a decline, and one said that the data quality was not good enough to be able to evaluate a trend. The respondents saying yes stated that there was enough information suggesting a trend and believed that a decline was occurring; two of the three specifically mentioned declines in Prince William Sound, and one each specifically mentioned declines in Glacier Bay and Kachemak Bay. One respondent saying no felt that there were so many problems with data, especially among-study variation in sampling and problems with sampling, that there was not reliable information; this respondent also indicated that annual population declines of 15–20% could only be caused by "catastrophic" problems in the marine system and that there was no evidence of such catastrophic changes occurring. The second respondent saw no evidence of declines in the area that that person had been surveying, whereas the third saw no evidence of declines in recent years and felt that the historical data that were used as evidence of a decline were so compromised that they should not be used for trend analysis. Two of the three respondents expressing uncertainty felt that there was too much uncertainty about trend data and analyses, whereas the third respondent indicated that there may instead be a spatial shift in Kittlitz's Murrelet populations, similar to what has been seen in other taxa (e.g., the large-scale changes in salmon distributions in the North Pacific in response to changes in the Pacific Decadal Oscillation). Again, the remaining respondent felt that the quality of the data was not adequate to determine any trend, let alone a declining trend.

Seven possible limiting factors were identified by the respondents: physiological stress, disease, reproductive problems, food limitation, climate change, fishing bycatch, and vessel-caused disturbance (Table 10). The factor that received the largest number of votes was food limitation, which was flagged by six, and possibly seven, of the respondents. The general opinion was that these birds often experience difficult foraging conditions, especially during the summer; and that they are closely tied to the availability of prey, making them vulnerable to factors that increase the variability of prey in space and time. One respondent suspects that food has become limiting in the fall (during the molt, which will put the birds under physiological stress and possibly will increase overwinter mortality), whereas a second suspects that food limitation may result in increased overwinter diseases (resulting in increased overwinter mortality) and another suspects that food may be so limiting that birds are in physiological stress coming out of the winter (resulting in a low probability of breeding). Finally, one respondent believes that the food limitation may be caused by the near-disappearance of capelin (*Mallotus villosus*) from the Gulf of Alaska after the 1976 regime shift, causing a food limitation in the summer.

Table 10. Results of interviews with Kittlitz's Murrelet experts about population trends of Kittlitz's Murrelets in Alaska and about factors affecting Kittlitz's Murrelet populations in Alaska. Identities of respondents are anonymous.

			Factors affecting populations						
Respondent	Are KIMU populations declining?	Why do you think so?	Physiological stress	Disease in winter	Reproductive problems	Food limitation	Climate change	Fishing	Vessel disturbance
A	uncertain	possible that bird populations shift spatially, since other taxa do				X			
B	yes	both PWS and Kachemak Bay data show a decline; personal observations of decline in Unakwik Inlet					X	X	?
C	yes	troubling trend data from several locations	X			X			
D	data quality not good enough to determine		NA	NA	NA	NA	NA	NA	NA
E	no	no evidence if decline from area respondent has surveyed				?			
F	uncertain	uncertainty about trend data and analyses			?				
G	yes	strong declines in PWS and Glacier Bay; possibly also Kachemak Bay data				X	X		
H	no	confusion caused by variation and problems in sampling	X	?		X			
I	uncertain	problems with sampling	X		X	X			
J	no	sees no evidence of decline in recent years and believes that the historical data are so compromised that they cannot be used for trend analysis				X			

Three respondents were of the opinion that, regardless of the reason, physiological stress was severe enough that it was affecting population trends. All of the respondents voting for this issue suspected that these birds are experiencing some sort of physiological stress during the fall and/or winter months, rather than during the breeding season; unfortunately, none were able to elucidate what sort of physiological stress may be occurring. Given our lack of knowledge about the main wintering areas of this species, it is not surprising that there is suspicion that conditions on the wintering grounds may be so stressful that these birds are experiencing increased mortality. One respondent also questioned whether it is possible that there has become some sort of disconnect in food webs that strongly affect these birds when they first head to the molting/wintering grounds, resulting in increased mortality rates over the winter.

The third issue that was raised involved reproductive problems as a possible factor limiting populations. One respondent is concerned that there are "troubling" suggestions of reproductive problems, whereas the other believes that these problems are widespread but is unclear what could be causing them.

The other four factors were suggested as possible limiting factors by the respondents. The issue that of disease, specifically in winter, was raised by one respondent, and primarily in passing, rather than as a major factor. Presumably, disease would be associated with other factors such as physiological stress and/or food limitation. Climate change was suggested as a limiting factor by two of the ten respondents, with both pointing out that Kittlitz's Murrelets are dependent on ice in both the summer and the winter. One respondent suggested that fishing bycatch might have an effect, albeit a small one. One respondent also suggested that vessel-based disturbance near tidewater glaciers also might be hampering the birds' ability to forage.

DISCUSSION

The amount of variation in methods used to quantify the abundance of Kittlitz's Murrelets is so great that it has been difficult for this author to capture it here. To some extent, these methods have evolved because of changes in technology that have helped improve sampling methodology in the field (e.g., the advent of GPS systems), changes in the statistical sophistication of scientists and the statistical tools available to them for analyzing data (e.g., GIS-based analyses of data, the development of strong statistical software), and changes in the objectives of studies as concerns began to be aired about the population trends of Kittlitz's Murrelets.

Examining the various studies chronologically within a geographic region may be the best way to see the evolution of techniques over time and, at the same time, the weaknesses in using older data for trend information. As a case study, let us examine the data from the Kenai Fjords. The original Bailey (1976) surveys were conducted to see what parts of the southern side of the Kenai Peninsula held the largest numbers of seabirds and marine mammals; these truly were baseline surveys designed to find the most-important areas for inclusion in a national park and/or a national wildlife refuge. (The Alaska National Interest Land Claims Act was not enacted until 1980.) Exact counts were not the most important objective of these surveys—large spatial coverage and quickly-generated approximate numbers were; as a result, the width of the sampling zone was unlimited because numbers were designed to be approximate and there was a desire not to exclude large groups of wildlife that happened to fall outside of a narrow, fixed sampling zone. Likewise, the broad-scale surveys of Nishimoto and Rice (1987) were designed to replicate the Bailey surveys, after most of the area had become Kenai Fjords National Park and some of it had become part of the Alaska Maritime National Wildlife Refuge; consequently, the spatial coverage was reduced from the original survey to the actual park boundaries but other attributes were kept similar. After the *Exxon Valdez* oil spill, Bailey and Rice (1989) conducted surveys that were designed to compare post-spill numbers with earlier data, meaning that the original study objectives were changed and that the approximate numbers now were to be used for trend information; the survey zone also was reduced from unlimited width to a 200-m-wide sampling zone. Despite the dramatic changes in sampling methods, the resulting data were presented as if they were comparable among studies. Later, more than a decade after the spill and after some concern began to be expressed about what appeared to be population declines of Kittlitz's Murrelets in the Gulf of Alaska, Van Pelt and Piatt (2003) conducted surveys that were compared with the earlier data. There were numerous weaknesses with the approach that they used, the greatest of which are (1) that very few of the approximately 100 nearshore segments that were being compared were in appropriate Kittlitz's Murrelet habitat and (2) that the comparisons were made only for the nearshore zone, where little of the population occurs and variability is high. Nevertheless, the 1986 and 1989 data were used for this comparison, despite problems with their comparability and quality. It is only with the surveys of Romano et al. (2006) and Arimitsu et al. (2010) that we see focused surveys using what appears to be an intensive sampling design that is laid out to sample preferred habitat for Kittlitz's Murrelets. There still are problems with some aspects of these surveys, however (e.g., multi-species surveys, rather than murrelet surveys; a need for sampling in more open water around the southern coast), but they are developing the scientific rigor and a study design that matches an intent to determine population trend with some degree of precision.

Unfortunately, this case study for the Kenai Fjords is not unique, and it also reveals important deficiencies with using the older data for population monitoring. In every case, the older data that are being used suffer from a variety of problems so severe that, in my opinion, they are unusable as baseline population data for trend analyses. These earlier studies suffer from problems with sampling methodology, study design, layout of sampling effort, insufficient sampling intensity, incorrect approach to stratification, excessive rates of unidentified birds, possible misidentification, and/or a variety of other problems. Several of the later studies attempt to use the earlier data in inappropriate analyses, resulting in conclusions about population trends that are questionable. It is only within the last 6–8 years that new study designs have been developed with elements that appear to be rigorous enough for population monitoring. Nevertheless, it is clear that there is a real need for the development of a coordinated and statistically-rigorous monitoring scheme focused on monitoring Kittlitz's Murrelet populations as a whole, across the state. There are attributes of the existing sampling schemes that should be incorporated into the new design, but it truly needs to be designed anew and focused only on Kittlitz's Murrelets, similar to the at-sea monitoring program that has been developed for Marbled Murrelets of the coasts of Washington, Oregon, and California.

By now, it should be apparent to the reader that I do not consider there to be enough data of sufficient consistency and quality to determine population trends with certainty within any region of Alaska. Similarly, data are not good enough to determine population trends across the state as a whole. There are, however, a few studies that, with some modification of methodology, may form the beginning of a monitoring scheme. The methodologies that appear to be most promising include Drew et al. (2008) and Hoekman et al. (2011a, 2011b) in Glacier Bay; Kissling et al. (2007c) in Icy Bay; Kuletz et al. (2003a) in Prince William Sound; Romano et al. (2006) and Arimitsu et al. (2008) on the Kenai Peninsula; Romano et al. (2005a, 2005b) in the Aleutian Islands; and Day et al. (in press) in the Chukchi Sea. None of these studies are perfect, but all of them contain elements that I believe are needed for a strong sampling program.

Although I have indicated here that the baseline data are not adequate for concluding whether Kittlitz's Murrelets have undergone dramatic, catastrophic declines across large parts of their range, I emphasize that this conclusion does not mean that the species has not undergone smaller declines in parts or all of its range, and also it is possible that there has been a population shift of this species. The evidence for declines, albeit smaller ones, comes from my own experience with sampling seabirds intensively in Prince William Sound since the *Exxon Valdez* oil spill of 1989. During the period 1989–1993, I regularly saw a few Kittlitz's Murrelets in places such as Drier Bay on Knight Island and in Galena Bay on Valdez Arm (Day, unpubl. data). I no longer see those birds, suggesting that they may no longer occupy what formerly was probably marginal nesting and feeding habitat and, hence, that these small populations either moved or disappeared over time.

I would not be surprised if these small, marginal populations have disappeared over time, much as small colonies of Pigeon Guillemots in Prince William Sound have.

It also is possible that populations either are shifting in the face of environmental change or that some populations are declining at the same time that others are increasing. For example, I studied birds at Adak in 1975, 1977, and 1978 and never saw Kittlitz's Murrelets at that time, even in protected waters such as Clam Lagoon (Day, unpubl. data). In contrast, recent surveys at Adak by Rob Kaler and Leia Kenney have recorded on the order of 30–40 Kittlitz's Murrelets at Clam Lagoon (R. Kaler, U.S. Fish and Wildlife Service, Anchorage, AK, pers. comm.), suggesting that populations there may have increased. Similarly, numbers of Kittlitz's Murrelets at both Unalaska and Atka islands now are estimated to be in the thousands (Romano et al. 2005a, 2005b). Hence, it appears that populations of Kittlitz's Murrelets may have increased in some locations. These increases, if true, either could be independent of population changes elsewhere within the species' range (i.e., environmental conditions are becoming more favorable for Kittlitz's Murrelets in the Aleutian Islands, allowing populations there to increase, regardless of population trends elsewhere) or they could be a result of movement of populations from places in the northern Gulf of Alaska where populations are believed to be declining (i.e., emigration from areas where environmental conditions are becoming less favorable for Kittlitz's Murrelets). Clearly, additional surveys need to be conducted at several locations in the Aleutians so that a rigorous baseline can be established for monitoring population trends there.

EXPERT OPINIONS

The opinions of experts on population trends of Kittlitz's Murrelets reflect a general lack of consensus about the studies that have been discussed here. Uncertainty about population trends, a belief in a decline. and a belief in no decline all were expressed in equal proportions. In addition, one respondent even felt that there was no way to evaluate a trend, given the quality of the data and study designs. Uncertainties were expressed primarily because of concerns about the baseline data and study designs. A few people felt strongly that there had been a decline, whereas a similar proportion felt strongly that there had not been one. One of the respondents recounted seeing many Kittlitz's Murrelets in Unakwik Inlet years ago, adding credence in their minds to the declines that they had felt they had documented.

The strongest consensus of opinion was about factors that strongly affect Kittlitz's Murrelet populations, with the greatest number believing that food limitation is the primary limiting factor and the second-greatest number suspecting that these birds may be experiencing some sort of physiological stress of one or more kinds. Climate change and reproductive problems were third and fourth in frequency, and single persons suggested a possible role of disease in the winter, fisheries bycatch, and glacial recession as factors possibly affecting populations.

CONCLUSIONS AND RECOMMENDATIONS

A careful review of available information makes it clear that there are serious questions about the validity of Kittlitz's Murrelet population estimates derived from existing data and that those data can provide nothing more than a ballpark estimate of numbers, either locally or regionally. To obtain data adequate for population monitoring, new protocols need to be developed, similar to what has been done for Marbled Murrelets. In developing a new monitoring program, however, several issues related to population monitoring need to be considered and/or evaluated. These issues are not listed in order of importance.

1. **Focus on the population of interest.** Is it the approximate size of the breeding population or the size of the total population that visits an area in the summer? If the size of the breeding population is of greatest interest, a period early in incubation should be sampled (i.e., early to mid-June in the northern Gulf of Alaska), before subadults arrive on the breeding grounds. If the size of the total population that visits/is associated with an area in the summer is of greatest interest, a period in early to middle chick-rearing (when numbers are highest, or

approximately mid-July in the northern Gulf of Alaska—but September and October in the Chukchi Sea) is most appropriate in many locations. Kissling et al. (2007c) and Kirchhoff (2008) suggest monitoring the peak of abundance, although I believe that consideration should be given to monitoring both periods: monitoring in June should give an idea of the approximate number of birds that might be attempting to breed, whereas monitoring in July helps one track the maximal size of the population (whatever those additional birds actually represent) and, in some locations, provides a chance to search for fledglings.

2. **Alternatively, consider monitoring during the period of lowest variability in numbers.** This period usually occurs around mid–late summer (around mid-July) in the northern Gulf of Alaska in most locations (Kirchhoff 2008, Kirchhoff et al. 2010)—but not all (e.g., Kenai Fjords, where the lowest variability is in early June; M. Arimitsu, U.S. Geological Survey, Gustavus, AK, pers. comm.). Monitoring when the variability is lowest will result in more-precise population estimates and will improve precision for trend monitoring and, hence, statistical power for detection of trends. In addition, surveying in mid-July reduces the chances that heavy ice will cause problems with sampling coverage within the glaciated fjords—a common problem earlier in the summer (Kissling, pers. comm.).

3. **Evaluate movements between monitored sites and between monitored and unmonitored sites.** Recent telemetry work by Kissling (pers. comm.) has found that Kittlitz's Murrelets from Icy Bay may visit Yakutat Bay, then be back in Icy Bay the next day; in fact, she estimates that ~10% of the Icy Bay birds travel back and forth to Yakutat Bay. Likewise, work by Lindell (2005) and Kirchhoff (2008) show regular movements of Kittlitz's Murrelets into and out of Glacier Bay. How often do birds move into or out of study areas, does that frequency vary geographically, daily, or seasonally, and does that frequency vary with extrinsic forces (e.g., availability of food) or some other factor? In addition, it is not clear exactly how one should include those birds into a population estimate for a particular bay.

4. **Develop an appropriate and statistically strong study design.** Evidence suggests that a stratified sampling design in which strata accurately reflect differences in the anticipated density of Kittlitz's Murrelets, specifically, will be optimal (e.g., Kuletz et al. 2003a; Hoekman et al. 2011a, 2011b). In contrast, the PWS-wide surveys of the USFWS are stratified by factors unrelated to the density of Kittlitz's Murrelets, resulting in inaccurate population estimates (McKnight et al. 2008). For example, the 1,033 birds estimated in 2000 based on an inappropriate stratification design (McKnight et al. 2008) is much lower than the 2,022 birds estimated in 2001 based on an appropriate design (Kuletz et al. 2003a). Similar differences were seen in estimates generated in the late 1990s between the appropriately-stratified studies of Day and Nigro (1999) and the inappropriately-stratified studies of McKnight et al. (2008). A stratified systematic sample with intense sampling in glaciated parts of fjords and less-intense sampling in outer parts of fjords, as seen in Romano et al. (2006) and Arimitsu et al. (2010), may be a good approach.

5. **Incorporate line-transect methodology into sampling methods because it generates more accurate density and population estimates than do strip transects**. Both Kirchhoff (2008) and Kissling et al. (2007c) used line transects. However, using line-transect methodology (especially detectability functions) to back-adjust strip-transect counts in a blanket fashion is inappropriate because both observer and platform have an important effect on detectability curves (A. E. Gall and Day, unpubl. data).

6. **Along the same lines, maintain consistency in survey platform and observers across years, when possible, so**

that detection functions for line transects can be used from one year to the next. Sample sizes from one year of surveying probably will not be large enough to produce accurate detection functions for many species, whereas data collected from the same platform and by the same observers over time can be combined to yield better detection functions.

7. **Incorporate flying birds into sampling methods and population-estimation methodology—but do it correctly.** Methods that use only birds on the water underestimate true population size and may be biased by substantial among-site and interannual variation in numbers of birds that are moving around, for reasons that are not known at this time. On the other hand, methods that also incorporate flying birds but continuously count them overestimate true population size. Strictly follow the snapshot methodology of Gould and Forsell (1989) for counting flying birds—adjust how often you do the snapshot count by determining the length of time that it takes for the ship to go 300 m (or whatever the size of your sampling zone is) ahead of the present position, so that you are doing a count on a "new" section of sampling zone ahead of the ship in each snapshot.

8. **Incorporate the nearshore–offshore gradient in densities into the sampling design and analytical methodology.** Doing so requires that sampling lines be laid out perpendicular (or approximately so) to shorelines. Unfortunately, the strength and location of the peak of this gradient appears to vary among years, even within the same bay (e.g., compare Kirchhoff 2008 with Kirchhoff et al. 2010), necessitating the use of GIS to develop post-sampling strata based on a particular study area in a particular year. Such an approach should achieve more accurate and more precise population estimates than many of the papers reviewed for this study, nearly all of which generally pooled all data beyond the nearshore zone into one offshore stratum. Although Kirchhoff (2008) suggests that the stratification should occur on depth, rather than distance from shore, the data are not convincing enough to take such an approach at this time; in addition, in most of the glaciated fjords in the northern Gulf of Alaska, depth is correlated with distance from shore, so distance probably is the better factor for stratification.

9. **Lay out a spatially-intensive series of sampling lines orthogonal to shorelines, to account for this nearshore–offshore density gradient; also consider sampling alternating sets of lines as replicate estimates**. Kissling et al. (2007c) recommend a similar approach and further suggest that the lengths of these survey lines be on the order of 2 km long and that they be spaced ~2 km apart to minimize disturbance to birds; an alternating set of lines spaced 1 km between these 2-km lines could form a second set of lines to be sampled. Kirchhoff (2008) also suggests orienting lines perpendicular to shorelines, and Drew et al. (2008) has a similar design.

10. **Use population size, rather than density, as the metric of interest.** As explained by Kissling et al. (2007c), large amounts of ice may dramatically alter densities within glaciated fjords, whereas populations tend to be more stable because the birds simply pack together more closely in the areas of open water.

11. **Minimize the number of unidentified birds in samples.** Unidentified birds complicate analyses and reduce confidence in population estimates and, consequently, trend analyses. The data in Hoekman et al. (2011b) clearly show that there is a positive relationship between the percentage of unidentified birds and the estimated population size of Kittlitz's Murrelets, showing that large numbers of unidentified birds result in overestimates of the true Kittlitz's Murrelet population size (Figure 2). Emphasize using excellent field surveyors and train them extremely well. I am unclear what an acceptable percentage of unidentified birds would be, but 5% would be a goal to aspire to; however, a statistician

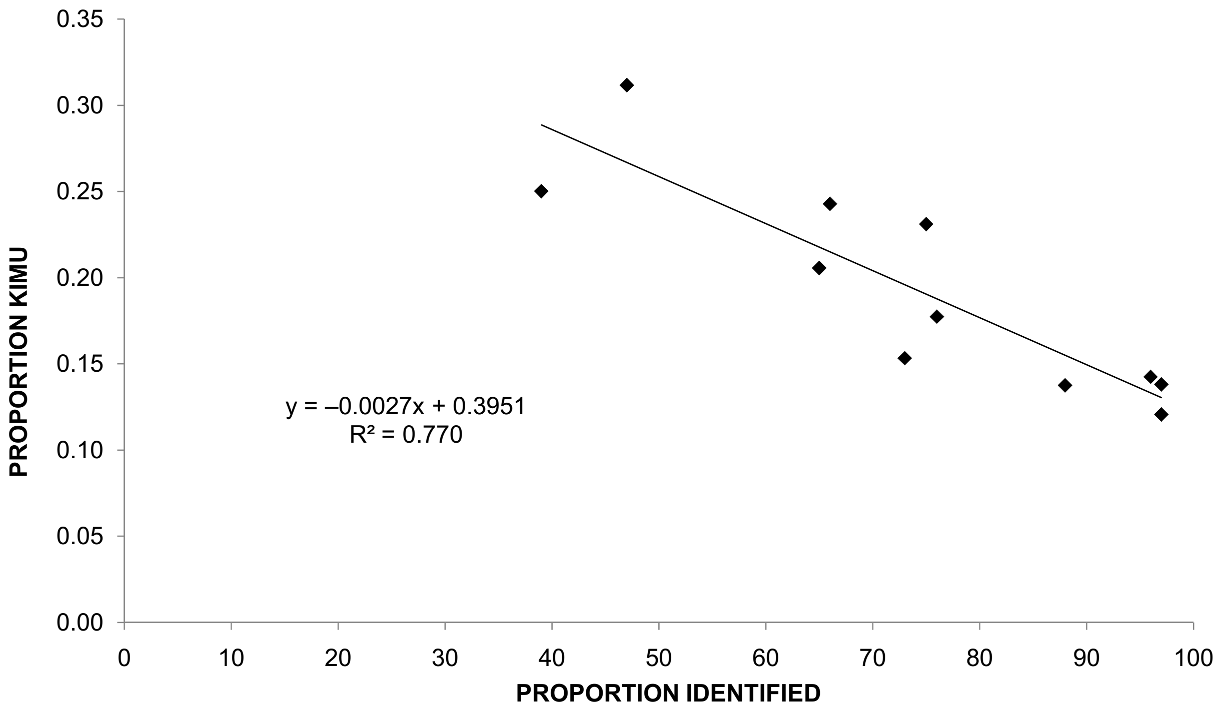

Figure 2. Effects of identification rate and apportionment of unidentified murrelets to species (based on whole-bay ratios of Kittlitz's Murrelets to Kittlitz's Murrelets + Marbled Murrelets) on estimates of the proportion of Kittlitz's Murrelets in the entire murrelet population of Glacier Bay, Alaska; plotted from data in Hoekman et al. (2011b).

should simulate data and determine the maximal acceptable level. Studies with levels of up to 89% unidentified murrelets are essentially worthless for population monitoring of Kittlitz's Murrelets.

12. **If you incorporate unidentified birds into population estimates by apportionment at all, do so extremely carefully.** Apportioning based on a simple KIMU:MAMU ratio across an entire bay or larger study area, as was done in several papers evaluated here, is not acceptable because Kittlitz's Murrelets always use some parts of study areas more than others and because doing so overestimates the population size of Kittlitz's Murrelets (Figure 2) because the numbers of Marbled Murrelets generally are much larger. On the other hand, apportioning based on ratios on one survey line may be too small a scale, possibly resulting in biased proportions. Apportioning based on ratios on a particular survey line and adjacent ones (a variation on adaptive sampling) may reduce the chances of biases in apportionment; another approach may be to use GIS to stratify the study area post-sampling (see above) and apportion based on ratios within each stratum. Clearly, further research needs to be done on how best to apportion unidentified birds.

13. **Conduct single-species surveys that examine only Brachyramphus murrelets.** Most of the studies considered here suffer from being multi-species surveys, thereby reducing counts of murrelets by an unknown amount. Further, given the high-profile nature of these data and their bearing on listing of the species for protection under the ESA, it is inappropriate to be searching for other species. On the other hand, some scientists have suggested having two murrelet surveyors and another observer who records all other species (Arimitsu, pers. comm.), thereby making the surveys more cost-efficient than single-species ones.

14. **Collect replicate samples for estimating densities and population sizes more accurately than is possible with only single replicates**. Replicates also improve one's ability to detect trends and helps one gain a better estimate of the variation around estimates. Several of the studies (e.g., Kissling et al. 2007b, Kirchhoff et al. 2010) show examples of dramatic among-survey variability and recommend the collection of replicate samples. Replicates should be conducted over a short period, preferably just a few days, because of the dramatic change in Kittlitz's Murrelet numbers over even a 10-day period (e.g., Day and Nigro 1999, Romano et al. 2004).

15. **Realize that the same sampling methodology that has to be developed almost certainly will not work across all of Alaska.** In reality, a sampling method for fjords in the northern Gulf of Alaska will need to be developed, as will one for the Aleutian Islands and for the northern Bering and Chukchi seas; a fourth one may need to be developed for the Alaska Peninsula. It also is possible that a separate methodology may be needed for places like the Outer Coast of Glacier Bay, the Malaspina Forelands, and the Lost Coast.

16. **Pay careful attention to when surveys are conducted because Kittlitz's Murrelet populations vary seasonally.** Unfortunately, it is not clear whether the mid-summer peak in abundance always occurs at the same time every year in a given location, and it is not clear if the peak in abundance occurs at the same time across a broad region (e.g., the northern Gulf of Alaska). My prediction, however, is that phenology varies interannually, so numbers on a particular date will vary among years. Hence, effort needs to be expended in answering this question if one objective of monitoring is to monitor the peak population.

17. **Conduct additional simulation analyses to determine sampling effort needed for locations other than Glacier Bay that have spatially-adequate data**. The Monte Carlo efforts by Drew et al. (2008) indicate that nearshore sampling should represent only ~4% of the total sampling effort within Glacier Bay (i.e., any effort greater than that represents oversampling of the nearshore area) and that sampling effort should cover at least ~8% of the total area for which the population estimate will be applied. Unfortunately, it is not known whether these percentages are similar for other locations and, if not, how much they may differ among sites.

18. **Determine what is an appropriate sampling unit for monitoring and determine how variable sampling units can be but still be comparable**. For example, is a nearshore segment 200 m wide and 1 km long but off a glacier face statistically and ecologically comparable to an offshore transect that is 300 m wide and 1 km long or one that is 300 m wide and 10 km long? Kissling et al. (2007c) recommend survey lines in the offshore zone that are on the order of 2 km long, whereas Hoekman et al. (2011b) used segments 4–8 km long, based on recommendations of Drew et al. (2008).

19. **When designing a new monitoring program, remember that among-survey spatial variation is the major component of variation that we face in estimating the variation around population estimates**. In contrast, the variation from detection probabilities is a minor component of this variation (Lukacs et al., in press). Hence, an intensive study design is more important than sampling protocol in minimizing variation in estimates (Kissling, pers. comm.).

20. **Consider the high mobility of Kittlitz's Murrelets when stratifying samples within bays.** Kissling et al. (2007c) show dramatic among-sample changes in the distribution of murrelets in Icy Bay, and Drew et al. (2008) and Day and Nigro (1999) show dramatic among-year changes in distribution in

Glacier Bay and Prince William Sound, respectively. It is possible that these dramatic changes in distribution to some extent reflect the highly dynamic nature of ice in the glaciated fjords, whereas changes in large bays with little ice (e.g., Glacier Bay) presumably represent temporal changes in oceanography or the distribution of preferred prey.

21. **Realize that not all data are adequate for long-term population monitoring.** This was perhaps the hardest and most important lesson that I have learned from this study. Seeing the evolution of methodology over time and the changes in use of old baseline data from their original intent has emphasized to me that one cannot use old data in ways beyond those for which they were designed—and that one has to examine old data carefully for quality and comparability to ensure that they actually can be used. Old data sets on raptor surveys, for example, may be appropriate for long-term comparisons because they were focused on just one or a few species in specific areas (e.g., along rivers), whereas large, general multi-species surveys at sea designed and executed for totally different purposes should not be considered comparable to newer, more focused surveys.

LITERATURE CITED

ADFG (Alaska Department of Fish and Game). 2006. Alaska's Comprehensive Wildlife Conservation Strategy. Alaska Department of Fish and Game, Juneau, AK. 824 pp.

Agler, B. A., S. J. Kendall, and D. B. Irons. 1998. Abundance and distribution of Marbled and Kittlitz's murrelets in Southcentral and Southeast Alaska. Condor 100: 254–265.

Agler, B. A., S. J. Kendall, P. E. Seiser, and D. B. Irons. 1995. Estimates of marine bird and Sea Otter abundance in lower Cook Inlet, Alaska, during summer 1993 and winter 1994. Minerals Management Service, Anchorage, AK. Report OCS Study MMS 94-0063. 124 pp.

Arimitsu, M., and J. Piatt. Undated [2008?]. *Brachyramphus* murrelet population estimates for Glacier Bay in 2008. Unpublished report prepared by U.S. Geological Survey Alaska Science Center, [unknown city, presumably Juneau], AK. 10 pp.

Arimitsu, M. L., J. F. Piatt, M. D. Romano, E. N. Madison, and J. S. Conaway. 2010. Kittlitz's and Marbled murrelets in Kenai Fjords National Park, south-central Alaska: at-sea distribution, abundance, and foraging habitat, 2006–08. U.S. Geological Survey Open-file Report No. 2010–1181. 68 pp.

Bailey, E. P. 1976. Breeding seabird distribution and abundance along the south side of the Kenai Peninsula, Alaska. Unpublished report prepared by U.S. Fish and Wildlife Service, [Unknown city, presumably Anchorage], AK. 69 pp.

Bailey, E., and B. Rice. 1989. Assessment of injury to seabird and marine mammal populations along the southeast coast of the Kenai Peninsula, Alaska, from the *Exxon Valdez* oil spill during summer of 1989. Unpublished report prepared by U.S. Fish and Wildlife Service, Alaska Maritime National Wildlife Refuge, Homer, AK, and Kenai Fjords National Park, Seward, AK. 38 pp. + appendices.

CBD (Center for Biological Diversity). 2009. Petition to list the Kittlitz's Murrelet as an endangered species under Alaska Endangered Species statutes. Center for Biological Diversity, San Francisco, CA. Petition filed with the State of Alaska 10 March 2009.

Day, R. H., A. E. Gall, A. K. Prichard, G. J. Divoky, and N. A. Rojek. In press. The status and distribution of Kittlitz's Murrelet *Brachyramphus brevirostris* in northern Alaska. Marine Ornithology.

Day, R. H., and D. A. Nigro. 1999. Status and ecology of Kittlitz's Murrelet in Prince William Sound, 1996–1998. Unpublished *Exxon Valdez* Oil Spill Restoration Project Final Report (Restoration Project 98142), prepared by ABR, Inc., Fairbanks, AK. 207 pp.

Drew, G. S., and J. F. Piatt. 2008. Using geographic information systems to compare non-uniform marine bird surveys: detecting the decline of Kittlitz's Murrelet (*Brachyramphus brevirostris*) in Glacier Bay, Alaska. Auk 125: 178–182.

Drew, G. S., S. G. Speckman, J. F. Piatt, J. M. Burgos, and J. L. Bodkin. 2008. Survey design considerations for monitoring marine predator populations in Glacier Bay, Alaska: results and post-hoc analyses of surveys conducted in 1999–2003. U.S. Geological Survey, Reston, VA. Administrative Report. 127 pp.

Gould, P. J., and D. J. Forsell. 1989. Techniques for shipboard surveys of marine birds. U.S. Fish and Wildlife Service, Fish and Wildlife Technical Report 25. 22 pp.

Hoekman, S. T., B. J. Moynahan, and M. S. Lindberg. 2011a. Monitoring Kittlitz’s and Marbled murrelets in Glacier Bay National Park and Preserve: 2009 Annual Report. National Park Service, Fort Collins, CO. Natural Resource Technical Report No. NPS/SEAN/NRTR—2011/440. 23 pp.

Hoekman, S. T., B. J. Moynahan, and M. S. Lindberg. 2011b. Monitoring Kittlitz’s and Marbled murrelets in Glacier Bay National Park and Preserve: 2010 Annual Report. National Park Service, Fort Collins, CO. Natural Resource Technical Report No. NPS/SEAN/NRTR—2011/441. 19 pp.

Kendall, S. J., and B. A. Agler. 1998. Distribution and abundance of Kittlitz's Murrelets in Southcentral and Southeastern Alaska. Colonial Waterbirds 21: 53–60.

Kirchhoff, M. 2008. Methodological considerations for at-sea monitoring of *Brachyramphus* murrelets in Glacier Bay, Alaska. Unpublished report prepared by Alaska Department of Fish and Game, Douglas, AK. 73 pp.

Kirchhoff, M., and V. Padula. 2010. The Audubon Alaska Watchlist 2010. Audubon Alaska, Anchorage, AK. 10 pp.

Kirchhoff, M., M. Smith, and S. Wright. 2010. Abundance, population trend, and distribution of Marbled Murrelets and Kittlitz's Murrelets in Glacier Bay National Park. Unpublished report to National Park Service, [unknown city, presumably Juneau], AK, and Alaska Department of Fish and Game, [unknown city, presumably Juneau], AK, by Audubon Alaska, Anchorage, AK, and Alaska Department of Fish and Game, Juneau, AK. Unpaginated.

Kissling, M., K. Kuletz, and S. Brockmann. 2007a. Distribution and abundance of Kittlitz's Murrelets along the outer coast of Glacier Bay National Park and Preserve. Pages 124–128 *in* Proceedings of the Fourth Glacier Bay Science Symposium (J. F. Piatt and S. M. Gende, eds.). U.S. Geological Survey, Reston, VA. Scientific Investigations Report 2007–5047.

Kissling, M. L., K., J. Kuletz, S. P. Brockmann, and N. R. Hatch. 2007b. Distribution and abundance of *Brachyramphus* murrelets and other marine species from Icy Bay to LeConte Bay, Southeast Alaska, 2002–2004. Unpublished report prepared by U.S. Fish and Wildlife Service Juneau Field Office, Juneau, AK. 72 pp. + appendices.

Kissling, M. L., M. Reid, P. Lukacs, S. M. Gende, and S. B. Lewis. 2007c. Understanding abundance patterns of a declining seabird: implications for monitoring. Ecological Applications 17: 2164–2174.

Kuletz, K. A., E. A. Labunski, and K. M. Brenneman. 2003a. Distribution and abundance of Kittlitz’s Murrelets in Prince William Sound, Alaska, summer 2001. Unpublished report by U.S. Fish and Wildlife service, Anchorage, AK. 68 pp.

Kuletz, K. J., E. A. Labunski, and S. G. Speckman. 2008. Abundance, distribution, and decadal trends of Kittlitz's and Marbled murrelets and other marine species in Kachemak Bay, Alaska. Unpublished report prepared by U.S. Fish and Wildlife Service, Anchorage, AK. 119 pp.

Kuletz, K., B. Manly, C. Nations, and D. Irons. 2007. Appendix J: Population trends of Kittlitz's and Marbled murrelets in Prince William Sound. *In* J. F. Piatt, K. J. Kuletz, A. E. Burger, S. A. Hatch, V. L. Friesen, T. P. Birt, M. L. Arimitsu, G. S. Drew, A. M. A. Harding, and K. S. Bixler. 2007. Status review of the Marbled Murrelet (*Brachyramphus marmoratus*) in Alaska and British Columbia. U.S. Geological Survey, Reston, VA. Open-file Report 2006–1387. Pp. 233–248.

Kuletz, K. J., S. W. Stephenson, D. B. Irons, E. A. Labunski, and K. M. Brenneman. 2003b. Changes in distribution and abundance of Kittlitz's Murrelets *Brachyramphus brevirostris* relative to glacial recession in Prince William Sound, Alaska. Marine Ornithology 31: 133–140.

Kushlan, J. A., M. J. Steinkamp, K. C. Parsons, J. Capp, M. Acosta Cruz, M. Coulter, I. Davidson, L. Dickson, N. Edelson, R. Elliot, R. M. Erwin, S. Hatch, S. Kress, R. Milko, S. Miller, K. Mills, R. Paul, R. Phillips, J. E. Saliva, B. Sydeman, J. Trapp, J. Wheeler, and K. Wohl. 2002. Waterbird Conservation for the Americas: The North American Waterbird Conservation Plan. Version I. Washington, DC. 78 pp.

Lindell, J. 2005. Results of at-sea Brachyramphus murrelet surveys in Icy Strait and other selected areas of Southeast Alaska 1993–1999. Unpublished report prepared by U.S. Fish and Wildlife Service, Juneau, AK. Irregularly paginated.

Lukacs, P. M., M. L. Kissling, M. Reid, S. M. Gende, and S. B. Lewis. In press. Testing assumptions of distance sampling on a pelagic seabird. Condor.

McKnight, A. E., K. M. Sullivan, S. W. Stephensen, D. B. Irons, K. J. Kuletz, and E. A. Labunski. 2003. Distribution, abundance, and foraging behavior of Kittlitz's (*Brachyramphus brevirostris*) and Marbled murrelets (*Brachyramphus marmoratus*) in College and Harriman fjords, Prince William Sound, Alaska, in summer 2003. Unpublished report by U.S. Fish and Wildlife Service, Anchorage, AK. 36 pp.

McKnight, A., K. M. Sullivan, D. B. Irons, S. W. Stephensen, and S. Howlin. 2008. Prince William Sound marine bird surveys, synthesis, and restoration.. *Exxon Valdez* Oil Spill Restoration Project Final Report (Restoration Project 080751), *Exxon Valdez* Oil Spill Trustee Council, Anchorage, AK. 136 pp.

Meehan, J. P. 1996. Status of Marbled and Kittlitz's murrelets at the Adak Naval Reservation, Alaska. Unpublished report prepared by U.S. Fish and Wildlife Service, Alaska Maritime National Wildlife Refuge, Adak, AK. Department of Defense Legacy Project Nos. 400 and 1658. 48 pp.

Nishimoto, M., and B. Rice. 1987. A re-survey of seabirds and marine mammals along the south coast of the Kenai Peninsula, Alaska, during the summer of 1986. Unpublished report prepared by U.S. Fish and Wildlife Service, Alaska Maritime National Wildlife Refuge, Homer, AK, and Kenai Fjords National Park, Seward, AK. 63 pp. + appendices.

Piatt, J., L. Climo, A. Springer, and T. Duncan. Undated [1991?]. Marine bird distribution in Glacier Bay National Park during the summer of 1991. Unpublished report prepared by U.S. Fish and Wildlife Service, Anchorage, AK. Unpaginated.

Piatt, J. F., K. J. Kuletz, A. E. Burger, S. A. Hatch, V. L. Friesen, T. P. Birt, M. L. Arimitsu, G. S. Drew, A. M. A. Harding, and K. S. Bixler. 2007. Status review of the Marbled Murrelet (*Brachyramphus marmoratus*) in Alaska and British Columbia. U.S. Geological Survey, Reston, VA. Open-file Report 2006–1387. 258 pp.

Piatt, J. F., N. L. Naslund, and T. I. van Pelt. 1999. Discovery of a new Kittlitz's Murrelet nest: clues to habitat selection and nest-site fidelity. Northwestern Naturalist 80:1–13.

Robards, M., G. Drew, J. Piatt, J. M. Anson, A. Abookire, J. Bodkin, P. Hooge, and S. Speckman. 2003. Ecology of selected marine communities in Glacier Bay: zooplankton, forage fish, seabirds, and marine mammals. Unpublished report prepared by U.S. Geological Survey, Anchorage, AK. 156 pp.

Romano, M. D., M. L. Arimitsu, J. F. Piatt, A. M. Agnes, and G. S. Drew. 2004. At-sea density and distribution of Kittlitz's Murrelets (*Brachyramphus brevirostris*) and Marbled Murrelets (*Brachyramphus marmoratus*) in Glacier Bay, Alaska, summer 2003. Unpublished report prepared for Glacier Bay National Park and Preserve, Gustavus, AK, by U.S. Geological Survey Alaska Science Center, Anchorage, AK. 68 pp.

Romano, M. D., J. F. Piatt, and A. R. DeGange. 2005a. At-sea density and abundance of Kittlitz's and Marbled murrelets around Unalaska Island, Alaska, June 2005. Unpublished report prepared by U.S. Geological Survey Alaska Science Center, Anchorage, AK. 31 pp.

Romano, M. D., J. F. Piatt, and C. Dubuisson. 2006. Kittlitz's and Marbled murrelets in Kenai Fjords National Park, Alaska: at-sea distribution and abundance, and initial observations of radio-marked Kittlitz's Murrelets. Unpublished report prepared for Kenai Fjords National Park, Seward, AK, by U.S. Geological Survey Alaska Science Center, Anchorage, AK. 47 pp.

Romano, M. D., J. F. Piatt, J. Williams, and A. DeGange. 2005b. At-sea density of Kittlitz's and Marbled murrelets around Atka Island, Alaska, June 2004. Unpublished report prepared by U.S. Geological Survey Alaska Science Center, Anchorage, AK. 26 pp.

Speckman, S. G., J. F. Piatt, and K. J. Kuletz. 2005. Population status and trends of *Brachyramphus* murrelets in lower Cook Inlet, Alaska. Unpublished report prepared for U.S. Fish and Wildlife Service, [unknown city, presumably Anchorage], AK, by U.S. Geological Survey Alaska Science Center, Anchorage, AK. 40 pp.

Speckman, S. G., A. M. Springer, J. F. Piatt, and D. L. Thomas. 2000. Temporal variability in abundance of Marbled Murrelets at sea in Southeast Alaska. Waterbirds 23: 364–377.

Stephensen, S. W., and B. A. Andres. 2001. Marine bird and marine mammal survey of Yakutat Bay, Disenchantment Bay, Russell Fiord, and Nunatak Fiord, Alaska. Unpublished report prepared by U.S. Fish and Wildlife Service, Anchorage, AK. 24 pp.

USFWS (U.S. Fish and Wildlife Service). 2008. Birds of Conservation Concern 2008. U.S. Fish and Wildlife Service, Arlington, VA. 85 pp. <http://www.fws.gov/migratorybirds>

Van Pelt, T. I., and J. F. Piatt. 2003. Population status of Kittlitz's and Marbled murrelets and surveys for other marine bird and mammal species in the Kenai Fjords area, Alaska. Unpublished report prepared for U.S. Fish and Wildlife Service, [unknown city, presumably Anchorage], AK, by U.S. Geological Survey Alaska Science Center, Anchorage, AK. 65 pp.

Van Pelt, T. I., and J. F. Piatt. 2005. Population status of Kittlitz's Murrelet *Brachyramphus brevirostris* along the southern coast of the Alaska Peninsula. Unpublished report prepared by U.S. Geological Survey Alaska Science Center, Anchorage, AK. 63 pp.