Potential Utility of Using Fixed-wing Aircraft Either Alone or Jointly with Boats to Survey for Marbled Murrelets at Sea

Draft report to the U.S. Fish and Wildlife Service

January 2000

By

Christopher W. Thompson[1], David R. Nysewander[2] and Joseph Evenson[2]
Washington Department of Fish and Wildlife
[1] 16018 Mill Creek Blvd., Mill Creek, Washington 98012
[2] 600 Capitol Way North, Olympia, Washington 98501

Executive Summary

There is broad agreement both scientifically and politically that Marbled Murrelet populations, and their annual reproductive success, can not be monitored on their nesting grounds in old growth forest; instead, adult murrelets and their offspring must be monitored while they are on the ocean. Despite advances in our knowledge of the biology of murrelets at sea, a number of unresolved issues have prevented the development of an accepted standardized protocol for surveying for murrelets at sea. One such issue is whether murrelet survey data collected from fixed-wing aircraft can be useful by itself or in combination with data collected from boats by applying a visibility correction factor (VCF) to data collected from aircraft to correct for the reduced visibility of murrelets from aircraft relative to boats. This study addressed this issue. Using different methods, we calculated air:boat VCFs varying from 0.396 to 0.473 with coefficients of variation ranging from 6.0% to 95.9%. We conclude that aircraft may be useful for surveying for murrelets to address some questions, but probably are not accurate enough to provide sufficient statistical power for long-term monitoring programs. However, additional evaluation by biostatisticians and marine seabird researchers of various ratio estimators as appropriate VCF estimators is necessary before any firm conclusions can be reached.

Acknowledgments

This study was funded by the U.S. Fish and Wildlife Service. We are grateful to John Piatt for generously sharing his unpublished data with us, and to Jeff Laake, John Pierce, and John Skalski for commenting on earlier versions of this report.

Table of Contents

List of Tables

List of Figures

Introduction

In accordance with the Endangered Species Act of 1973 (87 Stat 884, 16 USC 1531-1543, as amended in 1975), the U.S. Fish and Wildlife Service (USFWS) listed the Marbled Murrelet, *Brachyramphus marmoratus*, as a threatened species in 1992. Marbled Murrelet (hereafter murrelet) conservation and recovery in Washington requires a broad management scheme to recover regional sub-populations to be identified by the newly formed Marbled Murrelet Recovery Team. This process requires the cooperative efforts of governmental land management agencies such as the U.S. Forest Service (USFS), Washington Department of Natural Resources (DNR), and National Park Service (NPS), as well as private and tribal landowners, with the Washington Department of Fish and Wildlife (WDFW) and United State Fish and Wildlife Service (USFWS).

As the technical advisor to the USFWS in Washington, the WDFW serves as the central repository for the statewide murrelet database, coordinates surveys, and provides expertise to monitor management activities and population status.

The USFWS has initiated the development of murrelet management strategies with the formation of the Recovery Team and endorsement of Pacific Seabird Group Inland Murrelet Survey Protocol. At present there are nostandardized management recommendations. Evaluation of the effectiveness of any proposed management strategy will require long-term monitoring of murrelet populations. There is broad agreement both scientifically and politically that murrelet populations, and their annual reproductive success, can not be monitored on their nesting grounds in old growth forest; instead, adult murrelets and their offspring must be monitored while they are on the ocean. Marine murrelet researchers have made great advances in our knowledge of the biology of murrelets at sea. As a result, a draft standardized protocol for surveying for murrelets at sea will be completed in fall/winter 1999. However, many issues regarding methods for surveying for murrelets at sea remain controversial and unresolved. One such issue is whether murrelet survey data collected from fixed-wing aircraft can be combined with data collected from boats by applying a visibility correction factor (VCF) to data collected from aircraft to correct for the reduced visibility of murrelets from aircraft relative to boats. This study addresses this issue, and concludes that use of aircraft in this fashion is not advisable for most purposes.

Materials and Methods

Between 12 and 26 September 1994, WDFW (D. Nysewander et al.) conducted one to six replicate surveys for murrelets simultaneously by boat and fixed-wing aircraft of 27 strip transects (Fig. 1) between 1.12 and 7.71 km in length for a total of 75 transects. Boat surveys were conducted on WDFW's 24-foot R/V *Harlequin* with one observer on each side of the vessel; observers searched for murrelets in a 90E arc from the transect line to abeam of the vessel; strip width was 200 M (100 M on each side of the vessel). Fixed-wing aircraft surveys were conducted in a DeHavilland Beaver flying at an approximate height of 55 meters and speed of 160 km per hour; one observer on each side of the aircraft searched a strip width of 50 M for a total strip width of 100 M. Observers looked down from the aircraft at an angle between 33E and 58E from a line parallel to the ocean surface, thereby scanning a strip 50 M in width; the area surveyed by both aircraft observers constituted a 100M subset of the area 200M wide area surveyed by the boat observers. Observers recorded their observations into audiotapes that were later transcribed onto data sheet and entered into databases. All observers had extensive training and years of experience as aerial observers.   Murrelet densities were calculated as birds per square km of area surveyed. The boat and aircraft began each transect at the same time and location. Because the aircraft finished each transect long before the boat completed the transect, the aircraft circled around and conducted a second run of the transect, beginning at the same location as its first run, and typically completed the second run at about the same time as the boat.

Results

The murrelet data collected during the boat and aircraft transects are presented in Table 1.

Effect of transect length on estimates of murrelet air:boat correction factors. Transect lengths ranged from 1.12 to 7.71 km. When transect lengths were less than 7 km, a significant percentage of surveys by both aircraft and boats detected no murrelets (Table 2).

In addition, air:boat ratio values of zero occurred more frequently on short than long transects (Table 2). As a result, *a priori* one might expect that mean air:boat ratio would be lowest for short transects and increase asymptotically with increasing transect length. However, one might also expect the opposite result because of the relationship between variability in air:boat ratio and transect length, i.e. because short transect lengths are more subject to sampling error than are longer transects, variability in air:boat ratio is greatest at short transect lengths. Specifically, on short transects it is probabilistically more likely that many more (or less) murrelets than expected may be counted from the plane; in addition, if less (or more) murrelets than expected are counted from the boat (i.e., the opposite of what were counted from the plane), this will drive the resulting air:boat ratio further from the mean. The effect of such sampling error on resulting air:boat ratios is asymmetric; air:boat ratios can not decrease below zero, but they can increase to very high numbers. Thus, one might expect the mean air:boat ratio to be highest at short transect lengths, and to decrease asymptotically to a less variable mean value as transect length increases. This prediction is marginally supported by our data; regression of air:boat ratio on transect length indicates a trend for shorter transect lengths to yield higher air:boat ratios than longer transect lengths (Figs 2 and 3); however, these trends are not statistically significant for either the first ($P = 0.089$) or second ($P = 0.138$) run of the aircraft.

Coefficient of variation in murrelet density in relation to transect length. As one would expect, coefficient of variation in murrelet density decreases as transect length increases (Table 3).

Table 1. Marbled Murrelets counted simultaneously from fixed-wing aircraft and boats in relation to transect location and length.

Date	Transect number	Transect length (km)	Murrelets counted Aerial (Run 1)	Murrelet Aerial Density[1] (run 1)	Murrelets counted Aerial (Run 2)	Aerial Density[1] (run 2)	Murrelet Aerial No. Mean (Runs 1&2)	Murrelet Aerial Density[1] Mean (Runs 1&2)	Murrelets counted on Boat	Murrelet Boat Density[1]	Murrelet Air:Boat Ratio (Run 1)	Murrelet Air:Boat Ratio (Run 2)	Murrelet Air:Boat Mean Ratio (Runs 1&2)
15 Sept	7	1.12	2	17.86	0	0.00	1	8.93	8	35.71	0.500	0.000	0.250
15 Sept	28	1.74	0	0.00	0	0.00	0	0.00	0	0.00	—	—	—
16 Sept	16	1.91	0	0.00	4	20.94	2	10.47	12	31.41	0.000	0.667	0.333
12 Sept	16	1.91	3	15.71	5	26.18	4	20.94	3	7.85	2.000	3.333	2.667
12 Sept	2	2.23	4	17.94	2	8.97	3	13.45	10	22.42	0.800	0.400	0.600
23 Sept	2	2.23	2	8.97	0	0.00	1	4.48	7	15.70	0.571	0.000	0.286
22 Sept	2	2.23	2	8.97	6	26.91	4	17.94	17	38.12	0.235	0.706	0.471
13 Sept	2	2.23	0	0.00	1	4.48	0.5	2.24	13	29.15	0.000	0.154	0.077
15 Sept	6	2.43	0	0.00	0	0.00	0	0.00	2	4.12	0.000	0.000	0.000
23 Sept	17	2.52	15	59.52	0	0.00	7.5	29.76	24	47.62	1.250	0.000	0.625
16 Sept	17	2.52	12	47.62	4	15.87	8	31.75	21	41.67	1.143	0.381	0.762
15 Sept	17	2.52	2	7.94	22	87.30	12	47.62	50	99.21	0.080	0.880	0.480
22 Sept	17	2.52	4	15.87	0	0.00	2	7.94	34	67.46	0.235	0.000	0.118
12 Sept	17	2.52	10	39.68	2	7.94	6	23.81	21	41.67	0.952	0.190	0.571
15 Sept	5	2.61	5	19.16	1	3.83	3	11.49	17	32.57	0.588	0.118	0.353
16 Sept	19	2.91	14	48.11	13	44.67	13.5	46.39	37	63.57	0.757	0.703	0.730
23 Sept	19	2.91	4	13.75	4	13.75	4	13.75	18	30.93	0.444	0.444	0.444
22 Sept	19	2.91	3	10.31	3	10.31	3	10.31	23	39.52	0.261	0.261	0.261
13 Sept	19	2.91	10	34.36	6	20.62	8	27.49	33	56.70	0.606	0.364	0.485
12 Sept	14	3.05	0	0.00	3	9.84	1.5	4.92	0	0.00	—	—	—
16 Sept	14	3.05	0	0.00	0	0.00	0	0.00	0	0.00	—	—	—
15 Sept	14	3.05	1	3.28	0	0.00	0.5	1.64	2	3.28	1.000	0.000	0.500
16 Sept	29	3.32	3	9.04	3	9.04	3	9.04	5	7.53	1.200	1.200	1.200
22 Sept	29	3.32	6	18.07	8	24.10	7	21.08	49	73.80	0.245	0.327	0.286
23 Sept	29	3.32	16	48.19	17	51.20	16.5	49.70	61	91.87	0.525	0.557	0.541
16 Sept	30	3.39	0	0.00									

Table 1. Marbled Murrelets counted simultaneously from fixed-wing aircraft and boats in relation to transect location and length (cont.)

					0	0.00	0	0.00	4	5.90	0.000	0.000	0.000
22 Sept													
	30	3.39	0	0.00	0	0.00	0	0.00	0	0.00	—	—	—
13 Sept	3	3.5	4	11.43	2	5.71	3	8.57	4	5.71	2.000	1.000	1.500
22 Sept	3	3.5	2	5.71	1	2.86	1.5	4.29	10	14.29	0.400	0.200	0.300
12 Sept	3	3.5	0	0.00	2	5.71	1	2.86	8	11.43	0.000	0.500	0.250
23 Sept	3	3.5	21	60.00	4	11.43	12.5	35.71	30	42.86	1.400	0.267	0.833
12 Sept	15	3.63	2	5.51	2	5.51	2	5.51	6	8.26	0.667	0.667	0.667
22 Sept	15	3.63	10	27.55	3	8.26	6.5	17.91	43	59.23	0.465	0.140	0.302
23 Sept	15	3.63	3	8.26	0	0.00	1.5	4.13	13	17.91	0.462	0.000	0.231
12 Sept	12	4.03	0	0.00	1	2.48	0.5	1.24	6	7.44	0.000	0.333	0.167
12 Sept	25	4.25	0	0.00	0	0.00	0	0.00	4	4.71	0.000	0.000	0.000
22 Sept	27	4.35	27	62.07	5	11.49	16	36.78	55	63.22	0.982	0.182	0.582
23 Sept	27	4.35	37	85.06	46	105.75	41.5	95.40	83	95.40	0.892	1.108	1.000
16 Sept	27	4.35	7	16.09	2	4.60	4.5	10.34	38	43.68	0.368	0.105	0.237
15 Sept	27	4.35	5	11.49	5	11.49	5	11.49	67	77.01	0.149	0.149	0.149
12 Sept	11	4.38	7	15.98	6	13.70	6.5	14.84	25	28.54	0.560	0.480	0.520
13 Sept	11	4.38	0	0.00	0	0.00	0	0.00	31	35.39	0.000	0.000	0.000
16 Sept	11	4.38	7	15.98	10	22.83	8.5	19.41	29	33.11	0.483	0.690	0.586
15 Sept	11	4.38	2	4.57	4	9.13	3	6.85	69	78.77	0.058	0.116	0.087
22 Sept	11	4.38	6	13.70	15	34.25	10.5	23.97	45	51.37	0.267	0.667	0.467
23 Sept	11	4.38	24	54.79	20	45.66	22	50.23	46	52.51	1.043	0.870	0.957
12 Sept	1	4.58	4	8.73	1	2.18	2.5	5.46	17	18.56	0.471	0.118	0.294
13 Sept	1	4.58	2	4.37	0	0.00	1	2.18	10	10.92	0.400	0.000	0.200
23 Sept	1	4.58	12	26.20	14	30.57	13	28.38	46	50.22	0.522	0.609	0.565
22 Sept	1	4.58	12	26.20	18	39.30	15	32.75	33	36.03	0.727	1.091	0.909
13 Sept	8	4.63	0	0.00	0	0.00	0	0.00	0	0.00	—	—	—

Table 1. Marbled Murrelets counted simultaneously from fixed-wing aircraft and boats in relation to transect location and length (cont.)

15 Sept	9	4.78	0	0.00	0	0.00	0	0.00	9	9.41	0.000	0.000	0.000
15 Sept	10	4.81	11	22.87	5	10.40	8	16.63	29	30.15	0.759	0.345	0.552
16 Sept	13	4.95	0	0.00	0	0.00	0	0.00	2	2.02	0.000	0.000	0.000
15 Sept	13	4.95	0	0.00	2	4.04	1	2.02	8	8.08	0.000	0.500	0.250
15 Sept	20	5.05	8	15.84	12	23.76	10	19.80	45	44.55	0.356	0.533	0.444
22 Sept	20	5.05	5	9.90	4	7.92	4.5	8.91	40	39.60	0.250	0.200	0.225
16 Sept	20	5.05	4	7.92	3	5.94	3.5	6.93	20	19.80	0.400	0.300	0.350
13 Sept	20	5.05	6	11.88	0	0.00	3	5.94	14	13.86	0.857	0.000	0.429
23 Sept	20	5.05	9	17.82	6	11.88	7.5	14.85	56	55.45	0.321	0.214	0.268
23 Sept	18	5.57	0	0.00	0	0.00	0	0.00	0	0.00	—	—	—
16 Sept	26	5.57	7	12.57	12	21.54	9.5	17.06	191	171.45	0.073	0.126	0.099
12 Sept	18	5.57	0	0.00	0	0.00	0	0.00	2	1.80	0.000	0.000	0.000
16 Sept	18	5.57	0	0.00	0	0.00	0	0.00	3	2.69	0.000	0.000	0.000
15 Sept	26	5.57	15	26.93	9	16.16	12	21.54	136	122.08	0.221	0.132	0.176
22 Sept	26	5.57	10	17.95	6	10.77	8	14.36	167	149.91	0.120	0.072	0.096
22 Sept	18	5.57	0	0.00	0	0.00	0	0.00	0	0.00	—	—	—
15 Sept	18	5.57	0	0.00	0	0.00	0	0.00	1	0.90	0.000	0.000	0.000
23 Sept	26	5.57	2	3.59	7	12.57	4.5	8.08	96	86.18	0.042	0.146	0.094
15 Sept	21	7.19	10	13.91	12	16.69	11	15.30	93	64.67	0.215	0.258	0.237
13 Sept	21	7.19	9	12.52	6	8.34	7.5	10.43	31	21.56	0.581	0.387	0.484
16 Sept	4	7.71	1	1.30	0	0.00	0.5	0.65	9	5.84	0.222	0.000	0.111
12 Sept	4	7.71	10	12.97	5	6.49	7.5	9.73	21	13.62	0.952	0.476	0.714
22 Sept	4	7.71	19	24.64	14	18.16	16.5	21.40	60	38.91	0.633	0.467	0.550
13 Sept	4	7.71	14	18.16	14	18.16	14	18.16	59	38.26	0.475	0.475	0.475
Total			452		382		417		2281				

[1] Densities were calculated as murrelets per square kilometer.

Table 2. Percentage of transects on which no Marbled Murrelets were sighted as a function of transect length (km).

Transect Length (km)	Sample Size	Aerial First Run	Aerial Second Run	Neither Aerial Run 1 nor 2	Boat
1 - 2	4	50.00	50.00	25.00	25.00
2 - 3	15	13.33	26.67	6.67	0.00
3 - 4	15	33.33	33.33	20.00	20.00
4 - 5	21	33.33	28.57	23.81	4.76
5 - 6	14	35.71	42.86	35.71	14.29
6 - 7	0	—	—	—	—
7 - 8	6	0.00	16.67	0.00	0.00

Table 3. Coefficient of variation in Marbled Murrelet density estimates as a function of transect length (km).

Transect Length (km)	Sample Size	Aerial Density (first run)	Aerial Density (second run)	Aerial Average Density	Boat Density
1 - 2	4	115.9	116.9	85.1	93.3
2 - 3	15	85.2	141.9	77.5	55.2
3 - 4	15	140.6	149.7	13.5	12.99
4 - 5	21	132.2	150.1	13.6	78.8
5 - 6	14	97.9	107.1	94.4	11.71
6 - 7	0	—	—	—	—
7 - 8	6	55.2	66.5	58.4	69.9

Overall air:boat ratio. There are many ways to estimate ratios, and measures of their variance. We present three methods below, of which the last appears to be preferred by most statisticians (e.g. Cochran 1977).

The first method is to calculate the simple unweighted mean. By this method, the first run of the aircraft yielded an air:boat ratio of 0.473 " 0.055 (mean " SE, n = 68), and coefficient of variation (CV) of 95.9%; the second run of the aircraft yielded a significantly lower air:boat ratio (0.362 " 0.058, t = 2.080, df=67, P=0.041), and a higher CV (133.1%).

The second method involves weighting murrelet counts by transect length. Because longer transects contain more information, data from them should yield more accurate estimates of air:boat ratios. By this method, the first run of the aircraft yielded a mean air:boat ratio of 0.434 " 0.025, and CV of 93.0%; similar to our results above, the second run of the aircraft yielded a significantly lower air:boat ratio (0.320 " 0.023, t =4.894, df=67, P<0.0001), and higher CV (133.1%).
The correlation of murrelets counted from aircraft on its second run on murrelets counted from the boat yielded a slightly higher correlation coefficient (0.484) than the correlation coefficient

of murrelets counted from aircraft on its first run (r=0.437)(Figs. 4 and 5). Despite this, as noted above, both weighted and unweighted calculations yielded higher CVs on the second run than the first run of the aircraft.

Following Prenzlow and Lovvorn (1996), the third method is to calculate the overall air:boat ratio, R, known as the combined ratio estimator (Cochran 1977:165); R is 0.3963, and is calculated as follows:

$$\hat{R} = \frac{\sum_{i=1}^{n} a_i}{\sum_{i=1}^{n} b_i},$$ where

a_i = number of murrelets counted from the ground on the i^{th} transect
b_i = number of murrelets counted from the air on the i^{th} transect
n = number of boat transects

The estimated variance and standard error in R are 5.69 x 10^{-4} and 2.89 x 10^{-3}, respectively, and are calculated as follows:

$$\hat{V}(\hat{R}) = \frac{1}{n(n-1)\bar{b}^2}\left[\sum_{i=1}^{n} a_i^2 - 2\hat{R}\sum_{i=1}^{n} a_i b_i + \hat{R}^2 \sum_{i=1}^{n} b_i^2\right]$$

$$SE = \frac{\sqrt{\hat{V}(\hat{R})}}{\sqrt{n}}$$

The CV is 6.02%, and is calculated as follows:

$$CV = \frac{\sqrt{\hat{V}(\hat{R})}}{\hat{R}}$$

Discussion

Potential biases and errors in the data. Unfortunately, it is not possible to design a study that minimizes all, or even most, sources of potentially confounding error when trying to accurately measure and compare the number or density of murrelets, or other species, observed during simultaneous aerial and boat surveys. For example, our design suffers from at least one major potential source of error, i.e. that murrelets were free to move into and out of each transect area between the time it was surveyed by the boat and when it was surveyed by the plane, or vice-verse. An alternative design could have employed murrelet decoys deployed along various transect routes and fixed in space with lines and weights to the ocean floor. However, this design would not accurately simulate the avoidance behavior exhibited by live murrelets. We believe that our design provides a more realistic estimate of the correlation between boat and aerial estimate of murrelet abundance than is possible through alternative designs.

The purpose of this study was to determine whether murrelets can be counted at sea with sufficient accuracy from airplanes to be used either alone, or jointly with boats, to conduct marine surveys for murrelets. As noted above, to address this question, it is necessary to estimate a VCF, i.e. the ratio of murrelets seen from the air versus the number seen from the boat in the same transect area. It is essential that aerial and boat surveys conducted for this purpose be done simultaneously. Most studies that have estimated VCFs of birds or other animals have done so by comparing aerial and ground counts obtained from aerial and ground surveys conducted one day to many days apart from one another (Broome 1985, Savard 1982, Prenzlow and Lovvorn 1996, but see King and Conant 1982, Briggs et al. 1985). The resulting correlations and VCFs between aerial and ground counts in such studies are confounded because they incorporate two sources of error, namely the extent to which: (1) animals have moved into and/or out of the transect area between the time the area was surveyed by boat versus plane, and (2) observers in planes can count birds as accurately as observers from boats. Movement of birds into and out of the transect area increases in proportion to duration of time between the aerial and boat survey, thereby increasing the CV of the VCFs calculated from such data (Briggs et al. 1985). As a result, VCFs from such studies may be used to correct aerial count data, but they do not accurately reflect differences in visibility of any given taxa from the air versus the ground. In contrast, we conducted our surveys simultaneously. As a result, our data accurately reflect differences in visibility of murrelets from the air versus the ground, thereby allowing us to calculate a true VCF more accurately and precisely.

Rarity and sightability of murrelets. In contrast to most seabirds, including other alcids, murrelets are relatively rare, small in size, wary of aircraft and boats, and cryptic in plumage color during the breeding season when most at-sea surveying is conducted. In addition, during most of the breeding season, murrelets usually occur singly or in pairs (Thompson 1997a, b). These aspects of their abundance, appearance, and behavior makes them considerably more difficult to detect and identify than other seabirds such as Common Murres, *Uria aalge*, especially from aircraft, i.e., sightability of murrelets is considerably lower from aircraft than from boats. This is especially true in the continental United States where planes are not legally allowed to survey below 60 M, in contrast to Alaska where planes may survey as low as 35 M.

Effect of transect length on estimates of murrelet air:boat correction factors. Transect lengths ranged from 1.12 to 7.71 km. When transect lengths were less than 7 km, a significant percentage of surveys by both aircarft and boats detected no murrelets (Table 2). This indicates that if it was determined or decided that planes should be used alone or jointly with boats to collect data on murrelet abundance, and a correction factor applied to data collected from aircraft, then transects should be at least 7 km in length, preferably longer. The reason for this is that transects in which no murrelets are detected by plane yield a ratio of zero and, as a result, can not be corrected by a correction factor. At the same time, one can not ignore transects on which no murrelets are detected, and use only transects on which murrelets are detected in order to calculate murrelet abundance as this would artificially inflate estimates of murrelet abundance.

In addition, regression of air:boat ratio on transect length indicates a trend for shorter transect lengths to yield higher air:boat ratios than longer transect lengths. Although these trends are marginally non-significant for both the first and second run of the aircraft, these results further indicate that transect lengths should be longer (e.g., $7 km) rather than shorter.

Coefficient of variation in murrelet density in relation to transect length. As one would expect, coefficient of variation in murrelet density decreases as transect length increases (Table 3). Thus, from a statistical perspective, using transects at least 7 km in length, and preferably longer, will increase the statistical power with which density estimates can be made, and changes in density can be detected over time.

Overall air:boat ratio. As discussed above, there are many ways to estimate VCF's and measures of their variance. The second run of the aircraft yielded VCFs that were lower and had higher CVs than those obtained from the first run of the aircraft. These results are not surprising since one would expect that some birds on each transect would be scared off the transect by the boat and/or first run of the airplane prior to the beginning of the second run of the airplane; in a similar study by Piatt (1991, unpubl. data; discussed below), he conducted two runs of an airplane over a transect while a boat completed one run of the transect, and also found that the second run of the airplane yielded significantly lower densities of murrelets than did his first runs. Thus, we do not advocate using VCF's based on (1) the second run or (2) an average of the first and second run of the aircraft.

VCFs based on the first run of the airplane ranged from an unweighted mean of 0.473 " 0.055 (mean " SE) with a CV of 95.9% to a mean weighted by transect length of 0.434 " 0.025 with a CV of 93.0%. In contrast, the VCF, calculated as the combined ratio estimator (Cochran 1977:165), which is the recommended estimator of the VCF, was 0.3963 " 0.0029 with a CV of 6.0 %. This VCF has a lower mean, and much smaller standard error and CV than either the weighted or unweighted mean VCFs.

Now that we have calculated various VCFs, the question is how useful are they. The three methods for estimating VCFs yielded similar results; mean VCFs differed from one another by less than 20%. However, the CVs of the weighted and unweighted VCFs were more than ten-fold the CV of the combined ratio estimator. Smith (1995) argues that VCFs can be used if they meet at least one of the following two criteria: (1) the CV of the VCF is # 20%, or (2) the sum of the air counts and the sum of the ground counts each total at least 40. The first criterion is violated by 4-5 fold by the CVs of the weighted and unweighted means, but is easily met by the CV of 6.0% of the combined ratio estimator. The second criterion is satisfied by all methods for estimating VCFs. On this basis, the combined ratio estimate of the VCF, and possibly the other

VCFs, may be of some value for estimating numbers of murrelets, especially in areas such as British Columbia and Alaska where it is not logistically feasible to comprehensively survey for murrelets because ocean conditions are typically worse than in waters off the west coast of the United States, and murrelets occur over many-fold more miles of coastline than along the west coast of the United States. However, the main justification for surveying for murrelets is to enable resource managers to track relatively small changes in murrelet populations (e.g. 10-20%) over relatively small periods of time (e.g. 5-10 years). Boat surveys for murrelets in Washington typically yield CVs between 50% and 75% (Thompson 1999) whereas aerial surveys typically yield CVs greater than than 100%. In addition, our data, as well as that of Piatt (1991, discussed below) indicate a poor correlation between aerial and boat counts of murrelets. As a result, we doubt that aerial data can enable us to detect such changes in murrelet populations with as much or more statistical power, and as economically, as can be done with data collected from boats. Indeed, in the past few years, a growing consensus of marine seabird researchers believe that planes are not suitable for surveying for murrelets for the purpose of tracking population trends. This is reflected by the fact that the draft protocol for surveying for murrelets at sea, which is being developed by a coalition of biologists from academia, the private sector, and state and federal agencies, does not include any provision for surveying from aircraft.

The only other study comparable to ours that we are aware of that addresses the feasibility of surveying for murrelets from aircraft was conducted by Piatt (Piatt 1991, unpubl. data). Like us, he conducted simultaneous air and boat transects; however, his methods differed from ours in that (1) for many transects, the plane did not begin the transect until the boat had completed about half of the transect, (2) the plane flew at a height of 35M, and (3) observers scanned 100M on either side of the plane. Despite these differences, Piatt found similar results to ours, specifically (1) at low murrelet densities, aerial observers saw only 12% to 38% of the murrelets observers by boat observers, (2) the CVs of boat transect in different geographic areas were 53% to 67% of the CVs of aerial transects from the same areas. Thus, even at a lower altitude where murrelets were more visible to aerial observers, aerial murrelet counts were very poorly correlated with simultaneous counts of murrelets from boats. This further supports our view that aerial surveys are not advisable for surveying for murrelets in areas where they occur at relatively low densities for the purpose of monitoring population trends over time.

Literature Cited

Briggs, K.T., W.B. Tyler, and D.B. Lewis. 1985. Comparison of ship and aerial surveys of birds at sea. J. Wildl. Manage. 49:405-411.

Broome, L.S. 1985. Sightability as a factor in aerial survey of bird species and communities. Aust. Wildl. Res. 12:57-67.

Cochran, W.G. 1977. Sampling techniques. 3rd ed. John Wiley and Sons, New York.

King, J.G., and B. Conant. 1982. Comparison of air and surface counts of wintering waterbirds in a southeast Alaska bay. Pacific Seabird Group Bull. 9:73.

Prenzlow, D.M., and J.R. Lovvorn. 1996. Evaluation of visibility correction factors for waterfowl surveys in Wyoming. Journal of Wildlife Management 60:286-297.

Savard, J-P. L. 1982. Variability of waterfowl aerial surveys: observer and air-ground comparisons — a preliminary report. Canadian Wildlife Service Progress Notes 127.

Smith, G.W. 1995. A critical review of the aerial and ground surveys of breeding waterfowl in North America. National Biological Survey, Biological Science Report 5. 252 pp.

Thompson, C.W. 1997. Distribution and abundance of Marbled Murrelets and Common Murres on the outer coast of Washington — 1997 completion report to the *Tenyo Maru* Trustee's Council. Unpubl. Report, Washington Dept. of Fish and Wildlife, Mill Creek, WA

Thompson, C.W. 1997. Distribution and abundance of Marbled Murrelets on the outer coast of Washington. Winter 1996-1997. Unpubl. Report for the Washington Dept. of Natural Resources.

Thompson, C.W. 1999. Distribution and abundance of Marbled Murrelets and Common Murres on the outer coast of Washington — Summer 1997 through winter 1998-1999. Unpubl. report, Washington Dept. of Fish and Wildlife, Mill Creek, WA.

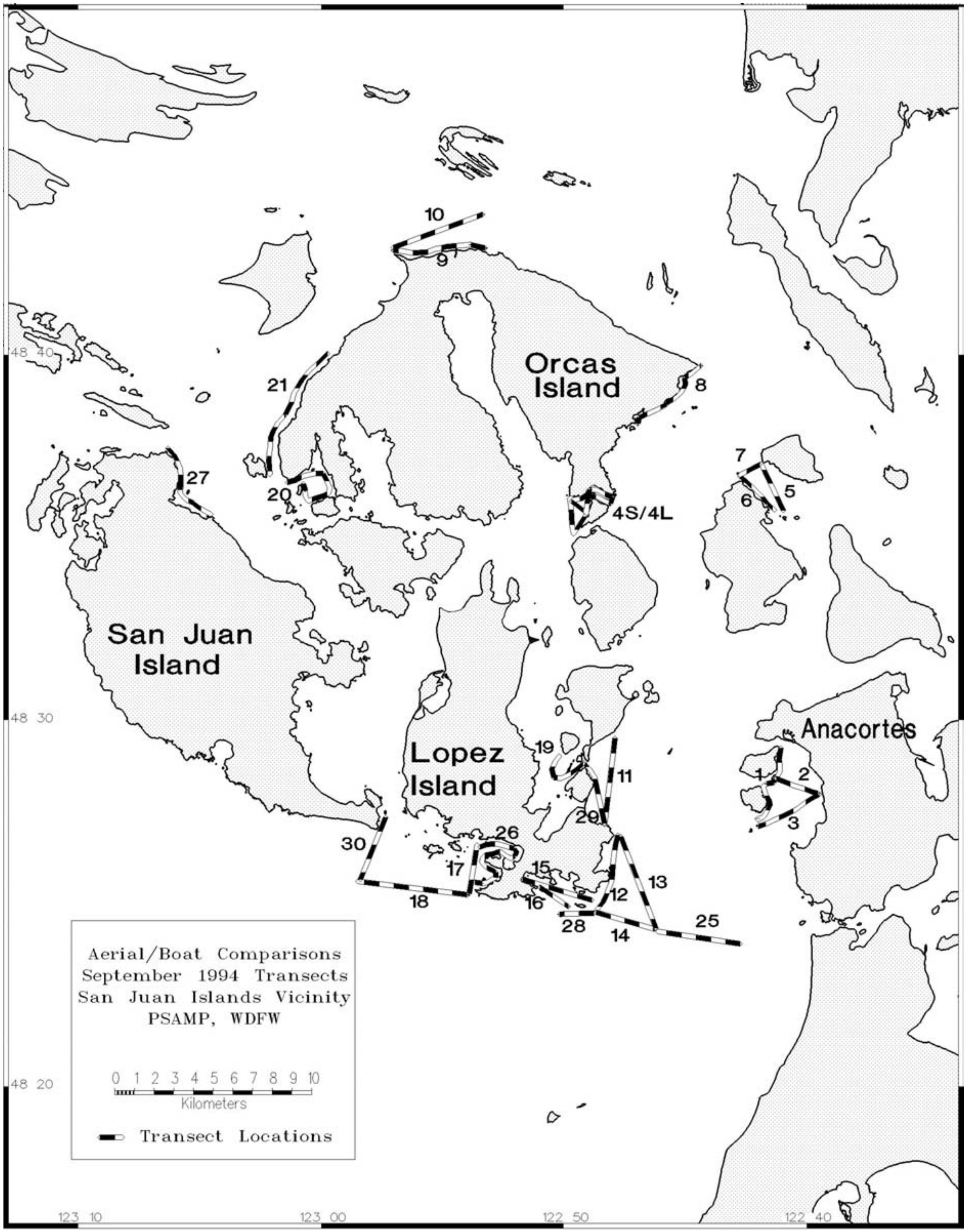

Figure 1. Map of Northern Puget Sound, Washington, indicating the locations of the transects used for surveying for Marbled Murrelets simultaneously from boats and aircraft.

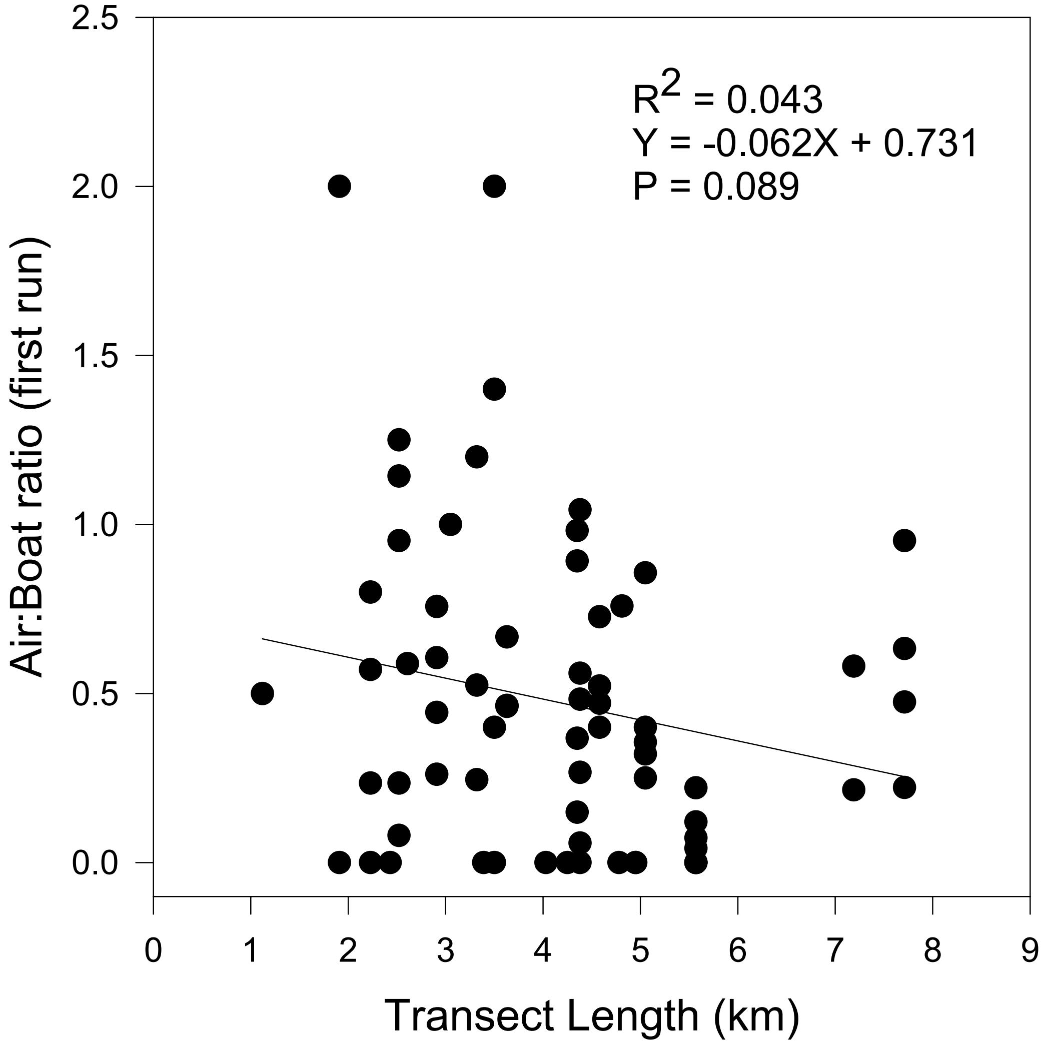

Figure 2. Linear regression of the ratio of murrelets seen from the aircraft during its first run over the transect area versus those seen from the boat in relation to transect length.

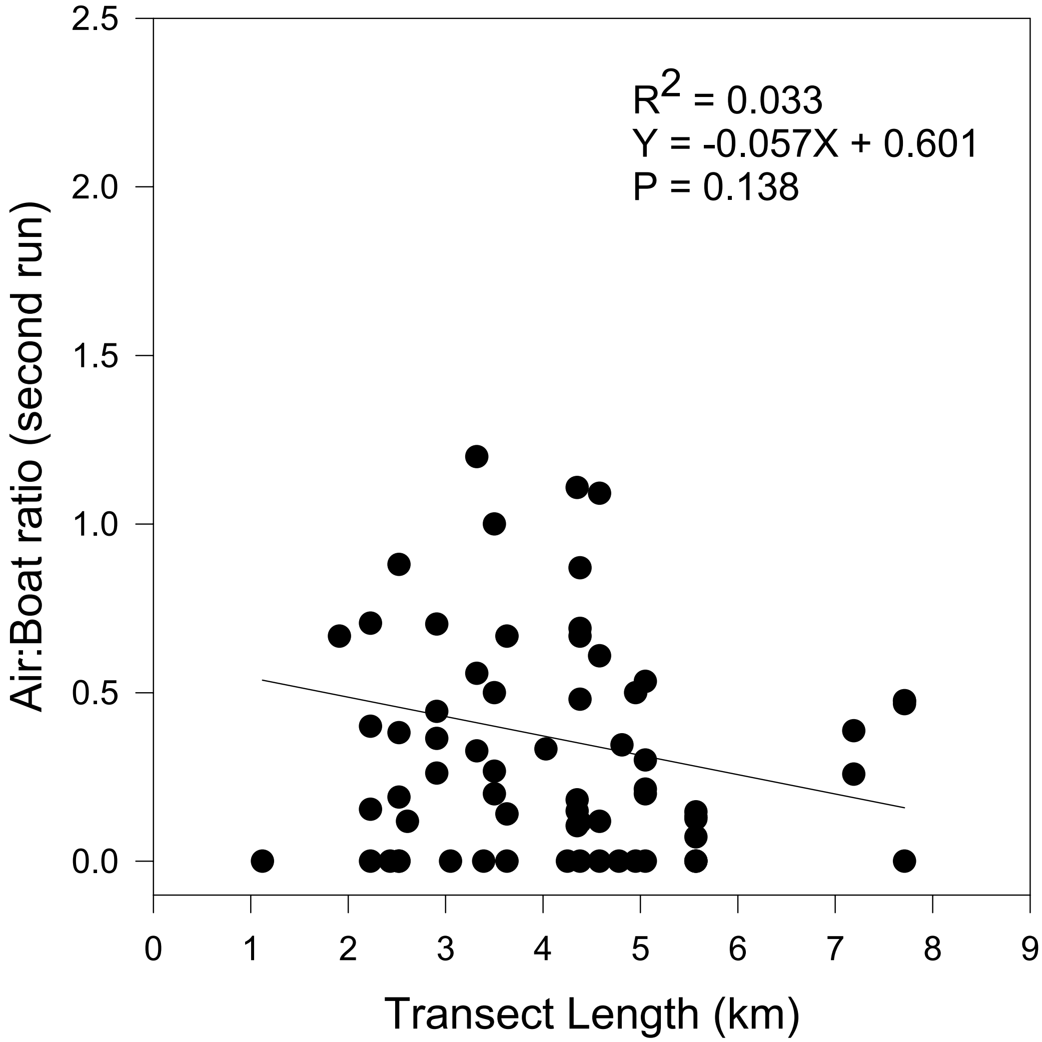

Figure 3. Linear regression of the ratio of murrelets seen from the aircraft during its second run over the transect area versus those seen from the boat in relation to transect length.

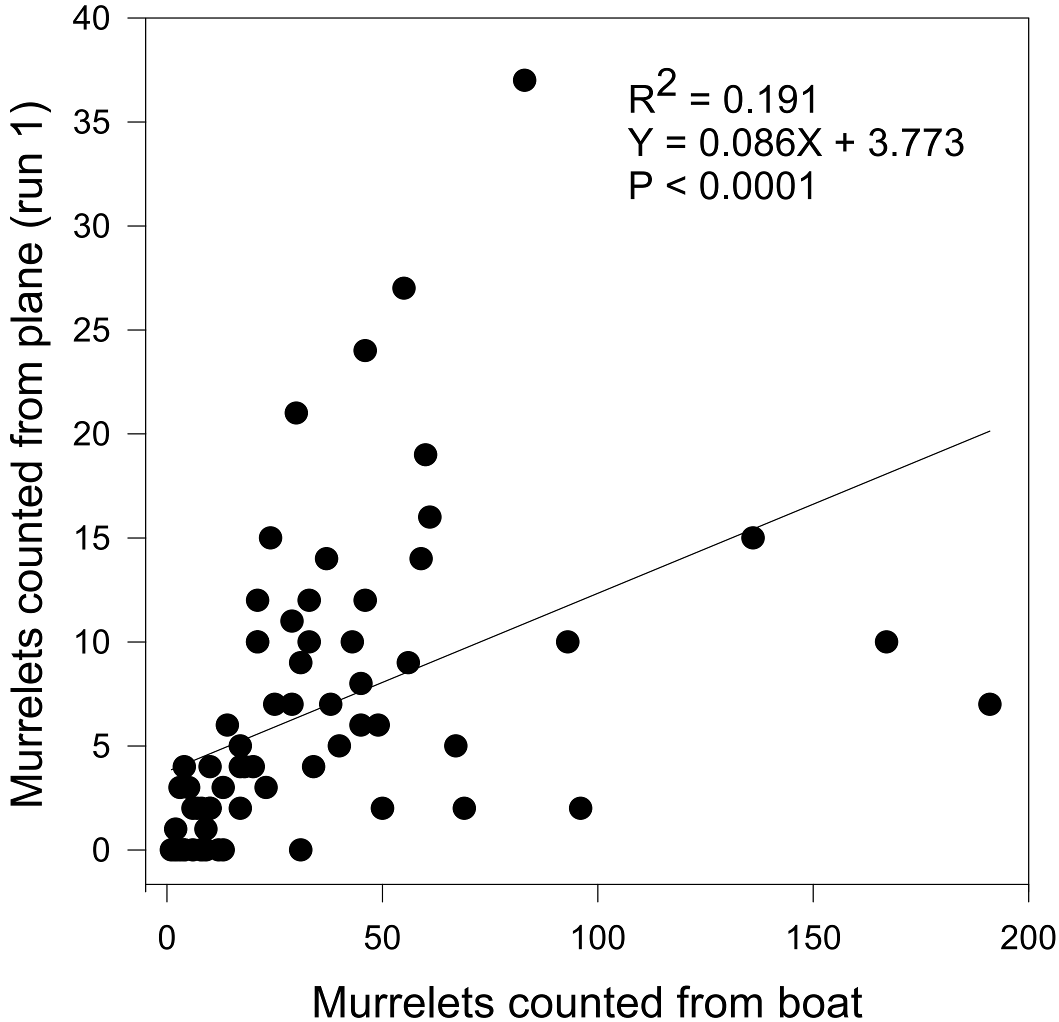

Figure 4. Linear regression of the number of Marbled Murrelets counted from the aircraft during its first run on the number of murrelets counted from the boat.

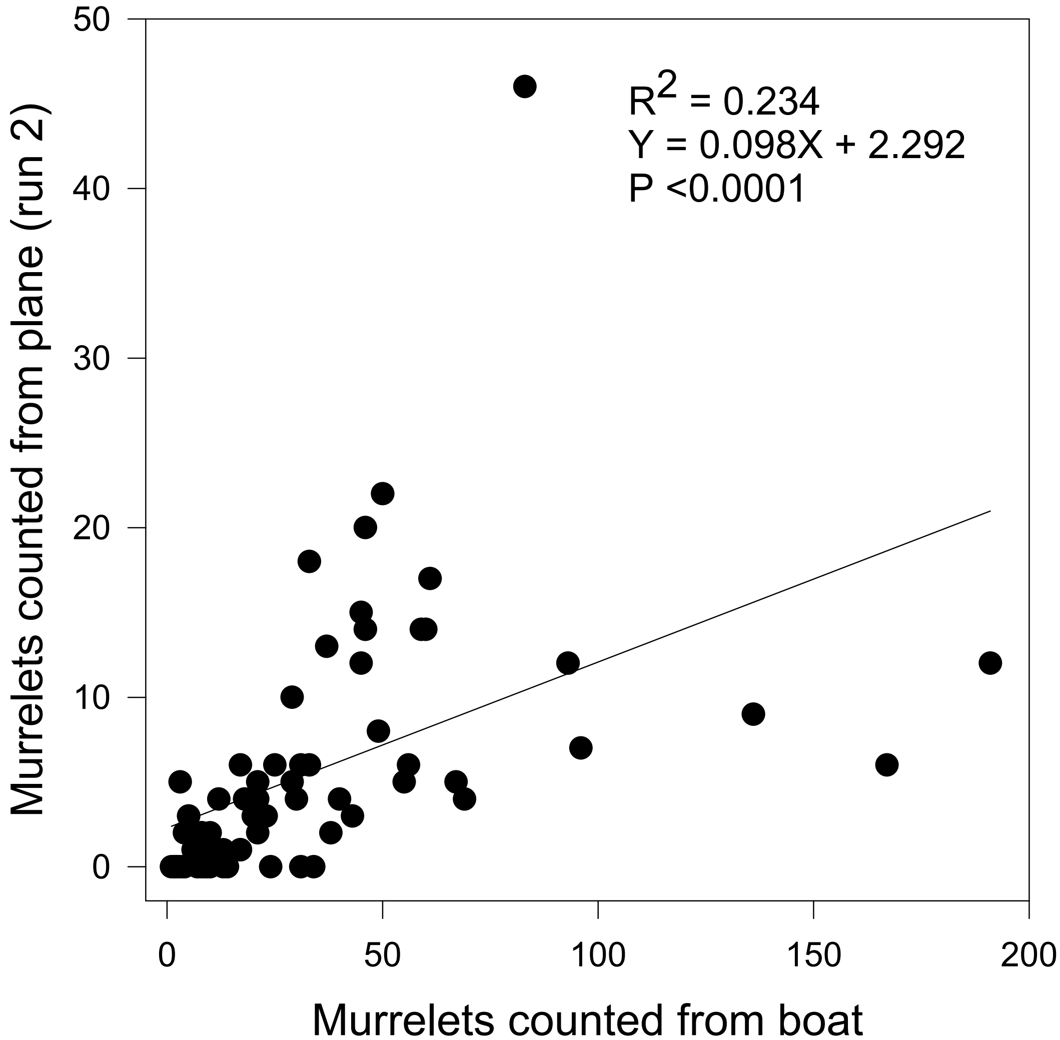

Figure 5. Linear regression of the number of Marbled Murrelets counted from the aircraft during its second run on the number of murrelets counted from the boat.