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USING GEOGRAPHIC INFORMATION SYSTEMS TO COMPARE NON-UNIFORM MARINE BIRD SURVEYS: DETECTING THE DECLINE OF KITTLITZ'S MURRELET (*BRACHYRAMPHUS BREVIROSTRIS*) IN GLACIER BAY, ALASKA

Gary S. Drew[1] and John F. Piatt

U.S. Geological Survey, Alaska Science Center, 1011 East Tudor, Anchorage, Alaska 99503, USA

Abstract.—Kittlitz's Murrelet (*Brachyramphus brevirostris*) is a rare seabird whose populations are concentrated in glaciated areas of Alaska. Declines in some parts of its range have led to increased concern over population viability. The remote and cryptic nesting habits of Kittlitz's Murrelets, in contrast to colonial seabirds, preclude monitoring their populations at nest sites and necessitate use of at-sea surveys to count birds. We compared surveys for seabirds in Glacier Bay, Alaska, during 1991, 1999, and 2000, to identify trends in the local Kittlitz's Murrelet population. The surveys conducted in 1999–2000 covered much of the same habitat as those conducted in 1991 but differed in aspects of survey design (i.e., start and stop points, navigation methods, and amount of offshore sampling). We developed a technique using a geographic information system to extract and recompile data from the 1999–2000 surveys that allowed spatially "matched" comparisons with the 1991 survey transects. This comparison of using "matched" transects indicated that the Kittlitz's Murrelet population in Glacier Bay had declined by 83% between 1991 and 1999–2000. Our analytical approach may be useful in similar situations in which current and historical surveys are not spatially uniform, particularly where there is a strong spatial component to the species distribution. *Received 19 October 2005, accepted 17 April 2007.*

Key words: Alaska, at-sea survey, *Brachyramphus brevirostris*, density, Glacier Bay, Kittlitz's Murrelet.

Utilización de Sistemas de Información Geográfica para Comparar Censos No-uniformes de Aves Marinas: Detección de la Disminución de *Brachyramphus brevirostris* en la Bahía Glacier, Alaska

Resumen.—*Brachyramphus brevirostris* es una ave marina rara cuyas poblaciones están concentradas en áreas de glaciares de Alaska. La disminución en ciertas partes de su área de distribución ha aumentado la preocupación sobre la viabilidad de la población. Los hábitos de nidificación remotos y crípticos de *B. brevirostris*, en contraste con los de las aves marinas coloniales, impide el monitoreo de sus poblaciones en los sitios de nidificación y requiere de censos en el mar para contar a las aves. Comparamos los censos de aves marinas en la Bahía Glacier, Alaska, durante 1991, 1999 y 2000 para identificar las tendencias en la población local de *B. brevirostris*. Los censos realizados en 1999 y 2000 cubrieron la mayoría de los mismos sitios que los realizados en 1991, pero difirieron en aspectos de diseño (i.e., puntos de inicio y fin, métodos de navegación y cantidad de muestreo mar adentro). Desarrollamos una técnica, usando un sistema de información geográfica para extraer y compilar los datos de los censos de 1999 y 2000, que permitió realizar comparaciones espaciales superpuestas con las transectas de los censos de 1991. Esta comparación indicó que la población de *B. brevirostris* en la Bahía Glacier había disminuido en un 83% entre 1991 y 1999–2000. Nuestro enfoque analítico puede ser útil en situaciones similares en las cuales los censos actuales e históricos no son espacialmente uniformes, particularmente donde existe un componente espacial importante en la distribución de la especie.

The Kittlitz's Murrelet (*Brachyramphus brevirostris*; hereafter "murrelet") is a small, noncolonial alcid that ranges from southeastern Alaska to the Russian Far East. Concerns over populations of the murrelet, which was never considered an abundant species, increased after the 1989 *Exxon Valdez* oil spill (Piatt et al. 1990, Van Vliet and McAllister 1994). Van Vliet (1993) estimated the prespill global population at 20,000 individuals, 95% of which bred in Alaska. The potential effects of climate change on

[1]E-mail: gary_drew@usgs.gov

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murrelet populations also have been noted as a source of concern (Kuletz et al. 2003). The combination of limited distribution, low numbers, and multiple potential threats led to a status review of murrelets by the U.S. Department of Interior, Fish and Wildlife Service (USFWS), and a subsequent petition for listing under the Endangered Species Act. The most recent USFWS estimate puts the global population at 9,500–26,700 individuals (Federal Register 2005).

Even under ideal circumstances, it can be difficult to assess population trends for seabirds. Population assessment is particularly difficult for noncolonial species such as the murrelet. To date, only 35 murrelet nests have been reported, mostly on mountainous talus slopes in recently deglaciated areas (Day et al. 1983, Day 1995, Piatt et al. 1999, Kaler 2006). The scattered and secretive nesting behavior of this species (Day et al. 1999) makes terrestrial monitoring impractical. During the breeding season, the murrelet's at-sea distribution is clumped and coastal (Isleib and Kessel 1973), providing an opportunity to monitor populations (Kuletz et al. 2003).

Using at-sea surveys, Kuletz et al. (2003) observed an 84% decline in the murrelet population of Prince William Sound, Alaska, between 1989 and 2000. The magnitude of the decline in Prince William Sound suggested that knowledge of population trends in other parts of the species' range would be important for determining the status of the global population. The purpose of the present study was to determine the trend of the murrelet population in Glacier Bay, southeastern Alaska, 600 km southeast of Prince William Sound. Glacier Bay is well known as breeding-season habitat for murrelets (Gabrielson and Lincoln 1959), and a recent survey of the southeastern Alaska archipelago found that Glacier Bay hosted the largest concentration of murrelets in southeastern Alaska (Kendall and Agler 1998).

The extensive at-sea seabird surveys in Glacier Bay during June 1999 and 2000 were designed to provide the National Park Service a comprehensive assessment of vertebrate marine predators. Although the initial goal was not to determine population trends, the increased interest in the status and trends of the murrelet led to our examination of methods for comparing these surveys to an earlier (1991) survey. The surveys conducted in 1999–2000 used identical counting methods and covered much of the same coastal habitat as those conducted in 1991 but differed with respect to survey design (i.e., start and stop points, navigation methods, and amount of offshore sampling). We developed a technique using a geographic information system (GIS) to extract and recompile data from the 1999–2000 surveys that allowed comparisons with the 1991 survey transects. Our goal was to develop a methodology for comparing surveys of different designs and to use this methodology to identify changes in the murrelet population of Glacier Bay.

METHODS

We conducted marine-bird surveys in Glacier Bay, Alaska (58°35′N, 136′10W), following standard sampling protocols (Gould and Forsell 1989), in June 1991, 1999, and 2000. In 1991, surveys were conducted from skiffs (<6 m in length). Surveys in 1999 and 2000 were conducted from larger vessels (16–22 m). All birds within 100 m on both sides and within 200 m forward of the boat were identified to species, yielding a 200 × 200 m sampling zone. In 1999 and 2000, we conducted surveys using sampling zones 200 m or 300 m in width, depending on vessel size. Observers aboard larger vessels (>15 m) counted all birds within 150 m on both sides and within 300 m forward of the boat. On smaller vessels (<6 m), observers limited the area of identification to 100 m on both sides and 200 m forward because of the lower viewing height. All surveys were conducted between 0700 and 2100 hours. As in 1991, we conducted continuous counts of flying birds. Although this method may overestimate the density of flying birds (Spear et al. 1992), it was necessary for comparative purposes to follow the same methodology as the 1991 survey.

Although the protocol for counting birds was identical among years, the comparison of the 1991 and 1999–2000 surveys was complicated by the use of different survey-transect layouts between periods. The 1991 survey consisted of transects that followed nearly the entire coastline (at 100 m from shore) and a small number of offshore transects that covered 2% of the offshore area of Glacier Bay (Fig. 1). The 1991 survey was designed as a one-time, small-boat (primarily coastal) reconnaissance with *ad-hoc* transects (typically from one geographic feature to another) marked on a nautical chart. For our analysis, we digitized the transect information from the chart. By contrast, the 1999–2000 surveys consisted of systematic transect design that covered most of the coastline and sampled 12% of the offshore area, with offshore transects spaced 2.5 km apart (Fig. 1). To increase the comparability of these surveys, we used only the coastal transects from all years in our testing. Global positioning system (GPS) receivers were used to provide accurate positioning for the 1999 and 2000 survey tracks. Bird data were recorded continuously with GPS positions using a real-time data-entry system.

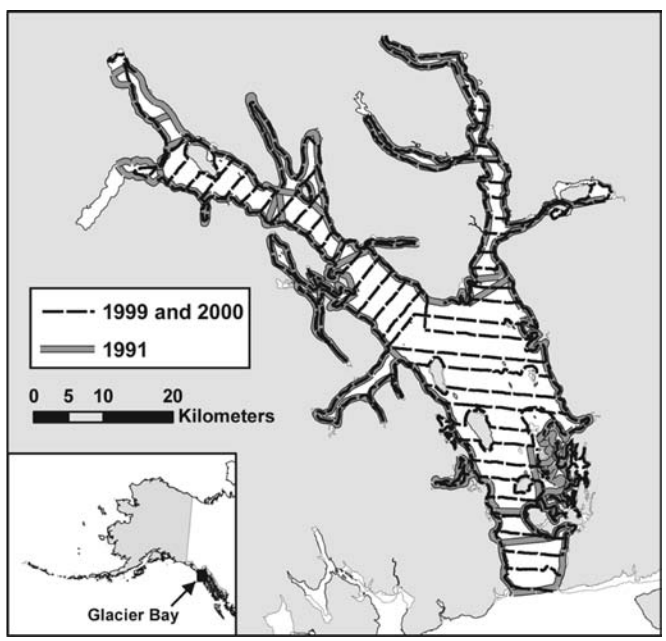

FIG. 1. Location of 1991 and 1999–2000 transect tracks in Glacier Bay, Alaska.

We used a GIS (ARCMAP 9.1; ESRI, Redlands, California) to match the locations of coastal survey transects by resampling the 1999–2000 transects to spatially match the 1991 transects. The 1991 transects were not precise in their exact tracks, but their start and stop locations were deemed reliable. Measurements taken from the GIS indicated that the digitized 1991 tracks were commonly farther offshore than should have been the case with a 200-m transect width. This appeared to be an artifact of the transcription process. We placed an 800-m buffer centered on the digitized 1991 transect tracks and used those polygons to clip out stretches of survey tracks and bird sightings recorded in 1999 and 2000 (Fig. 2). The width of the buffer was arbitrary and was chosen after testing buffers of various sizes to match as many transect locations as possible. Actual differences in survey tracks were probably much less than the buffer size suggested and were attributable to the inaccurate 1991 tracks. Murrelet sightings were tallied for each matched transect and divided by the matched area to provide matched density samples. The analyses of matched transects included only transects that were $\geq$2 km in length and sampled in all three years. We used a standard Monte Carlo randomization technique (Noreen 1989) to test whether murrelet densities differed over the three sample years. We first calculated the F-statistic based on the original data set, then randomized the data while treating transects as blocks and tested (1,000 times) for the likelihood of a greater F-statistic.

The analysis of at-sea seabird survey data is often problematic (Schneider and Piatt 1986). Difficulties can be classified as being either inherent to the survey data used in analyses or related to making statistical comparisons among surveys. Seabird surveys typically have numerous zero values, non-normal data distributions, and variability in the spatial scale of bird aggregations. All these problems make the use of parametric statistics suspect (Schneider and Piatt 1986). As a result, we used a Monte Carlo randomization technique (Noreen 1989, Manly 1997) to test whether murrelet densities differed over the three sample years. Given a significant difference among years, a Bonferroni z-test was applied to determine which of the years were significantly different.

The potential for some difference in survey-based bias between the 1991 and 1999–2000 surveys led us to conduct Monte Carlo randomization tests on 10 of the most common marine bird species observed on transects. If there was a bias attributable to some survey effect, we would expect to see a systematic trend in bird densities. Tests on Arctic Tern (*Sterna paradisaea*), Black-legged Kittiwake (*Rissa tridactyla*), Canada Goose (*Branta canadensis*), Common Merganser (*Mergus merganser*), Harlequin Duck (*Histrionicus histrionicus*), Mew Gull (*Larus canus*), Pelagic Cormorant (*Phalacrocorax pelagicus*), Pigeon Guillemot (*Cepphus columba*), and White-winged Scoter (*Melanitta fusca*) found no significant negative trends among these species, and only Glaucous-winged Gull (*L. glaucescens*) showed a positive trend. On the basis of these findings, we concluded that there was no bias attributable to survey effects.

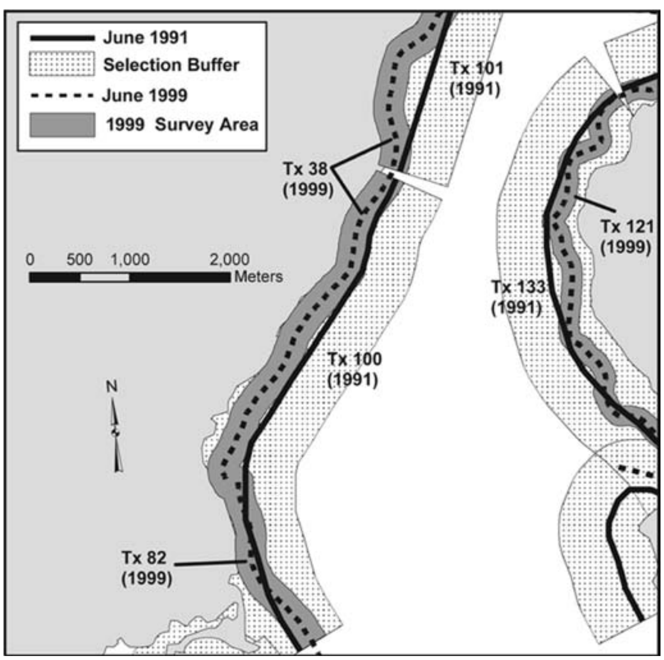

Fig. 2. Diagram illustrating our process for matching 1999–2000 data with transects from 1991. Solid red lines represent 1991 transects, dashed lines represent 1999–2000 transects, and labels delineate individual transects. Stippled areas represent buffers around 1991 transects used to clip data from 1999 and 2000 transects.

Results

As expected, frequency histograms indicated that the distribution of murrelet densities on transects in all three years were non-normal because of the large number of transects with no murrelets (zeros) and highly skewed density values. Differences in transect length and number also contributed to unequal variability among surveys (Table 1). Because of these issues, we concluded that our decision to use randomization techniques to test for differences among years was appropriate. Of the 139 coastal transects from the 1991 survey, we were able to "match" data from 1999–2000 to the same general locations for 125 transects. This provided us with three years of data matched by transect, which allowed us to test for differences between years while effectively controlling for spatial effects (Table 2).

Randomization tests on the matched transects indicated a significant difference among years ($F = 12.01$, df = 2 and 372, $P < 0.001$). A Bonferroni z-test indicated that murrelet densities were similar in the 1999 and 2000 surveys, but those densities were

Table 1. Number of transects, distance surveyed, area sampled, and range for coastal transects in Glacier Bay during 1991, 1999, and 2000. The area sampled depended on transect length and width, which varied among the vessels used for surveys in different years (see text).

Year	Number of transects	Transect length (km)			Area sampled (km^2)
		Total	Mean	Range	
1991	139	651	4.4	0.9–12.0	130
1999	63	772	12.1	3.4–48.8	161
2000	62	779	12.2	3.8–49.8	181

TABLE 2. Kittlitz's Murrelet densities (birds per square kilometer) in Glacier Bay, Alaska, on coastal transects surveyed in 1991, 1999, and 2000, using matched transect data sets.

Statistic	Matched transects 1991	1999	2000
Sample *n*	125	125	125
Mean density (birds per square kilometer)	6.96	0.94	1.40
Standard deviation	22.45	2.24	4.45
Coefficient of variation	3.22	2.34	3.16

lower than the 1991 density estimate ($P < 0.05$). Mean density on matched transects was considerably higher in 1991 than in 1999 and 2000 (Fig. 3).

DISCUSSION

Our interyear comparison of bird sightings from spatially matched transects revealed large and significant changes in murrelet density. The combination of a standard randomization technique to overcome statistical limitations and our use of a GIS to control for spatial variation provided us with confidence that the murrelet population in Glacier Bay has undergone a recent and rapid decline.

Given the current small global population estimate for murrelets of 9,500–26,700 birds, population declines of any scale are cause for concern. Our comparison of murrelet densities from coastal transects in 1991 and the average of densities from the

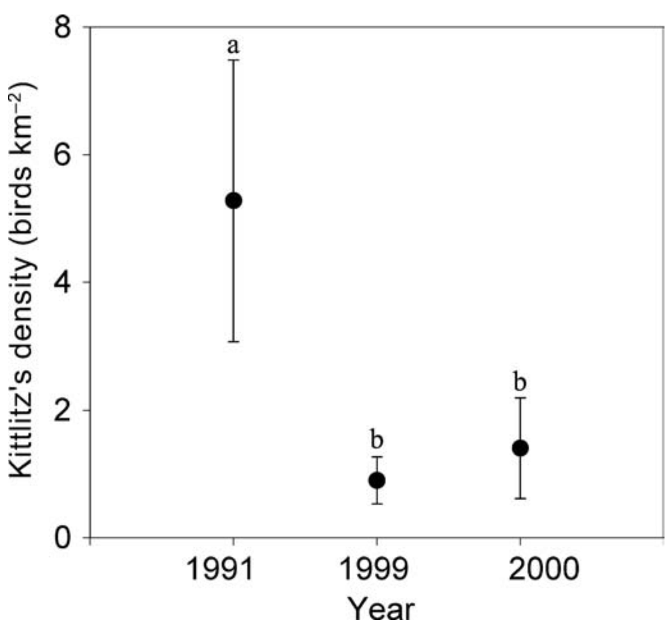

FIG. 3. Comparison of Kittlitz's Murrelet density (mean + 95% confidence interval) among years for matched transects (1991, $n = 125$; 1999, $n = 125$; 2000, $n = 125$). Bars sharing the same letters were not statistically different (Bonferroni z, $P < 0.05$).

1999–2000 surveys indicates an 83.2% decline in the Glacier Bay population. Although dramatic, this decline is in line with the estimated 84% murrelet population decline in Prince William Sound from 1989 to 2000 (Kuletz et al. 2003). Concordance between two areas separated by 600 km suggests that a regional–scale phenomenon may be responsible. Researchers have speculated that the decline of murrelet populations may be related to the rapid recession of glaciers in Alaska over the past several decades (Van Vliet 1993, Day et al. 2003).

Murrelets generally have been associated with areas of glacial outflow (Isleib and Kessel 1973, Kendall and Agler 1998, Day et al. 2003, Kuletz et al. 2003). Day et al. (2003) speculated that the murrelet's large eye may be an adaptation for foraging in the low light levels common in areas of high sedimentation. In Prince William Sound, murrelets have been attracted to stable or advancing glaciers but not to retreating ones (Kuletz et al. 2003). Kuletz et al. (2003) speculated that this difference could be caused by a trophic cascade initiated by lowered salinity and increased sedimentation characteristic of retreating glaciers (Weslawski et al. 1995). Conversely, retreating glaciers may eventually result in decreased turbidity, affecting the availability of foraging habitat. Murrelet populations also may be affected by changes in nesting success. Currently, we know little about the nesting behavior of this species and the associated risk of nest predation, which makes it difficult to determine whether dynamics associated with nesting areas are contributing to population changes. The recession of glaciers could lead to an increase in risk as more habitats become accessible to terrestrial predators. At a larger scale, there may also be increases in avian predators that have expanded their range northward. Although a decline in murrelet populations in Glacier Bay coincides with the rapid recession of glaciers in that area (Field 1947, Hall et al. 1995), causal linkages between population declines and habitat change are lacking. Collection of more information about food availability, anthropogenic disturbance, winter habitat, and nesting behavior may help us understand the current population declines.

Although randomization techniques have been available to researchers for some time, the addition of the spatial matching technique is an innovation that assisted in controlling for spatial variability. This approach could make older surveys with limited location information more directly comparable than was previously possible. In addition, where there is prior knowledge of strong spatial fidelity, this matching technique should provide a more powerful test of differences between surveys.

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