APPENDIX
MODELING POPULATION TREND IN KITTLITZ'S MURRELET

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DATA

Data for these analyses were estimates of population size and their standard errors for the months of March (Table 1) and July (Table 2) in Prince William Sound, as well as estimates of population density and their standard errors in Glacier Bay (Table 3). Note that standard errors were obtained from the 95% confidence intervals provided to us using SE = CI/1.96.

Table 1. Population estimates (Est) and standard errors (SE) for March in Prince William Sound.

	Kittlitz's Murrelets		Marbled Murrelets		Unidentified Birds	
Year	Est	SE	Est	SE	Est	SE
1972	346	335	11567	1231	0	0
1973	3219	1953	72675	12964	0	0
1990	958	816	13764	3030	11379	3585
1991	466	203	7717	2344	15328	3718
1993	448	166	7360	2087	6176	1667
1994	0	0	23260	7930	13058	2535
1996	181	121	25801	4608	18351	3447
1998	78	49	29147	5810	4621	1416
2000	0	0	17570	5411	5874	1076

Table 2. Population estimates (Est) and standard errors (SE) for July in Prince William Sound.

	Kittlitz's Murrelets		Marbled Murrelets		Unidentified Birds	
Year	Est	SE	Est	SE	Est	SE
1972	63229	40879	236633	26391	4570	4018
1989	6436	1608	59284	6033	41634	4194
1990	5231	4315	39486	5095	36624	4036
1991	1184	572	42477	4669	62816	7149
1993	2710	685	14177	2295	142546	21365
1996	1280	696	63455	8185	17429	3056
1998	279	98	49879	4818	3036	1089
2000	1033	683	52377	7383	1077	519

Table 3. Estimates of population density (Est) and standard errors (SE) in Glacier Bay.

	Kittlitz's Murrelets		Marbled Murrelets		Unidentified Birds	
Year	Est	SE	Est	SE	Est	SE
1991	5.04	0.97	31.17	3.96	19.74	3.53
1999	1.01	0.28	13.01	1.88	5.54	0.92
2000	0.99	0.31	3.44	0.65	5.08	0.70

METHODS

In the main part of this report a model is proposed for determining population trends in Kittlitz's Murrelets (KIMU) and Marbled Murrelets (MAMU). This model accounts for the unidentified birds, and assumes that the probability of being identified is the same for both species but differs from year to year. The model also assumes that KIMU and MAMU have different but constant trends over time. Let N_K and N_M represent the unknown numbers or densities of KIMU and MAMU, respectively, in the starting year, t_0. The symbols K_t, M_t, and U_t are the estimates of KIMU, MAMU, and unidentified birds, respectively, in year t. Let θ_K and θ_M represent the annual population trend for KIMU and MAMU, respectively, let γ_t be the probability that a bird will be identified in year t, and let E_{Kt}, E_{Mt}, and E_{Ut} represent sampling error terms. The model is then

$$K_t = N_K \theta_K^{t-t_0} \gamma_t + E_{K_t}$$

$$M_t = N_M \theta_M^{t-t_0} \gamma_t + E_{M_t}$$

and

$$U_t = \left(N_K \theta_K^{t-t_0} + N_M \theta_M^{t-t_0}\right)\left(1-\gamma_t\right) + E_{U_t}$$

We estimated the parameters in this model through a weighted least squares nonlinear regression. Let $t_0,\ldots t_n$ represent the years of available estimates, the unknown parameter vector be denoted by $\Theta = [N_K, N_M, \theta_K, \theta_M, \gamma_{t0},\ldots,\gamma_{tn}]$, the expected population size be represented by $f(\Theta)$, and let Y_t and V_t represent the population estimate and its variance, respectively, for all birds. Least squares regression seeks the best estimate of Θ, denoted $\hat{\boldsymbol{\Theta}}$, such that

$$Q = \sum_t \left\{\left[Y_t - f\left(\hat{\boldsymbol{\Theta}}\right)\right] / V_t\right\}^2$$

is minimized.

We obtained estimates of the variance of $\hat{\boldsymbol{\Theta}}$ via simulation. We assumed that population sizes or densities for all three groups of birds (KIMU, MAMU, and unidentified) were lognormally distributed with means and variances given by the estimates in Tables 1-3. Population sizes or densities were generated for each group of birds and then parameters were estimated using nonlinear regression. Empirical variances were obtained from the set of all parameter estimates. Each simulation based on an original dataset entailed 5000 iterations, though the nonlinear optimization routine failed to converge occasionally, but always less than 3% of the iterations.

The data from Prince William Sound in March (Table 1) were problematic because of the presence of zero standard errors. In principle, estimated mean sizes of zero are not a problem, but as the formula for weighted regression shows above, the minimization criterion Q is undefined for zero variance. Therefore, our analysis of the March data is based only on the years 1990, 1991, 1993, 1996, and 1998. A more complicated analysis might be possible (e.g., substitution of small non-zero values for the offending standard errors), but due to time constraints we chose the more straightforward approach. The consequence of excluding 4 of 9 years with very low estimates is likely an upward bias in the trend estimates.

We analyzed three subsets of the data from Prince William Sound in July (Table 2): (1) including all years; (2) excluding 1972; and, (3) excluding both 1972 and 1993. Note that the estimates for population size and its standard error for KIMU were both unusually large in 1972, while in 1993, the estimated number of unidentified birds was extremely large.

All analyses were conducted in Matlab 6.0.

RESULTS

Parameter estimates for initial population sizes (N_K and N_M) were somewhat sensitive to initial guesses used in the nonlinear optimization. However, estimates for all other parameters were quite stable, irrespective of initial guesses. For results reported here, we used "reasonable" initial guesses based on available information. Initial values for N_K and N_M were taken from estimated sizes or densities in year t_0 (Tables 1-3). In all simulations, the other initial values were $\theta_K = \theta_M = 1$, and $\gamma_t = (K_t + M_t)/(K_t + M_t + U_t)$. Initial values for θ_K and θ_M represent stable populations, and the initial values for γ_t values are the observed proportions of identified birds. Means and standard deviations of parameter estimates from the simulations are shown in Tables 4-8.

The parameter estimates suggest that KIMU is declining ($\theta < 1.0$) in both seasons and in both locations. Furthermore, MAMU is declining in most cases; the exception is Prince William Sound in March (Table 4), where $\theta_M = 1.1172$ (an increase of 11.72% per year). In general, the estimated rate of decline is much greater for KIMU than for MAMU except at Glacier Bay (Table 8) where the trends are very similar. Using all data from Prince William Sound in July (Table 5), the estimate of θ_K is 0.8186 (a decline of 18.14% per year). Excluding data from 1972 (Table 6) or both 1972 and 1993 (Table 7) results in even lower estimates of 0.6898 and 0.6844, respectively (declines of 31.02% 31.56% per year). The estimates of θ_M and γ_t (for those years in common) are strikingly similar in all three cases, though, of course, the estimates of both N_K and N_M differ substantially, depending on the starting year.

Table 4. Parameter estimates for the model of population trend for Prince William Sound in March. Means and standard deviations are from the simulation of lognormally distributed populations, based on 4892 iterations.

Parameter	Mean	Standard Deviation
N_K	2254	1139
N_M	15031	2682
θ_K	0.6857	0.0632
θ_M	1.1172	0.0398
γ_{1990}	0.6119	0.1439
γ_{1991}	0.3510	0.1062
γ_{1993}	0.5838	0.0587
γ_{1996}	0.5656	0.0945
γ_{1998}	0.8653	0.0402

Table 5. Parameter estimates for the model of population trend for Prince William Sound in July, using data from all 8 years. Means and standard deviations are from the simulation of lognormally distributed populations, based on 4950 iterations.

Parameter	Mean	Standard Deviation
N_K	79179	29467
N_M	236102	16788
θ_K	0.8186	0.0107
θ_M	0.9486	0.0036
γ_{1972}	0.9855	0.0127
γ_{1989}	0.5968	0.0351
γ_{1990}	0.5421	0.0347
γ_{1991}	0.4329	0.0443
γ_{1993}	0.1754	0.0300
γ_{1996}	0.7681	0.0425
γ_{1998}	0.9426	0.0147
γ_{2000}	0.9800	0.0099

Table 6. Parameter estimates for the model of population trend for Prince William Sound in July, using data from 7 years (excluding 1972). Means and standard deviations are from the simulation of lognormally distributed populations, based on 4999 iterations.

Parameter	Mean	Standard Deviation
N_K	9446	2242
N_M	94223	4778
θ_K	0.6898	0.0307
θ_M	0.9499	0.0085
γ_{1989}	0.6096	0.0340
γ_{1990}	0.5558	0.0340
γ_{1991}	0.4161	0.0450
γ_{1993}	0.1828	0.0312
γ_{1996}	0.7663	0.0454
γ_{1998}	0.9436	0.0175
γ_{2000}	0.9799	0.0097

Table 7. Parameter estimates for the model of population trend for Prince William Sound in July, using data from 6 years (excluding 1972 and 1993). Means and standard deviations are from the simulation of lognormally distributed populations, based on 5000 iterations.

Parameter	Mean	Standard Deviation
N_K	9080	2380
N_M	93222	4922
θ_K	0.6844	0.0368
θ_M	0.9492	0.0090
γ_{1989}	0.6083	0.0342
γ_{1990}	0.5548	0.0348
γ_{1991}	0.4225	0.0464
γ_{1996}	0.7644	0.0437
γ_{1998}	0.9433	0.0179
γ_{2000}	0.9794	0.0099

Table 8. Parameter estimates for the model of population trend for Glacier Bay. Means and standard deviations are from the simulation of lognormally distributed populations, based on 5000 iterations. N_K and N_M represent densities.

Parameter	Mean	Standard Deviation
N_K	7.76	1.57
N_M	49.26	5.22
θ_K	0.8334	0.0312
θ_M	0.8298	0.0134
γ_{1991}	0.6469	0.0465
γ_{1999}	0.6438	0.0688
γ_{2000}	0.4650	0.0483

Figure 1 shows the estimated and predicted population sizes for all three groups of birds for Prince William Sound in March. Particularly for KIMU, the model appears to fit the estimates reasonably well. Similarly, Figure 2 shows population sizes for Prince William Sound in July, using data for all years. Predicted population sizes for KIMU change when questionable data are excluded (compare Figure 2a to Figures 3 and 4). Omitting the problematic years leads to smaller residuals (estimated−predicted) in 1989 and 1990, but a larger residual in 2000. However, whether only 1972 or both 1972 and 1993 are excluded makes little difference in predicted population size for the years in common (compare Figure 3 to Figure 4). In general, the Figures 2-4 demonstrate that the model provides a reasonable fit to the population estimates. Though only three years of data were available for Glacier Bay, the model appears to provide a good fit to the data (Figure 5).

Considering the results for for Prince William Sound in July and assuming an initial (1972) population of 79179 as estimated in Table 5, the estimate of θ_K leads to a predicted population of 291 in 2000, and the predicted population in 2025 is less than 2. On the other hand, starting with the 1989 estimate of 9080 and $\theta_K = 0.6844$ (Table 7) yields a predicted population of only 140 in 2000. By 2012 the predicted population is less than 2. Of course, any prediction of extinction or quasi-extinction must be qualified by the unrealistic assumption of a constant rate of change in population size, and by the uncertainty in the population estimates.

In Glacier Bay the estimate of θ_K is 0.8334. In this case the original estimates are densities (birds per km^2) rather than population sizes. However, the implication of the estimated trend can be assessed by the fact that it implies that the population density in 2026 is predicted to be less than 1% of the density in 2000, and less than 0.1% of the 2000 density by the year 2039.

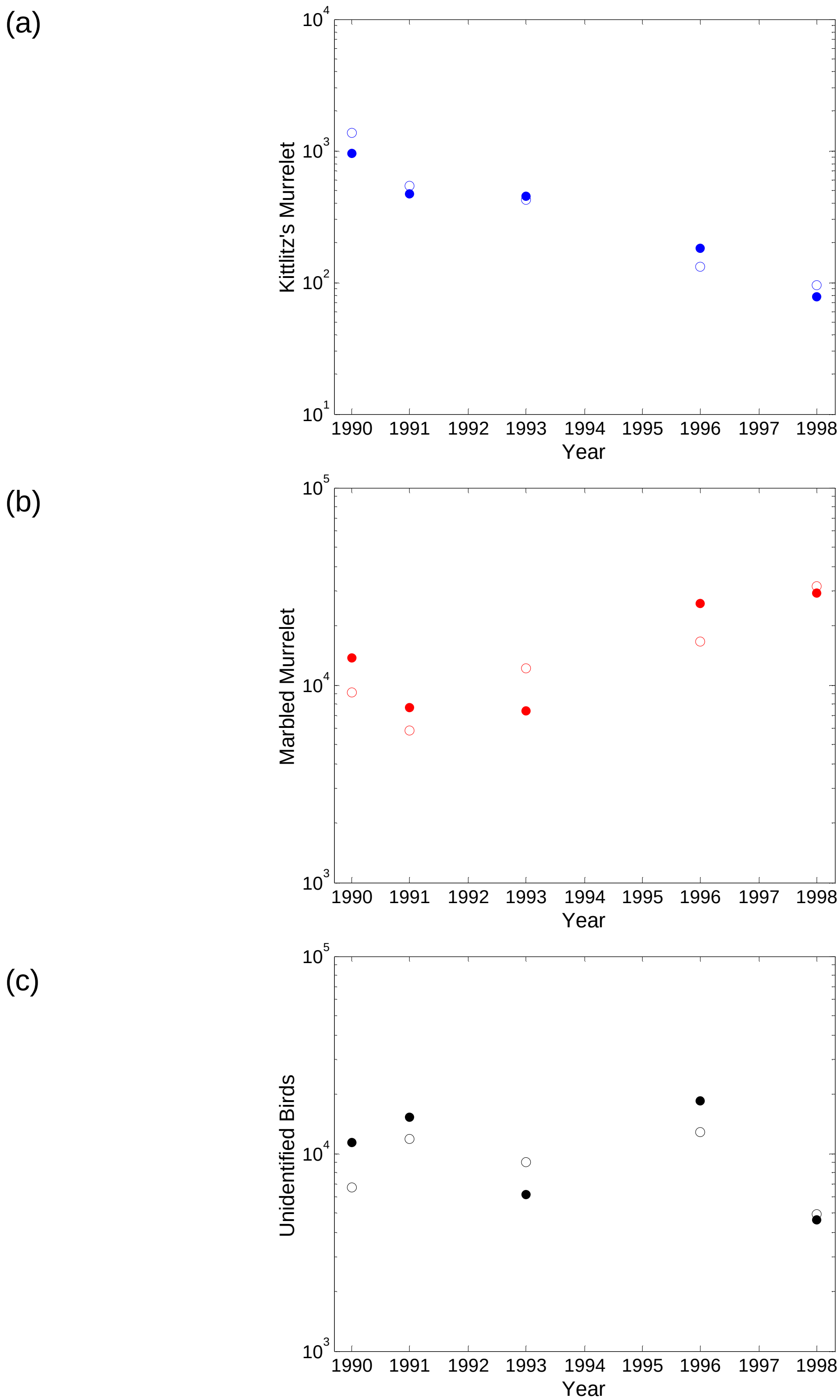

Figure 1. Population sizes of (a) Kittlitz's Murrelet, (b) Marbled Murrelet, and (c) unidentified birds for Prince William Sound in March, excluding data from 1972, 1973, 1994, and 2000. Closed circles represent estimated size and open circles represent size predicted from the nonlinear regression model.

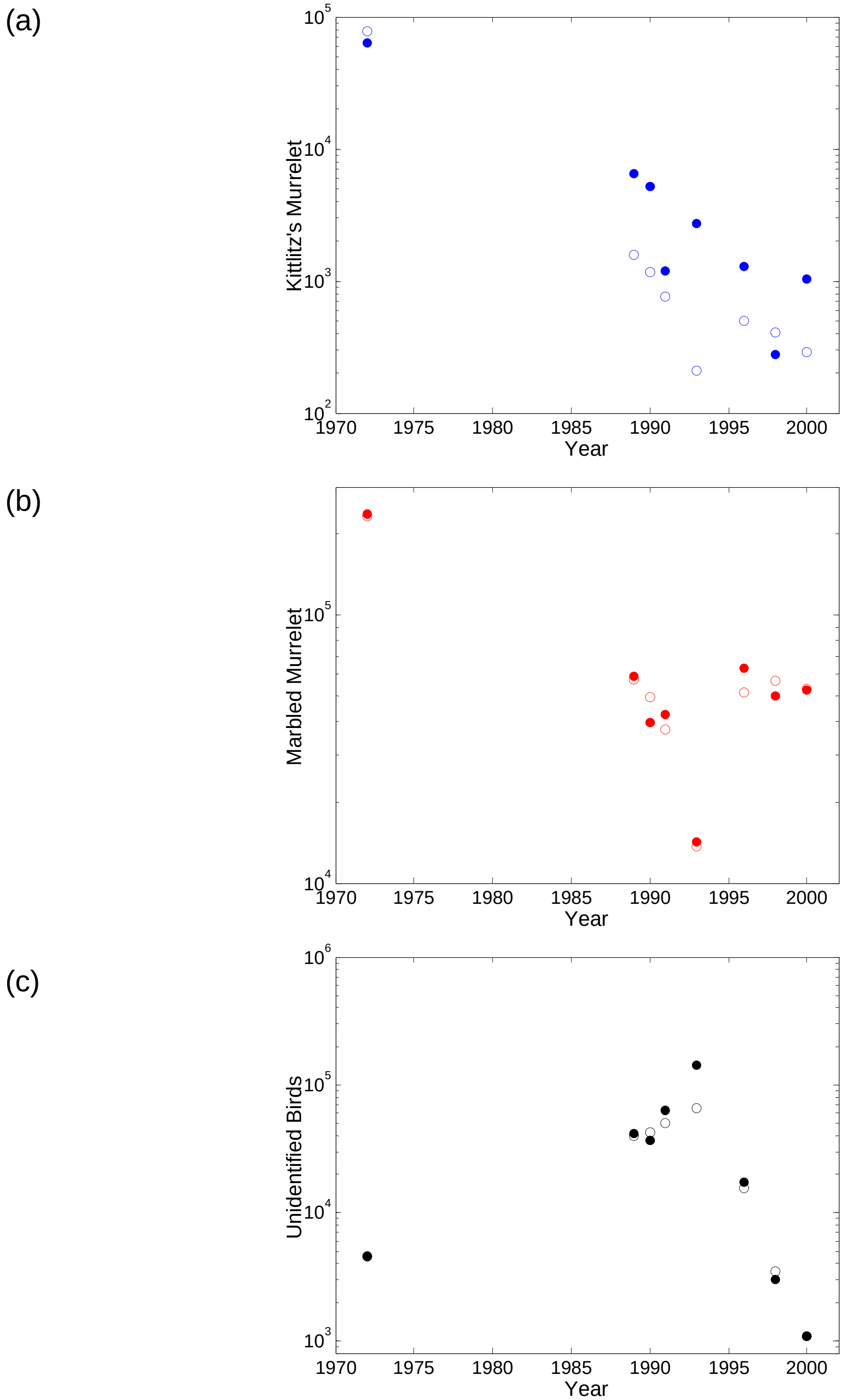

Figure 2. Population sizes of (a) Kittlitz's Murrelet, (b) Marbled Murrelet, and (c) unidentified birds for Prince William Sound in July, using data from all years. Closed circles represent estimated size and open circles represent size predicted from the nonlinear regression model.

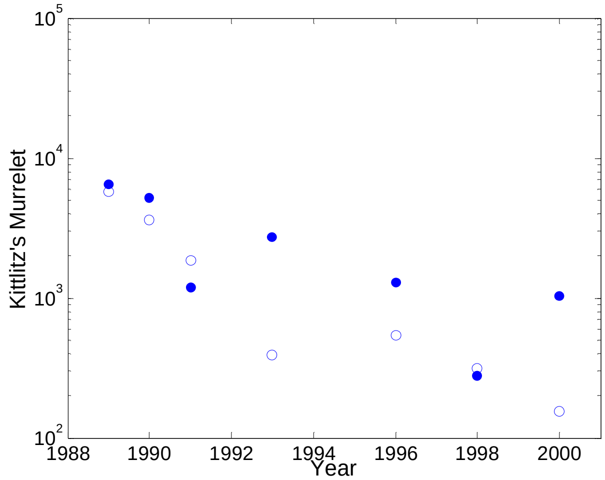

Figure 3. Population sizes of Kittlitz's Murrelet for Prince William Sound in July, excluding data from 1972. Closed circles represent estimated size and open circles represent size predicted from nonlinear regression.

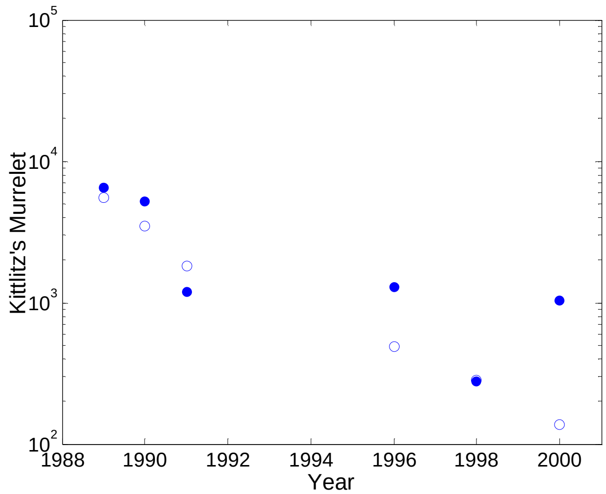

Figure 4. Population sizes of Kittlitz's Murrelet for Prince William Sound in July, excluding data from 1972 and 1993. Closed circles represent estimated size and open circles represent size predicted from nonlinear regression.

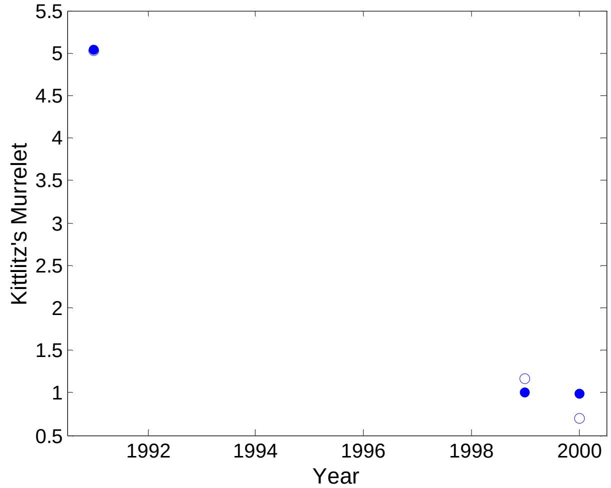

Figure 5. Population densities of Kittlitz's Murrelet for Glacier Bay. Closed circles represent estimated size and open circles represent size predicted from nonlinear regression.