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OBSERVER VARIABILITY IN PINNIPED COUNTS: GROUND-BASED ENUMERATION OF WALRUSES AT HAUL-OUT SITES

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ABSTRACT

Pinnipeds are often monitored by counting individuals at haul-out sites, but the often large numbers of densely packed individuals at these sites are difficult to enumerate accurately. Errors in enumeration can induce bias and reduce precision in estimates of population size and trend. We used data from paired observers monitoring walrus haul-outs in Bristol Bay, Alaska, to quantify observer variability and assess its relative importance. The probability of a pair of observers making identical counts was <0.1 for walrus groups with >50 individuals. Mean count differences ranged up to 25% for the largest counts, depending on beach and observers. In at least some cases, there was a clear tendency for counts of one observer to be consistently greater than counts of the other observer in a pair, indicating that counts of at least one of the observers were biased. These results suggest that efforts to improve accuracy of counts will be worthwhile. However, we also found that variation among observers was relatively small compared to variation among visits to a beach so that efforts to account for other sources of variation will be more important.

Key words: Pacific walrus, *Odobenus rosmarus*, pinniped, observer error, observer bias, aggregation, group size, terrestrial haul-outs, population monitoring, trend estimation.

Pinniped populations are often monitored by counting individuals at places where they aggregate such as haul-outs or rookeries (Eberhardt *et al.* 1979, Erickson *et al.* 1993). These sites may be on land or ice (Bowen and Siniff 1999) and aggregations may include hundreds or even thousands of individuals (Fay 1982). Animals may be

concealed from observers by other animals in the aggregation or by physical features of the haul-out (Eberhardt *et al.* 1979). One of the most basic problems with monitoring these sites is obtaining accurate counts (Eberhardt *et al.* 1979).

Magnitudes of errors in enumerating groups of animals can be related to the number of individuals in the group (Young and Peace 1999), obstructions that may conceal some individuals for a portion of the observation period (Cogan and Diefenbach 1998, Young and Peace 1999), distance between the observer and the group (Rugh *et al.* 1990), and a variety of other factors (Erwin 1982, Rappoldt *et al.* 1985). Errors may vary among observers because of differences in their training and experience (Erwin 1982), methods used for enumerating or estimating group size (Sauer *et al.* 1994), and intrinsic abilities (Erwin 1982, Rappoldt *et al.* 1985). Errors in enumeration reduce precision of population estimates (Estes and Gilbert 1978) and the ability to detect changes in abundance. These errors can also result in biased estimates of population size or trend (Thomas 1996, Link and Sauer 1997).

There have been few efforts to quantify observer errors in counts of pinnipeds at haul-out sites and the relative importance of these errors is not well understood. Comparisons to photographs suggest that visual counts from aerial surveys of terrestrial haul-outs tend to underestimate numbers of harbor seals (Thompson and Harwood 1990) and walruses (Mansfield and St. Aubin 1991) and that visual estimates are unreliable for larger aggregations. There is some evidence that direct visual estimates by ground-based observers also tend to underestimate numbers of walruses at terrestrial haul-outs (Mansfield and St. Aubin 1991, Gilbert *et al.* 1992[1]). Slip and Burton (1999), however, found observer errors to be relatively small with no consistent bias in ground-based visual counts of southern elephant seals at terrestrial haul-outs.

The walrus population in Bristol Bay, Alaska is monitored with visual counts by ground-based observers at terrestrial haul-out sites where the walruses seasonally aggregate. Some of the most important haul-outs in Bristol Bay are on Round Island,[2] and they have been monitored since 1977.[3] From 1998 to 2001 most of the Round Island counts were conducted by paired observers. These data provide an opportunity to investigate differences between simultaneous, independent counts of hauled-out walrus groups by two different observers. The true numbers of walruses in each group are unknown, so these data cannot be used to directly assess errors in enumeration. However, the differences in paired counts provide information about observer-related variation that affects bias and variance of population estimates.

Three aspects of the variation in counts are important: (1) the proportion of counts that are different, (2) the magnitude of the differences, and (3) whether counts by one observer are consistently greater than those by the other. A consistent direction in the

[1] Gilbert, J., G. Fedoseev, D. Seagars, E. Razlivalov and A. Lachugin. 1992. Aerial census of Pacific walrus, 1990. U.S. Fish and Wildlife Service Administrative Report R7/MMM 92-1 (unpublished). 33 pp. Available from USFWS, Marine Mammals Management, 1011 E. Tudor Rd., Anchorage, AK, 99577.

[2] Frost, K. J., L. F. Lowry and J. J. Burns. 1982. Distribution of marine mammals in the coastal zone of the Bering Sea during summer and autumn. Final Report, Research Unit 613, NOAA Outer Continental Shelf Assessment Program (unpublished). 188 pp. Available on loan from Alaska Resources Library & Information Services, 3211 Providence Drive, Suite 111, Anchorage, AK, 99508.

[3] VanDaele, L., L. Pamplin and D. W. Collinsworth. 1990. Report to the Alaska Board of Game: Status and management of the Walrus Islands State Game Sanctuary. Alaska Department of Fish and Game Report (unpublished). 13 pp. Available from ADFG, Division of Wildlife Conservation, 333 Raspberry Rd., Anchorage, AK 99518.

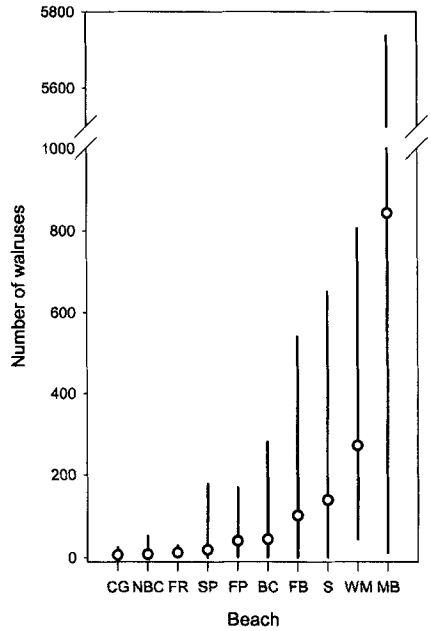

Figure 1. Means and ranges of numbers of hauled-out walruses counted by pairs of observers on beaches at Round Island, Alaska. Statistics are based on 1,265 visits selected according to criteria described in text.

differences indicates counts of at least one of the observers are biased. We estimated parameters related to these aspects of count variation as functions of relevant covariates. We also estimated variance components associated with multiple visits to a beach, multiple observers per visit, and multiple counts per observer per visit.

METHODS

Round Island is a small island (2.9 km^2) located in the far northern portion of Bristol Bay, Alaska, about 20 km from the nearest mainland. It is one of seven islands comprising the Walrus Islands State Game Sanctuary. Counts from the Round Island haul-outs have regularly provided one of the components used for estimating size of the Pacific walrus population (Gilbert 1999).

Ten beaches are used from late spring to late fall by walruses for hauling out. All the beaches are located at the bases of cliffs with varying degrees of accessibility to observers. Estimated numbers of hauled-out walruses vary widely within and among beaches (Fig. 1).

Monitoring

Most beaches have a single standard observation point along the tops of cliffs. However, up to four observation points are used for some beaches because there is no single point that allows an unobstructed view of the entire beach. Viewing distances from observation points to locations on the beaches range from 19 to 1,100 m

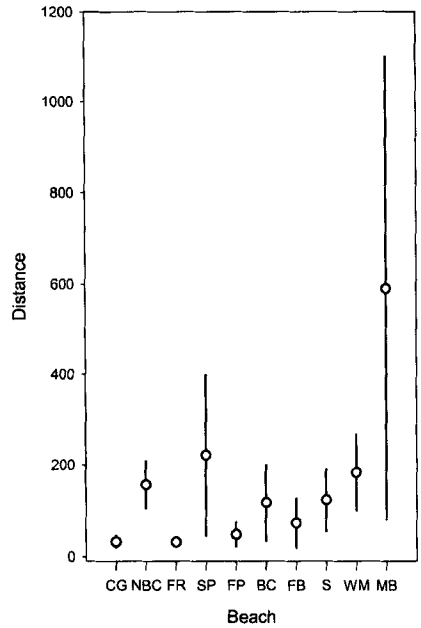

Figure 2. Distances (m) from standard observation points to midpoints of walrus haul-out beaches at Round Island, Alaska. Error bars indicate range of distances from observation points to points on beaches.

(Fig. 2). At all beaches except BC and MB, the observation points are located almost directly above the main part of the beach used for hauling out so the viewing angle to the walruses is usually nearly straight down or only slightly oblique. At BC and MB, the observation points are located across a cove from the portion of beach where walruses usually haul out so the viewing angle is highly oblique.

Accessible haul-out beaches on Round Island were monitored approximately daily from early May through mid-August most years since 1977. During 1998–2001, most counts were made by two observers who independently, but simultaneously, counted the number of walruses hauled out on each beach. Observers did not discuss their counts, except informally, after all counts for a visit to a beach were completed. Beaches were visited in a standard sequence, with a visit to each beach in this sequence comprising a set. Up to three sets of visits were conducted per day. During each visit, observers positioned themselves at standard observation points and usually made at least three replicate counts of walruses on the beach. Smaller groups of walruses were enumerated by counting individuals. Larger groups were usually enumerated by deciding on an appropriate group size (*e.g.*, 2, 5, or 10 walruses), visually estimating the average area occupied by groups of that size, and then counting the number of such areas occupied by walruses. The counting technique used on each occasion was at the discretion of the observer. Observers used 10 × 42 binoculars to aid in counting when deemed necessary. More detail on the monitoring protocol is provided by Cody (2001).[4]

[4] Cody, M. 2001. Round Island field report, 2001. U.S. Fish and Wildlife Service Report (unpublished). 43 pp. Available from USFWS, Marine Mammals Management, 1011 E. Tudor Rd., Anchorage, AK 99507.

Analysis

We began by considering all visits during 1998–2001 with two observers and at least three counts per observer. We calculated the average starting times and numbers of walruses from the first three counts by each observer for each visit. For simplicity in most of what follows, we refer to these averages as the counts and count times. The three counts for each observer were considered separately only in the variance components analysis. For all analyses, we restricted further consideration to those visits where at least one of the counts was >0 and the difference between count times was ≤10 min.

For each visit, we calculated the average count $m_{jk} = (c_{1jk} + c_{2jk})/2$ and the absolute difference between counts $d_{jk} = |c_{1jk} - c_{2jk}|$, where c_{ijk} is the count for the k'th visit by i'th observer in the j'th observer pair. We used the natural log of m_{jk} as an index to represent relative numbers of hauled-out walruses.

We used logistic regression (Hosmer and Lemeshow 2000) to estimate the probability of identical counts for a visit. For each observer pair, we only considered visits to beaches with ≥ 10 visits by that pair. The dependent variable was $y_{jk} = 1$ if $d_{jk} = 0$ and $y_{jk} = 0$ otherwise. We used likelihood ratio tests to assess differences in probabilities relative to observer pairs, beaches, and numbers of hauled-out walruses (log-average-counts), beginning with the fullest estimable model containing all of these effects and their interactions. We removed interactions and then main effects from the model if their likelihood ratio P values were >0.05. We also combined groups of beaches or observer pairs if likelihood ratio tests did not indicate a difference ($P \leq 0.05$). If we retained an interaction term for log-average-count, we set slope parameters to 0 for levels of the interacting variable with likelihood ratio P values >0.05 for the slope parameters. We used the resulting, more parsimonious model to estimate probabilities of identical counts as functions of the relevant variables. All models were fit by maximum likelihood. Variance estimates for the final model were adjusted for overdispersion based on deviance. Confidence intervals were estimated by back-transforming normal theory intervals for the linear predictors.

We also used logistic regression to estimate the conditional probability that the second observer (alphabetically) in a pair would have the highest count for a visit, given the counts were not identical. If there was no consistent tendency for one observer to have higher counts than the other, we would expect the estimated probability to be near 0.5. We used only visits with non-identical counts (*i.e.*, $d_{jk} \neq 0$) and, for each observer pair, we considered only visits to beaches with ≥10 visits by that pair. The dependent variable was $y_{jk} = 1$ if $c_{1jk} - c_{2jk} < 0$ and $y_{jk} = 0$ if $c_{1jk} - c_{2jk} > 0$. We used the same approach for testing and estimation as above except we considered only effects of beaches and log-average-counts nested within observer pairs.

We used generalized linear regression with a log link and gamma errors (McCullagh and Nelder 1989) to estimate the conditional expectation of the absolute difference between counts for a visit, given the counts were not identical. Gamma errors were used because the variance was approximately proportional to square of the mean. Again, we only used visits with non-identical counts and, for each observer pair, only visits to beaches with ≥10 visits by that pair. We used the absolute difference between counts (d_{jk}) as the dependent variable. The general approach for testing and estimation was the same as for the logistic regression models, with observer pair, beach, average count, and interactions of these variables

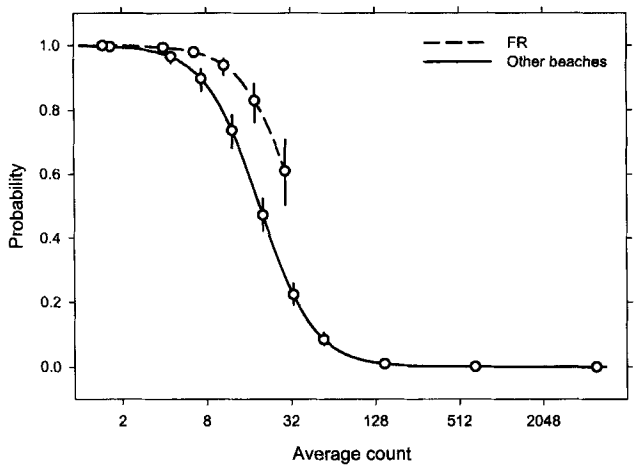

Figure 3. Estimated probabilities of two observers making identical counts of walruses hauled out on beaches at Round Island, Alaska. Probabilities are not plotted beyond the range of observed walrus numbers at specified beaches. Error bars indicate 95% confidence intervals for representative values.

as predictors. Models were fit by maximum likelihood. Confidence intervals were estimated by back-transforming normal theory intervals for the linear predictors.

Finally, we estimated variance components associated with multiple counts per observer, multiple observers per visit, and multiple visits per beach. For this analysis we considered only visits to FR and only observers with ≥ 10 visits. FR was the beach with the highest number of visits and the highest numbers of walruses (Fig. 3). We used the natural log of the individual counts as the dependent variable. Variance components were estimated with maximum likelihood from a mixed model (Littell *et al.* 1996) that included a fixed effect for year and random effects for observers, visits, observer*visit interaction, and counts within observer*visit. We used likelihood ratio tests with $\alpha = 0.05$ to determine whether to include the year effect and the observer*visit interaction in the model. Confidence intervals were estimated with Wald-statistics and Satterthwaite approximated degrees of freedom. Using the estimated variance components, we estimated standard errors of the mean log(count) per year that would result from varying numbers of visits, observers per visit, and counts per observer as $V_1/n_1 + V_2/n_2 + V_3/(n_1\ n_2) + V_4/(n_1\ n_2\ n_3)$, where n_1 and V_1 are the number of visits and the variance among visits, n_2 and V_2 are the number of observers and the variance among observers, V_3 is the variance component for the observer*visit interaction, and n_3 and V_4 are the number of counts and the variance among counts for an observer during a visit.

Results

Counts were the same for both observers in 298 (27%) of the 1,109 visits suitable for consideration. These included visits by five observer pairs at two to nine beaches each. There were not enough suitable visits at beach WM to include in analyses. Probabilities of identical counts were related to the number of hauled-out

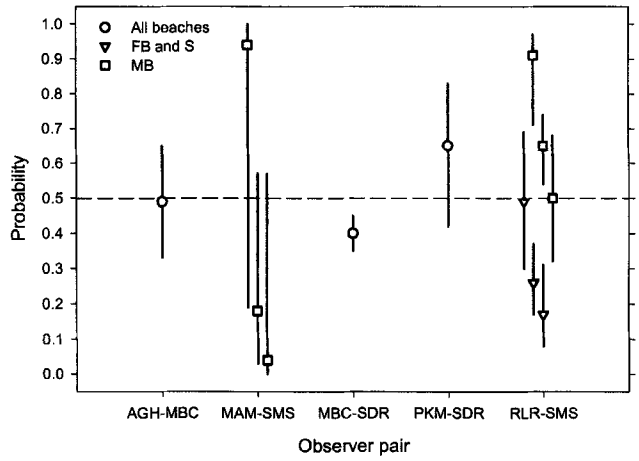

Figure 4. Estimated probabilities of the second observer in a pair having a higher count than the first for groups of hauled-out walruses at beaches on Round Island, Alaska. Beaches considered were FB, MB, and S for AGH-MBC; MB for MAM-SMS; BC, FB, FP, MB, and S for MBC-SDR; FB and MB for PKM-SDR; and FB, MB, and S for RLR-SMS. Sequences of points for a given observer pair and beach represent, from left to right, values corresponding to the minimum, mean, and maximum walrus counts. Error bars indicate 95% confidence intervals.

walruses (log-average-count, $\chi_1^2 = 364.45$, $P < 0.01$) and beach ($\chi_8^2 = 16.51$, $P = 0.04$), but did not differ among observer pairs ($\chi_4^2 = 7.98$, $P = 0.09$). At most beaches, the probability of identical counts was over 0.9 for groups of less than about 8 walruses, but decreased rapidly with increasing group size until the probability was under 0.1 for groups of more than about 50 walruses (Fig. 3). Probabilities of identical counts were slightly higher at beach FR ($\chi_1^2 = 10.87$, $P < 0.01$, Fig. 3), but did not differ among the other beaches ($\chi_7^2 = 5.64$, $P = 0.58$).

Of the 811 visits with differing counts, 762 met the criterion of being at beaches with $\geq$10 visits by an observer pair. These included visits by five observer pairs at one to five beaches each (Fig. 4). Probabilities of the second observer having higher counts were related to the number of hauled-out walruses ($\chi_5^2 = 16.73$, $P = 0.01$) and differences among beaches ($\chi_{13}^2 = 63.01$, $P \leq 0.01$). However, the effect of walrus numbers was only evident for pairs RLR-SMS ($\chi_1^2 = 6.96$, $P = 0.01$) and MAM-SMS ($\chi_1^2 = 5.62$, $P = 0.02$). Beach-related differences were only evident for RLR-SMS ($\chi_2^2 = 37.36$, $P < 0.01$). The probability of observer SDR having higher counts than MBC was <0.50 at all beaches (Fig. 4). The probability of observer SMS having higher counts than RLR increased above 0.50 at MB as the numbers of walruses decreased, but decreased below 0.5 at other beaches as numbers of walruses increased (Fig. 4). Confidence intervals for estimated probabilities of the second observer having the highest count included 0.50 for the other three observer pairs. Sample sizes were much smaller for these pairs (visits $\leq$ 41 per pair) than for MBC-SDR (478 visits) or RLR-SMS (204 visits), and confidence intervals were correspondingly wider (Fig. 4).

Magnitudes of count differences increased with numbers of hauled-out walruses ($\chi_1^2 = 275.50$, $P < 0.01$), but were smaller for MBC-SDR than for other observer

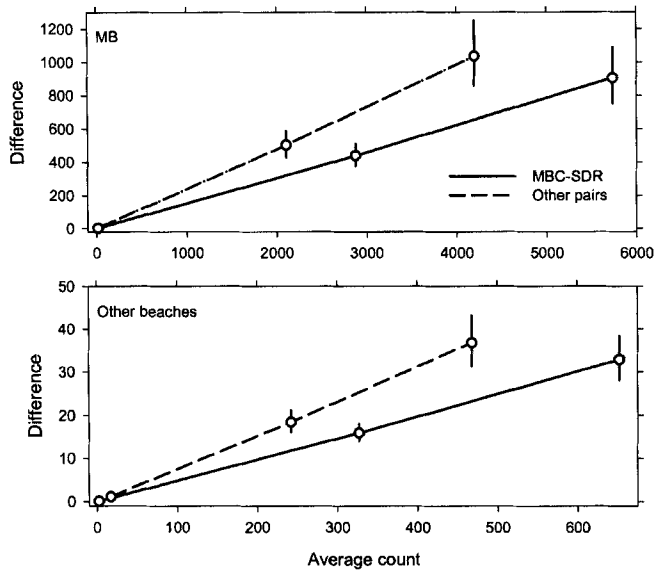

Figure 5. Estimated absolute differences between counts by two observers for groups of hauled-out walruses at beaches on Round Island, Alaska. Differences are plotted only over the range of observed walrus numbers at each group of beaches. Error bars indicate 95% confidence intervals for representative values.

pairs ($\chi_1^2 = 19.84$, $P < 0.01$) and were larger at MB than at other beaches ($\chi_1^2 = 69.82$, $P < 0.01$, Fig. 5). We did not detect any differences in these magnitudes among other observer pairs ($\chi_3^2 = 1.73$, $P = 0.63$) or beaches ($\chi_3^2 = 4.93$, $P = 0.18$). Although there were no interactions on the scale of the analysis ($\chi_{18}^2 = 12.64$, $P = 0.81$), effects of observer pair and beach manifested primarily as differences in effects of increasing walruses numbers on the original scale of measurement (Fig. 5).

For estimating variance components, we used data from 386 visits, each made by two of seven observers to beach MB. Estimated components were 0.78 (95% CI = 0.68, 0.90) for variance among visits, 0.0017 (95% CI = 0.0005, 0.0412) for variance among observers, 0.022 (95% CI = 0.019, 0.026) for the observer*visit interaction, and 0.0082 (95% CI = 0.0077, 0.0089) for variance among counts by an observer during a visit. Based on these estimates, the number of observers had a substantially larger effect than the number of counts per observer on the standard error of the mean count per year (Fig. 6). However, effects of varying numbers of observers and counts per observer were both small relative to the effect of varying numbers of visits (Fig. 6).

Discussion

Differences Between Counts

Differences in counts of hauled-out walruses made by paired observers were frequent and often large, and certain observers tended to make consistently higher

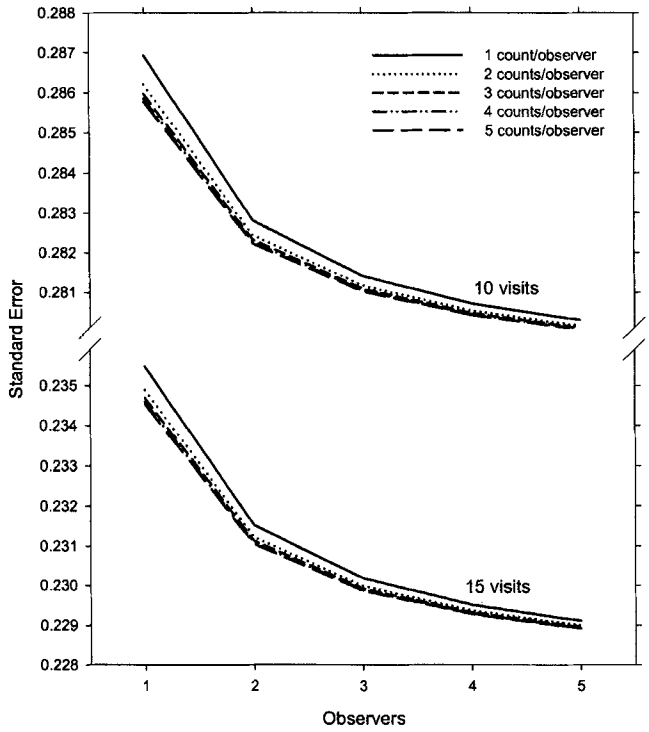

Figure 6. Standard errors of the estimated mean number of hauled-out walruses per visit as a function of number of visits, number of observers per visit, and number of counts per observer for beach MB on Round Island, Alaska.

counts than others. There were few cases where there was any difference between counts for visits with average counts of less than about 10 walruses, and these counts are likely to be quite accurate. However, as the numbers of hauled-out walruses increased beyond this level, the frequency of discrepancies also rapidly increased (Fig. 3), and the accuracy of counts becomes more doubtful. In at least some cases, there was a clear tendency for counts of one observer to be consistently higher than counts of the other observer in a pair (Fig. 4), indicating that counts of at least one of the observers were biased. Moreover, the magnitudes of the differences were substantial, ranging up to 25% for the largest counts of hauled-out walruses (Fig. 5). The biases in counts of individual observers were reflected in a variance among counts by different observers that was substantially larger than the variance among counts by a single observer (Fig. 6). We had no information about the true numbers of hauled-out walruses in our study, but limited comparisons of ground-based counts to aerial photographs at Round Island[5] and in Hudson Bay (Mansfield and St. Aubin 1991) have suggested that ground-based counts tend to underestimate the number of walruses present.

[5] Gilbert, J., G. Fedoseev, D. Seagars, E. Razlivalov and A. Lachugin. 1992. Aerial census of Pacific walrus, 1990. U.S. Fish and Wildlife Service Administrative Report R7/MMM 92-1 (unpublished). 33 pp. Available from USFWS, Marine Mammals Management, 1011 E. Tudor Rd., Anchorage, AK, 99577.

Factors Affecting Differences

Differences in counts depended on the beach where the counts were made and on the number of hauled-out walruses, though these effects were somewhat confounded because some beaches tended to be associated with consistently higher numbers of walruses (Fig. 1). Group size is one of the most widely recognized factors affecting errors in enumerating groups of animals (Erwin 1982, Thompson and Harwood 1990, Mansfield and St. Aubin 1991, Young and Peace 1999). Beach effects may be related at least partially to differences in viewing distances (Rugh *et al.* 1990), and presence of obstructions (Mansfield and St. Aubin 1991, Cogan and Diefenbach 1998). Beaches also differed in their viewing angles, with more oblique angles increasing the potential for some walruses to be concealed by others in the group. The largest differences between paired counts were at MB (Fig. 5), the beach with the largest viewing distance (Fig. 1), most oblique viewing angle, and largest numbers of walruses. The highest probabilities of identical counts were at FR (Fig. 3). This beach consists of a single flat rock that is viewed from a relatively short distance (Fig. 2) from almost directly above and has relatively low numbers of walruses (Fig. 1).

Observer experience may also be a factor affecting differences in counts (Erwin 1982). MBC and SDR were the most experienced of the observer pairs, serving as the primary observers for three of the four years considered here. All other observers had ≤ 1 yr experience. The paired counts by MBC and SDR had the smallest differences (Fig. 5) and among the lowest probabilities of consistent differences (Fig. 4) of all the observer pairs.

Implications for Monitoring

Counting errors can have a substantial effect on bias and variability of population and trend estimates (Estes and Gilbert 1978, Thomas 1996, Link and Sauer 1997). The effects of these errors will be most important at haul-outs where the errors occur most frequently and are largest. Our results suggest these will tend to be haul-outs with the highest numbers of animals, the largest viewing distances, and the most oblique viewing angles. Haul-outs such as MB, where unfavorable viewing conditions combine with large numbers of animals, have the most potential to impact regional counts.

Analysis of variance components suggests that additional counts per observer would do little to reduce variability of estimated numbers on haul-outs (Fig. 6). In any case, based on these results, we would not recommend more than three counts per observer. Increasing the number of observers would be more effective in reducing variability, but would also be more expensive. It may be possible to reduce this source of variation more cost effectively with additional standardization of counting techniques and training of observers (Kepler and Scott 1981, Erwin 1982).

It may also be possible to use technologies such as digital photography or other imagery to reduce bias and increase precision of the counts. Photography has been generally recommended for counting large pinniped aggregations at haul-outs (Eberhardt *et al.* 1979, Erickson *et al.* 1993). Aerial photography has been widely used for counting haul-out aggregations of such species as harp seals (Myers and Bowen 1989), Steller sea lions (Snyder *et al.* 2001, Calkins *et al.* 1999), and harbor seals (Thompson and Harwood 1990, Frost *et al.* 1999). Ground-based photography has not been as effective (Mansfield and St. Aubin 1991). Vertical format aerial

photography may be the most accurate technique for enumerating most walrus haul-outs in Bristol Bay (Fay *et al.* 1997, Gilbert 1999), but it may be more cost effective to make optimal use of ground-based personnel who are already stationed at many of these sites throughout most of the haul-out season for other purposes.[6,7] Fay *et al.* (1997) recommended aerial photography with ground-based calibration for estimating numbers at these haul-outs.

Although it may be possible to reduce variation due to observer error, it should be emphasized that variation among counts per observer and among observers was relatively small compared to variation among visits to a beach (Fig. 6). Additional factors affecting variation among visits are likely to include a variety of environmental effects such as disturbance, weather, tidal state, and time-of-day (Fay and Ray 1968, Salter 1979, Mansfield and St. Aubin 1991). Effective use of haul-out monitoring data requires an understanding of how these factors relate to haul-out behavior (Richard and Campbell 1988). Such an understanding can provide a basis for developing models to adjust for effects of environmental covariates (Erickson *et al.* 1989, Calkins *et al.* 1999, Frost *et al.* 1999).

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