OPTIMIZING THE WIDTH OF STRIP TRANSECTS FOR SEABIRD SURVEYS FROM VESSELS OF OPPORTUNITY

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SUMMARY

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We present a study to determine the most appropriate strip width for conducting at-sea surveys of marine bird populations from novel platforms of opportunity. We surveyed seabirds during two seasonal (spring, fall) cruises across the North Pacific in 2002. We used these observations to quantify potential biases associated with varying the survey strip width. More specifically, we compared the proportion of the sighted birds that were identified to species level, and the observed and expected apparent densities (birds•km^{-2}) of various taxa from 100-m, 200-m and 400-m strip transects. We also examined the effects of weather (Beaufort sea state, cloud cover) and bird behavior (sitting versus flying) on species-specific identification rates and density estimates. Although various taxa showed distinct detection curves, we conducted a community-level analysis to determine the most effective strip transect for surveying the entire avifauna. Based on the results, we determined that a 400-m strip width was most appropriate for our large and high-speed survey platform, the bulk-cargo carrier *Skaubryn.* We offer some suggestions to select the most suitable strip width for seabird surveys from vessels of opportunity. We urge marine ornithologists using novel survey platforms to test the underlying assumptions of at-sea survey techniques and to determine the methods best suited for their specific survey conditions.

Key words: At-sea surveys, distance sampling methods, platforms of opportunity, population surveys, seabirds, strip transects, survey biases, survey methods

INTRODUCTION

Marine bird at-sea distributions are surveyed using two standardized population surveying techniques: line transects and strip transects (Buckland *et al.* 1993). Line transects use the perpendicular distances to individual sightings to model a detection function, which quantifies the probability of observing an object given its distance from the trackline. This approach allows for species-specific differences in detectability (e.g. small-sized vs. large-bodied taxa) under a variety of behavioral (e.g. flying vs. sitting on the water) and environmental (e.g. visibility, Beaufort sea state) conditions. The resulting perpendicular sighting distributions are then used to estimate the surface area effectively searched during surveys. Strip transects, on the other hand, assume that observers detect every target within the survey strip, and estimate seabird relative abundance by dividing the number of individuals sighted by the area of ocean surface surveyed. Ultimately, the width of the survey strip represents a compromise between the desire to cover as much surface area as possible and the ability to detect every bird within the area surveyed (Tasker *et al.* 1984, van Franeker 1994, Becker *et al.* 1997).

Several investigations have outlined recommendations for the standardization of seabird surveys, including addressing the relative movement of flying birds with respect to the vessel, recording environmental data to account for species-specific differences in detectability and quantifying the attraction of ship-followers (Griffiths 1982, Duffy 1983, Spear *et al.* 1992, Borberg *et al.* 2005). Although standardized techniques have been advocated, a requirement for a flexible approach is widely recognized, given that the suitability of the survey methods may vary for specific objectives and survey platforms (Tasker *et al.* 1984, Haney 1985, Spear *et al.* 2004).

Increasingly, marine ornithologists are conducting methodology studies to assess which survey techniques are most appropriate given the particular field conditions (e.g. weather, survey platform) and the avifauna (e.g. overall density, species composition) for a specific study area and time period. In particular, several researchers have investigated how the apparent densities of various species change as a function of the survey methods employed (line transects vs. strip transects) and the width of the strip (100 m, 200 m, 300 m). For instance, previous studies have showed that seabird density estimates from line transects are higher than those based on 100-m and 200-m strip transects. These results have led to the use of line transects to survey inconspicuous species, especially when accurate population densities are required to assess conservation status (Strong *et al.* 1995, Becker *et al.* 1997, Mack *et al.* 2002).

Unfortunately, distance sampling techniques are extremely effort-intensive and impractical, especially in areas of high bird densities and for species that occur in large flocks. Thus, strip transects are most commonly used to survey birds at sea. However, because no discussion about how to select the most appropriate survey strip width for surveying an entire seabird community has appeared in the literature, field studies regularly use the standard 300-m strip originally advocated by Tasker and coworkers (1984).

Although seabird counts from strip transects are normalized by surface area, the resulting apparent densities (expressed as birds•km^{-2}) are influenced by a variety of exogenous factors, including platform characteristics (e.g. height above the water, speed over ground) and environmental conditions (e.g. weather, visibility) in addition to inherent species-specific variations in detectability and degree of vessel attraction and avoidance. In particular, changing the width of the survey strip likely influences apparent seabird abundance in two ways:

- failure to detect all individuals at the outer edge of the survey strip (Strong *et al.* 1995), and
- movement of birds across the outer edge of the strip because of their attraction to or avoidance of the vessel (Hyrenbach 2001).

These biases may in turn change the apparent composition of the avifauna, by making conspicuous taxa and ship-following species (e.g. albatrosses, fulmars) appear disproportionately more numerous and inconspicuous taxa not attracted to survey vessels (e.g. alcids, phalaropes) disproportionately less numerous (Dixon 1977, Weins *et al.* 1978, Griffiths 1982, Borberg *et al.* 2005).

Because of the broad applicability of strip transects, a standardized approach to guide the selection of an appropriate survey strip width is needed. In particular, the extent to which changing the strip width modifies the apparent composition of the avifauna remains poorly understood. In 2002, we initiated a study to quantify seasonal and interannual changes in seabird communities across the North Pacific Ocean, using a bulk-cargo carrier as a platform of opportunity. Given this unusual survey platform, we sought to quantify potential species-specific biases associated with unequal detectability, the differential ability to identify seabirds with increasing distance from the vessel, and discrepancies in vessel attraction and avoidance. During the first year of this study, we undertook a pilot project to assess the most appropriate strip width for conducting standardized seabird surveys, given the potential biases described above.

The proliferation of at-sea studies of marine bird populations employing disparate platforms of opportunity requires standardized survey methods to facilitate comparisons of overall densities and community structure across space and time. In this paper, we offer suggestions for the development of such criteria. We hope that marine ornithologists will undertake similar methodology studies as part of developing and expanding monitoring programs.

METHODS

Study area

The cruise track from British Columbia (Canada) to Hokkaido (Japan) traversed the eastern (California Current) and the western (Kuroshio) boundary currents of the North Pacific, crossed both the eastern and the western Subarctic Gyres, and ventured into the southern Bering Sea (Batten *et al.* 2006). To evaluate the influence of a broad range of abiotic (weather) and biotic (bird density and community composition) conditions, we conducted replicate seasonal surveys of the same survey track in June 2002 and October 2002 (Table 1).

The same observer (MH) recorded seabird and weather observations during both surveys, during all daylight hours, while the vessel cruised at speeds between 12.2 km•h^{-1} and 29.1 km•h^{-1} [mean ± standard deviation (SD): 24.5 ± 2.1 km•h^{-1}]. We divided the tracks into discrete survey bins, defined as uninterrupted five-minute observation periods (approximately 2.0 km at 24.5 km•h^{-1}).

Environmental data

To account for potential detectability biases, we recorded general qualitative weather conditions (sunny/rainy/foggy), as well as the horizontal visibility (m), cloud cover and Beaufort sea state for each discrete survey bin (Table 1). We quantified cloud cover as the proportion of the sky obscured by clouds, expressed in 5% intervals from 0% to 100%, and assessed sea state using a scale from 0 to 12 (www.wrh.noaa.gov/pqr/info/beaufort.php).

We discarded from subsequent analyses any survey bin with visibility of less than 800 m.

Seabird surveys

We used strip transect methods to survey marine birds from the flying bridge/pilot-house/forecastle deck of the bulk-cargo carrier *Skaubryn,* at eye height of 25 m/25 m/10 m above the sea surface respectively. The weather conditions influenced the position of the observer, with 84.2% and 16.8% of the observations from the high (25 m) and the low (10 m) observation platforms respectively. The observer enumerated the birds on only the one side of the vessel with the best visibility (least glare or wind) continuously. All birds were identified to the lowest possible taxonomic level and were recorded as being either on the water or in flight. Ship-following individuals were recorded when first encountered and ignored thereafter, for the remainder of the day (Tasker *et al.* 1984). The observer determined the radial distance to every sighting using a geometric hand-held range-finder and ignored any bird beyond the 800-m "identification horizon" (Weins *et al.* 1978, Heinemann 1981). Individual birds and flocks were assigned to one of four non-overlapping survey strips

TABLE 1
Sampling effort and environmental conditions during the two cruises from British Columbia (Canada) to Hokkaido (Japan)

Cruise	Dates	Sample size (5-min transects)	Cloud cover[a] (%)	Sea state[b] (Beaufort)	Survey effort[b] Rain (%)	Fog (%)	Rain & fog (%)
Spring	Jun 1–14	885	100 (0–100)	2 (2–7)	7.8	10.7	5.1
Fall	Oct 5–20	967	100 (0–100)	6 (4–8)	18.1	14.3	11.9
TOTAL		1852	100	4	13.2	12.6	8.6

[a] Median (range).
[b] Proportion of the transects with rain and fog.

(0-100 m, 100-200 m, 200-400 m, and 400-800 m) on the basis of the distance of the bird closest to the vessel (Pyle 2007).

To quantify the composition of the avifauna within our study area, we combined the observations from the spring and the fall cruises. Thus, we considered a total of 7408 counts comprising the birds observed within four separate survey strips (0–100 m, 100–200 m, 200–400 m, 400–800 m) along 1852 five-minute bins. For each of these bins, we computed the density (birds•km^{-2}) of 62 taxa, consisting of one or more closely related species. We focused our analyses on 16 "common" taxa, which were sighted in at least 25 survey bins. Together, these taxa contributed 99% of all the birds sighted during this study (Appendix 1).

Indices of seabird detectability

Because we were interested in changes in detection rates with increasing distance from the vessel, we compared seabird densities for three different strip widths: 100 m, 200 m and 400 m (Weins *et al.* 1978, Hyrenbach 2001). We performed three comparisons for every taxon, by iteratively using broader strip widths. We first compared bird densities within the two survey strips closest to the vessel: 0–100 m versus 100–200 m. Next, we combined the observations from these two 100-m survey strips and compared bird densities from 0 m to 200 m and from 200 m to 400 m from the vessel. Finally, we combined the observations from the first three survey strips and compared bird densities from 0 m to 400 m and from 400 m to 800 m from the vessel.

We used the coefficient of detection (CD) to compare taxon-specific sighting rates for various survey strips, as follows:

$$\mathrm{CD} = (1 / P_n)\ (n / b)$$

such that

$$D_b = (D_n)\ (\mathrm{CD}),$$

where P_n is the proportion of all birds within the narrow strip, n and b are the widths of the narrower and broader strip transects used in the comparison, D_n is the density estimated using the narrow strip width, and D_b is the extrapolated density estimated using the broad strip width. The CD allowed us to compare pair-wise seabird densities for the three strip widths (100 m, 200 m, 400 m). A CD of 1 implies that bird sightings are distributed uniformly across the two survey widths. In contrast, values larger or smaller than 1 indicate that birds occur disproportionately outside or within the narrow strip respectively.

Statistical analyses

We quantified two potential biases associated with changes in the strip width:

- the ability to identity birds to species level, and
- changes in apparent bird densities.

Moreover, whenever possible, we tested for the influence of bird behavior and changing weather conditions on species-specific detectability. However, because of the unequal number of sightings across weather conditions, we did not perform all of these analyses for each taxon and behavior observed in the field. Thus, this paper uses a subset of these analyses to illustrate the influence of the strip width on apparent seabird densities. We use these results to select the most appropriate strip width for surveying seabirds from our specific observation platform.

To determine the strip width at which the observer's ability to detect and to identify seabirds declined significantly, we used repeated comparisons involving up to 16 taxa and three strip widths. We performed all the analyses using the Systat 7.0 software (Wilkinson 1997). Because we performed a total of 86 statistical comparisons, we assumed significance at $\alpha = 0.005$ to maintain the overall probability of committing a type I error below the generally accepted 0.05 level (Zar 1984). We considered statistical results between 0.05 and 0.005 to be marginally significant.

TABLE 2
Comparison of the proportion of birds identified to species-level, as a function of their radial distance from the vessel

Taxonomic group [a]	Birds observed	Species	Proportion of identified birds				Paired strip-width comparison [b]		
			(0–100 m)	(100–200 m)	(200–400 m)	(400–800 m)	100 vs. 200	200 vs. 400	400 vs. 800
Phalaropes	89	2	100	98.36	50	0	2.286 (0.5–0.25)	74.789 **(<0.001)**	230.157 **(<0.001)**
Murres	222	2	100	100	100	92.73	0.00 (0.99)	0.00 (0.99)	10.356 (0.02–0.01)
Storm-petrels	1552	2	99.24	99.70	100	99.16	0.204 (0.97)	0.598 (0.95–0.9)	0.456 (0.97–0.95)
Dark shearwaters	82 388	2	62.12	55.22	52.88	59.02	0.984 (0.95–0.9)	0.443 (0.95–0.9)	0.280 (0.9–0.75)
Jaegers	50	4	100	100	91.67	75	0 (0.99)	11.915 **(<0.001)**	17.499 (<0.001)
Gadfly petrels	293	4	100	98.89	100	100	0.493 (0.5–0.2)	1.209 (0.9–0.7)	0.655 (0.9–0.7)
Gulls	6592	6	99.78	99.60	99.48	99.63	0.056 (0.99–0.97)	0.048 (0.99–0.97)	0.456 (0.95–0.9)
Alcids	3599	13	99.63	99.29	94.99	92.51	0.110 (0.99–0.95)	4.155 (0.25–0.1)	3.575 (0.5–0.25)

[a] For each taxonomic group, the proportions of identified birds within four strip widths are shown, as well as the statistical results of pair-wise comparisons of these proportions within three progressively wider strip widths.

[b] G statistic (P value). Bold font denotes significant results at $\alpha = 0.005$ ($df = 1$, G critical = 7.879).

Species identification

First, we determined the effect of the strip width on the ability to identify different seabird species when individuals that were flying and sitting on the water were combined. We considered eight groups of related species with at least 50 individuals sighted, including four pairs of congeners that are difficult to identify at sea (Red *Phalaropus fulicaria* vs. Red-necked *Ph. lobatus* Phalaropes; Common *Uria aalge* vs. Thick-billed *U. lomvia* Murres; Leach's *Oceanodroma leucorhoa* vs. Fork-tailed *O. furcata* Storm-Petrels; Sooty *Puffinus griseus* vs. Short-tailed *P. tenuirostris* Shearwaters), two groups including four species each (jaegers and skuas; gadfly petrels), and two specious families including six (gulls, Laridae), and 13 (alcids, Alcidae) species [consult Appendix 1 for scientific names of species mentioned in the text]. Under a null hypothesis of a constant ability to identify all taxa with increasing distance from the vessel, we would expect that unidentified birds would occur in the same relative proportion across the three strip widths. Conversely, if birds farther away were more difficult to identify, we would anticipate a higher proportion of unidentified birds in the strip widths farther from the vessel.

To test this prediction, we compared the expected and observed proportions of unidentified birds within three strip widths (100 m, 200 m, 400 m) using *G* tests (Zar 1984). Three pair-wise comparisons were therefore performed for each taxonomic group (Table 2). We first compared the proportion of identified birds within the 0–100 m and the 100–200 m survey strips, and then those within the 0–200 m and 200–400 m strips, and finally those within the 0–400 m and 400–800 m strips. We also assessed the optimal strip width for the entire community by using paired nonparametric Wilcoxon tests (Zar 1984) to compare, for increasingly wider paired strip widths, the proportion of identified birds across the eight taxonomic groups considered.

Seabird behavior

We assessed not only whether changes in strip width influenced the ability to identify seabirds, but also whether they affected their densities (birds•km^{-2}) apparent to the observer. Because the detectability of flying and sitting birds varies, we considered these behaviors separately (Dixon 1977, Duffy 1983). After eliminating "rare" taxa (those sighted in less than 25 transects), we considered 22 distributions involving 16 taxa: six sitting and flying, and 10 flying only. To assess the influence of seabird behavior, we used *G* tests (Zar 1984) to compare the distributions of flying and sitting individuals of the same species across the strip widths (Table 3). Under a null hypothesis of no vessel attraction or avoidance and no change in detectability with increasing distance from the ship, we would expect bird densities—regardless of species and behavior—to be invariant across survey strips. In other words, we would expect the four adjacent survey strips (0–100 m, 100–200 m, 200–400 m, 400–800 m) to respectively contain 12.5%, 12.5%, 25%, and 50% of all birds sighted (Fig. 1, Table 3).

Apparent densities

Because most (>80%) of the birds we sighted were in flight, we focused our subsequent analyses on flying individuals exclusively. We considered 16 "common" flying species (sighted in more than 25 transects) and assessed how their densities varied across the four strip widths. We used the CD with *G* tests (Zar 1984) to quantify changes in the relative abundance of each species with increasingly wider strip widths. By comparing the coefficient values for the three

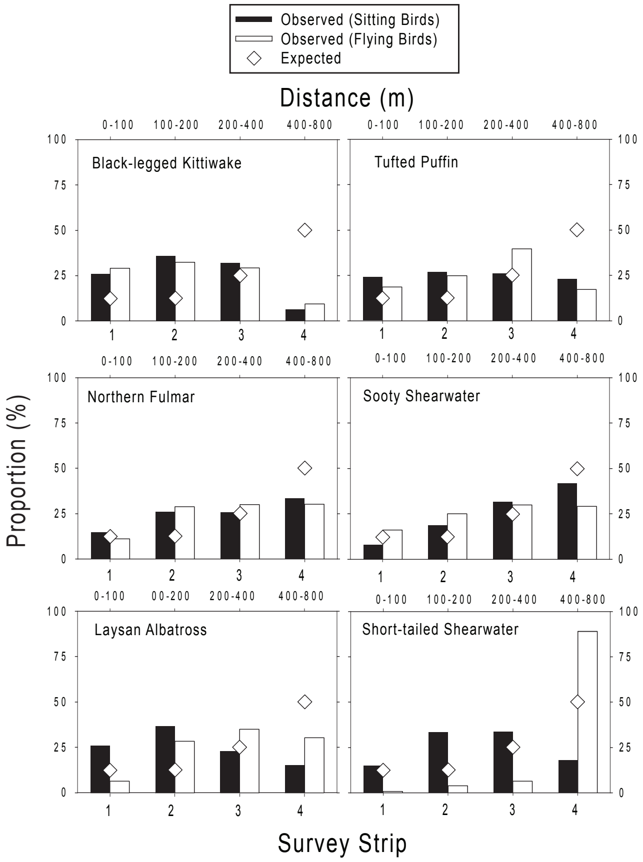

Fig. 1. Distributions of flying and sitting birds belonging to six "common" taxa (sighted in at least 25 five-minute transects). For each species, the observed (histograms) and the expected (diamonds) proportions of birds sighted within four discrete strip widths are shown.

TABLE 3
Comparison of the relative distribution of flying and sitting birds of six "common" taxa (recorded in at least 25 five-minute transects) within the four strip widths considered in this study

Species	Birds sitting	Birds flying	*G* statistic	*p* Value [a]
Black-legged Kittiwake *Rissa tridactyla*	2 084	4 075	1.100	0.75–0.90
Tufted Puffin *Fratercula cirrhata*	661	1 364	4.451	0.25–0.10
Northern Fulmar *Fulmarus glacialis*	1 062	8 062	1.161	0.75–0.90
Sooty Shearwater *Puffinus griseus*	831	13 187	6.157	0.25–0.10
Laysan Albatross *Phoebastria immutabilis*	186	689	21.547	**<0.001**
Short-tailed Shearwater *P. tenuirostris*	13 794	18 882	114.848	**<0.001**

[a] Bold font denotes significant results at $\alpha = 0.005$ ($df = 3$, G critical = 7.815).

sets of paired strips of equal width (i.e. 0–100 m vs. 100–200 m, 0–200 m vs. 200–400 m, 0–400 m vs. 400–800 m), we were able to determine at which specific strip width these apparent densities varied significantly.

To derive some general patterns for flying seabirds, we used *G* tests (Zar 1984) to compare the proportion of the 16 species-specific CD values for the three strip widths described earlier. Under a scenario of equal detectability and no avoidance of or attraction to the vessel, we would expect CD values of 1 regardless of the strip width. In contrast, CD values larger and smaller than unity for any given strip width would suggest a systematic bias in apparent flying bird densities across the 16 species considered.

Weather conditions

Finally, we compared the densities of flying birds for the 16 "common" taxa to assess whether environmental conditions (i.e. Beaufort sea state, cloud cover) influenced apparent seabird densities. To account for spatial gradients in species distributions and environmental conditions across the study area, we used a repeated-measures analysis of variance (ANOVA) framework (Zar 1984) to compare data from the four paired strip widths collected simultaneously along the cruise track. This approach allowed us to compare the seabird densities (birds•km^{-2}) from the four adjacent strip widths (0–100 m, 100–200 m, 200–400 m, 400–800 m) under the same sets of co-varying environmental conditions. Before we performed the ANOVA, we transformed the seabird data by taking the log (bird density + 0.001). Thus, bins with no sightings (bird density = 0) were recoded with a value of –3.

RESULTS

Seabird surveys

We surveyed seabirds during 30 days and a total of 1852 five-minute bins across the North Pacific Ocean and the southern Bering Sea. Overall, cloud cover and sea state conditions ranged from 0% to 100% and from 2 to 8 respectively (Table 1) and were negatively correlated (Spearman rank correlation, r_s, = –0.117, n = 1852, $p < 0.001$). Weather conditions were calmer in spring, with a lower mean Beaufort sea state and proportionally fewer days of rain and fog.

To determine whether the observer shifted position when the weather conditions changed, we tested for differences in weather conditions during five-minute bins surveyed from the low (10 m) and the high (25 m) vantage points. The Beaufort sea state was significantly different (*t* test: $df = 1546$, $t = 16.76$, $p < 0.001$) for the high (mean ± SD: 4.9 ± 1.9; n = 1303) and the low (mean ± SD: 2.8 ± 1.3; n = 245) vantage points. The percentage cloud cover also differed (*t* test: $df = 1546$, $t = -8.93$, $p < 0.001$) during the high (mean ± SD: 69.5 ± 37.5; n = 1303) and the low (mean ± SD: 91.9 ± 25.8; n = 245) observations. Because of the co-variation in weather conditions and observer height above the sea surface, we included environmental conditions in our analysis, but did not consider potential biases associated with changes in the vantage point of the observer.

The observer recorded a total of 113 209 individuals belonging to 61 taxa within the 800-m "identification horizon" (Weins *et al.* 1978). Of these, 82.1% and 17.9% were individuals flying and sitting on the water respectively. Nevertheless, the rank of species abundance for sitting and flying birds was significantly correlated ($r_s = +0.789$, n = 61, $p < 0.001$), indicating that the same numerically dominant species were sighted in flight and sitting on the water. Overall, 68.3% of the birds sighted were identified to species level, with most (91.5%) of the unidentified individuals consisting of "dark shearwaters," a code commonly used to refer to Sooty and Short-tailed Shearwaters (Appendix 1).

Species identification

The ability to identify seabirds to species level changed significantly with an increase in the strip width (Table 2). The statistical tests revealed that, as the strip width increased from 100 m to 200 m to 400 m, a significant decline was registered in the proportion of identified birds in none, two, and two of the eight taxonomic groups considered.

In particular, 50% of the phalaropes sighted within the 200–400 m survey strip were identified, but none of those sighted within the wider strip widths were identified to species level. All jaegers and skuas sighted within survey widths up to 200 m were identified to species level, but only 75% were identified within the survey strips greater than 400 m. The same pattern was apparent for the murres, with 100% and 93% of the birds being identified to species level when sighted within and beyond 400 m respectively. However, that result was marginally significant ($0.01 < p < 0.02$).

For the other five taxonomic groups under consideration, we documented no changes in the proportion of individuals identified to species level across the three strip widths. The storm-petrels, gadfly petrels and gulls showed very high identification rates, ranging from 100% to 99% of all individuals sighted. We observed the same result for the dark shearwaters, although they were identified to species level at a much lower rate (52%–62%). For the alcids, we detected a decline in the proportion of identified birds for wider strip widths, from 99.6% in the closest survey strips (0–100 m) to 92.5% in the farthest (400–800 m). However, this decrease was not statistically significant.

When we considered the eight taxonomic groups together, the overall proportion of identified birds within the first two strip widths (0–100 m vs. 100–200 m) did not vary significantly (Wilcoxon test with normal approximation: $Z = -1.572$, $p = 0.116$, n = 8). This case held when we contrasted the 0–200 m with the 200–400 m strip widths ($Z = -1.521$, $p = 0.128$, n = 8). However, when we contrasted the proportion of identified birds within the 0–400 m and the 400–800 m strip widths, we detected a marginally significant difference ($Z = -2.383$, $p = 0.017$, n = 8), suggesting that the observer's inability to identify seabirds to species beyond 400 m was a pervasive phenomenon.

Influence of seabird behavior

Seabirds did not occur in equal proportions across the various strip widths (Table 3). All twelve comparisons (six species by two behaviors) revealed significant differences between the observed and the expected relative distributions in the 0–100 m, 100–200 m, 200–400 m, and 400–800 m survey strips ($G > 128.5$, $df = 3$, and $p < 0.001$ for all 12 comparisons). Most birds—whether sitting or flying—aggregated at intermediate distances from the vessel, with a decrease in their apparent abundance within the farthest strip width (400–800 m).

For four species, no significant differences were evident between the distributions of flying and sitting individuals across the four survey strips (Table 3, Fig. 1). For instance, the Black-legged Kittiwake *Rissa tridactyla* and the Tufted Puffin *Fratercula cirrhata* were disproportionately more abundant within the first two survey strips

(0–200 m), with less than 25% of these birds (whether flying or sitting) occurring in the farthest survey strip (400–800 m, Fig. 1). Conversely, the Northern Fulmar *Fulmarus glacialis* and the Sooty Shearwater were disproportionately more abundant farther away from the vessel, with more than 25% of all birds (flying and sitting) occurring within the most distant survey strip (400–800 m). The other two species showed very different responses, with significant differences in the relative distribution of flying and sitting birds across the four strip widths (Table 2, Fig. 1). For the Laysan Albatross *Phoebastria immutabilis* and the Short-tailed Shearwater, sitting birds occurred significantly closer to the vessel than did flying birds (Fig. 1).

Seabird densities

To account for the observed differences in the detectability of flying and sitting birds, we focused our subsequent analyses on flying individuals, which accounted for most of our observations (81% of all birds). The analysis of apparent bird densities within various survey strips revealed that flying birds were not distributed equally with increasing distance from the vessel. For eight of the 16 "common" taxa, the relative densities across survey strips differed significantly from the null expectation. Seven other taxa showed a marginally ($0.05 < P < 0.005$) significant response, and the remaining group (dark shearwaters) showing a nonsignificant pattern ($0.05 < p < 0.10$; Table 4). Overall, the comparison of the CDs for increasingly large survey strips revealed that flying birds were most numerous at intermediate distances from the vessel.

The large CDs (>1) for the comparison between the two 100-m strip widths (0–100 m vs. 100–200 m) suggest that flying birds were more abundant farther away from the trackline (median 1.87; minimum 1.06 for the Black-legged Kittiwake; maximum 18.50 for the Rhinoceros Auklet *Cerorhinca monocerata*). The CDs for all 16 taxa were greater than 1, yielding a distribution of CD values significantly different from the expectation under a scenario of no avoidance or attraction (Wilcoxon test with normal approximation: $Z = -3.516$; $p < 0.001$, n = 16). Conversely, when we compared the CD values for the two 200-m strip widths (0–200 m vs. 200–400 m), they were not significantly different from the null expectation of CD = 1 (median 0.94; minimum 0.65 for the Glaucous-winged Gull *Larus glaucescens*; maximum 2.66 for the Streaked Shearwater *Calonectris leucomelas*; Wilcoxon test with normal approximation: $Z = +0.398$, $p = 0.691$, n = 16). Finally, the CD values for the two 400-m strips (0–400 m vs. 400–800 m) were also significantly different from the null expectation (Wilcoxon test with normal approximation: $Z = 2.638$, $p = 0.008$, n = 16), with 14 of the 16 values smaller than 1 (median 0.72; minimum 0.52 for the Glaucous-winged Gull; maximum 4.53 for the Sooty Shearwater).

Weather conditions

When we compared the distributions of flying seabirds across the four survey strips, we documented pervasive effects of Beaufort sea state and cloud cover on bird sightability for 13 of the 16 "common" taxa analyzed. We observed a significant interaction term between the survey strip width and cloud cover (four instances) and between the survey strip width and Beaufort sea state (nine instances) (Table 5). These results illustrate the effects of changing environmental conditions on seabird detectability, and the influence of the width of the survey strip on apparent densities.

TABLE 4
Comparison of the relative distribution of flying birds of 16 "common" taxa (recorded in more than 25 five-minute transects) within the four strip widths considered in this study

Species	Birds (n)	*G* statistic	*p* Value [a]	CD indices [b]		
				100 m vs. 200 m	200 m vs. 400 m	400 m vs. 800 m
Ancient Murrelet *Synthliboramphus antiquus*	282	10.021	0.025–0.01	3.63	1.38	0.88
Black-footed Albatross *Phoebastria nigripes*	55	8.973	0.05–0.025	2.10	0.81	0.81
Black-legged Kittiwake *Rissa tridactyla*	4 075	46.741	**<0.001**	1.06	0.74	0.55
Dark Shearwater *Puffinus griseus* / *P. tenuirostris*	35 634	7.242	0.10–0.05	1.65	1.01	0.76
Fork-tailed Storm-Petrel *Oceanodroma furcata*	616	10.328	0.025–0.01	1.52	1.38	0.74
Glaucous-winged Gull *Larus glaucescens*	228	74.003	**<0.001**	1.20	0.65	0.52
Laysan Albatross *Phoebastria immutabilis*	689	14.830	**0.005–0.001**	2.72	1.00	0.72
Leach's Storm-Petrel *O. leucorhoa*	733	12.116	0.01–0.005	1.80	0.88	0.72
Mottled Petrel *Pterodroma inexpectata*	238	12.881	0.01–0.005	2.47	1.03	0.73
Northern Fulmar *Fulmarus glacialis*	8 062	10.745	0.025–0.01	1.28	0.86	0.70
Rhinoceros Auklet *Cerorhinca monocerata*	168	32.186	**<0.001**	18.50	0.76	0.74
Sooty Shearwater *P. griseus*	13 187	40.155	**<0.001**	2.96	1.21	4.53
Streaked Shearwater *Calonectris leucomelas*	6 536	12.246	0.01–0.005	1.76	2.66	1.03
Short-tailed Shearwater *P. tenuirostris*	18 882	25.315	**<0.001**	1.17	0.96	0.60
Thick-billed Murre *Uria lomvia*	107	28.154	**<0.001**	2.61	0.91	0.62
Tufted Puffin *Fratercula cirrhata*	1 364	22.837	**<0.001**	1.14	0.77	0.63

[a] Bold font denotes significant results at $\alpha = 0.005$ ($df = 3$, G critical = 7.815).

[b] Coefficients of detection (CDs) for three paired distance bands. A CD of 1 implies that bird sightings are distributed uniformly across the two paired survey strips. Values larger and smaller than 1 indicate that birds occur disproportionately outside and within the narrow strip width respectively.

DISCUSSION

Here, we present the first methodology analysis of seabird sightings from a large bulk cargo carrier, and we provide recommendations for future surveys from novel platforms of opportunity. Notably, we develop criteria for assessing the appropriate strip width to survey an entire seabird community, whereas previous studies have taken a single-species approach (e.g. Becker *et al.* 1997, Hyrenbach 2001).

In our attempt to quantify the most effective strip width for our study region and survey platform, we weighed a variety of potential biases. We considered the proportion of individuals that were identified to species level, and the relative distribution of birds as a function of the radial distance from the vessel. Additionally, we illustrated the potential effects of bird behavior (flying vs. sitting on the water) and weather conditions (cloud cover, Beaufort sea state) by contrasting the apparent densities of birds within different survey strips of varying widths. For the sake of brevity, we focused our analysis on the most prevalent behavior (81% of the birds sighted were in flight) and 16 "common" taxa (sighted in at least 25 five-minute transects). Based on our analyses, we make the following recommendations:

- Although we recognize that the objectives and conditions of individual studies should dictate the use of specific survey techniques, we call for researchers to quantify potential survey biases and to make detection and identification coefficients available as part of their study results. These analyses will help to integrate disparate at-sea surveys and will facilitate comparisons across time and space. This quantification is particularly important in estimates of community-level patterns of species richness and diversity (e.g. Ford *et al.* 2004).
- In principle, line transect methods are preferable to fixed-width strip transects because they provide an empirically derived optimum detection function for various species and weather conditions. Unfortunately, line-transect techniques are extremely effort-intensive and often impractical, particularly in areas of high bird densities and for species that occur in large flocks (e.g. phalaropes) and those that fly fast (e.g. shearwaters). In addition to estimating the distance to every sighting, line transects require dedicated observations to ensure that all birds close to the trackline are detected [perfect detectability, $g_0 = 1$ (Buckland *et al.* 1993)]. Thus, we recommend the use of line transects in instances where bird densities are sparse and when enough observers are available (Mack *et al.* 2002, Spear *et al.* 2004). In most situations, however, strip transects will be more practical or the only feasible option.
- Before fixed-width transect methods are used, it is imperative to test whether the underlying assumption of perfect detectability within the survey strip is met (Buckland *et al.* 1993, Hyrenbach *et al.* 2001). In other words, observers should determine whether their ability to detect birds changes significantly with increasing distance from the vessel. We have shown that variability in detection distances may be more complicated than a simple linear decrease or increase of bird numbers. Namely, we found that some species were most numerous at intermediate distances (200–400 m) from the vessel (Fig. 1). In particular, alcids and storm-petrels were difficult to detect within 100 m of the vessel. This pattern may be a consequence of our large survey platform, which caused detection "blind spots" for animals close to the vessel, enhancing the avoidance by species that dive or fly away as a vessel approaches. Thus, we suggest that investigators test for nonlinear variation in species-specific detectability and identification rates with increasing distance from the vessel.
- Methodologically, testing for nonlinear variation can be achieved by using a hand-held range finder to score bird sightings into various

TABLE 5
Comparison of the relative abundance of flying birds of 16 "common" taxa (recorded in more than 25 five-min transects) within four strip widths, as a function of distance and weather conditions (cloud cover, Beaufort sea state)

Species	Occurrence [transects (n)]	Distance × cloud cover [a]		Distance × Beaufort sea state [a]	
		***F* statistic**	***p* Value**	***F* statistic**	***p* Value**
Ancient Murrelet *Synthliboramphus antiquus*	55	3.389	0.017	10.745	**<0.001**
Black-footed Albatross *Phoebastria nigripes*	49	2.617	0.049	1.965	0.117
Black-legged Kittiwake *Rissa tridactyla*	288	2.315	0.074	30.106	**<0.001**
Dark Shearwater *Puffinus griseus* / *P. tenuirostris*	41	1.829	0.139	7.688	**<0.001**
Fork-tailed Storm-Petrel *Oceanodroma furcata*	214	5.78	**<0.001**	2.871	0.032
Glaucous-winged Gull *Larus glaucescens*	78	10.9	**<0.001**	15.24	**<0.001**
Laysan Albatross *Phoebastria immutabilis*	283	1.766	0.151	22.029	**<0.001**
Leach's Storm-Petrel *O. leucorhoa*	271	5.99	**<0.001**	2.867	0.035
Mottled Petrel *Pterodroma inexpectata*	124	2.418	0.064	0.468	0.705
Northern Fulmar *Fulmarus glacialis*	758	1.273	0.282	8.355	**<0.001**
Rhinoceros Auklet *Cerorhinca monocerata*	30	2.235	0.076	1.032	0.397
Sooty Shearwater *Puffinus griseus*	234	1.829	0.139	7.688	**<0.001**
Streaked Shearwater *Calonectris leucomelas*	121	27.69	**<0.001**	25.549	**<0.001**
Short-tailed Shearwater *P. tenuirostris*	67	2.251	0.080	6.077	**<0.001**
Thick-billed Murre *Uria lomvia*	52	1.057	0.366	4.417	0.004
Tufted Puffin *Fratercula cirrhata*	329	2.232	0.082	1.038	0.375

[a] Repeated measures ANOVA. Bold font denotes significant results at $\alpha = 0.005$ (n = 1852 five-minute transects, *df* = 3, 5547).

survey strips extending outward from the bow of the ship on one or both sides of the track evaluated (Heinemann 1981, Pyle 2007). More specifically, we recommend using a series of pre-determined distance bands of fixed width, instead of attempting to quantify the radial distance to each sighting. The configuration of survey strips will vary across studies, but we advocate using a series of nested transects of increasing width (0–100 m, 100–200 m, 200–400 m, 400–800 m, 800–1600 m) to facilitate pair-wise comparisons using increasingly wider survey strips.

- In addition to the total number of birds of a given species sighted, we suggest that investigators evaluate whether the proportion of identified individuals is influenced by changing the width of the survey strip. Because the occurrence of unidentified birds can inhibit comparison of closely-related species, the strip-width influence should be a critical consideration when evaluating a study method.
- We documented several cases in which bird behavior (flying versus sitting) and weather conditions (cloud cover, Beaufort sea state) affected the relative abundance of birds in each strip-width category. We suggest that investigators address these potential effects in their methodology assessments. More specifically, we recommend the use of a repeated measures ANOVA framework to incorporate these potential biases into statistical analyses. In addition to testing for these detectability biases, researchers must evaluate the potential co-variation of observation conditions. Specifically, observer height above the water and the choice by observers to stand outside in the flying bridge or indoors in the pilot house may be weather-dependent. Thus, we urge researchers to test for systematic changes in observation conditions associated with weather conditions.
- All of our observations were made by one person (MH), but in studies involving multiple observers, we advocate analyses of inter-observer variability. These comparisons can include species identification rates and apparent bird densities (Van Der Meer and Camphuysen 1995). Another important consideration is whether the number of observers will change throughout the study, and how to develop correction factors to account for this potential variability (Spear *et al.* 2004). These biases could be incorporated into a repeated measures ANOVA framework as co-factors.
- The novel contribution of this paper is its attempt to select a specific survey method and strip width by comparing the relative abundance of birds in various strip widths for multiple species, behaviors, and weather conditions. To reach this decision, we suggest using community-level metrics, such as the proportion of sighted birds successfully identified to species level, together with species-specific metrics, such as the coefficient of detection of the most numerous taxa. Paired statistical tests or a repeated measures ANOVA framework can then be used to compared those metrics for various strip widths.
- A variety of processes, including the changing detectability of flying/sitting birds with increasing distance from the vessel and the response (attraction or avoidance) of seabirds to vessels, may bias seabird surveys at sea. It may thus be extremely difficult—and probably impossible—to select a survey strip capable of mitigating all biases for all species encountered during a survey, particularly given changing weather and visibility conditions. Alternatively, researchers may consider using several nested strips to survey various species, with a narrow (<300 m) and a broad (>300 m) transect for inconspicuous and conspicuous taxa respectively (Spear *et al.* 2004, Pyle 2007).

CONCLUSIONS

We present several approaches for quantifying potential biases associated with strip transect surveys. We urge marine ornithologists to use similar approaches to test the underlying assumptions of widely-accepted survey methods. It is our hope that standardized methodological observations and correction factors will enhance the long-term applicability of at-sea survey data, by facilitating the integration of observations from various platforms and datasets collected using disparate methods.

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APPENDIX 1

Sightings of the 16 "common" seabirds considered in the present analysis during the spring (1–14 June 2002) and the fall (5–20 October 2002) pilot surveys from British Columbia (Canada) to Hokkaido (Japan), showing the seasonal occurrence [spring (s), fall (f)] and the relative contribution (Prop.) of each taxa out of the total number of birds sighted (113 209); together, these taxa accounted for 99% of all the birds sighted.

Order	Family	Common name	Scientific name	Season	Prop. (%)
Procellariiformes	Procellariidae	Dark shearwater	*Puffinus griseus* / *P. tenuirostris*	s / f	31.5
		Mottled Petrel	*Pterodroma inexpectata*	s / f	0.2
		Northern Fulmar	*Fulmarus glacialis*	s / f	8.1
		Short-tailed Shearwater	*P. tenuirostris*	s / f	28.9
		Sooty Shearwater	*P. griseus*	s / f	12.4
		Streaked Shearwater	*Calonectris leucomelas*	s / f	6.5
Procellariiformes	Hydrobatidae	Fork-tailed Storm-Petrel	*Oceanodroma furcata*	s / f	1.5
		Leach's Storm-Petrel	*Oceanodroma leucorhoa*	s / f	0.8
Procellariiformes	Diomedeidae	Black-footed Albatross	*Phoebastria nigripes*	s / f	0.1
		Laysan Albatross	*Phoebastria immutabilis*	s / f	0.8
Charadriiformes	Laridae	Black-legged Kittiwake	*Rissa tridactyla*	s / f	5.4
		Glaucous-winged Gull	*Larus glaucescens*	s / f	0.2
Charadriiformes	Alcidae	Ancient Murrelet	*Synthliboramphus antiquus*	s / f	0.3
		Rhinoceros Auklet	*Cerorhinca monocerata*	s / f	0.2
		Thick-billed Murre	*Uria lomvia*	s / f	0.1
		Tufted Puffin	*Fratercula cirrhata*	s / f	1.8