SAMPLE SIZE ESTIMATES

A Preliminary Analysis of Sample Sizes Required for Mark-Recovery and Mark-Resighting Studies of Manatees (Trichechus manatus) in Florida

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RECOMMENDATIONS

1. Estimation of survival rates by means of tags recovered from carcasses should be a long-term (10 years) project. The estimate obtained would be a mean annual rate for the duration of the study. The sample sizes required to obtain yearly survival rate estimates (in contrast to a mean rate) with the desired precision would be too high to be feasible. About 40 to 210 manatees would need to be marked annually under a 10-year program to obtain a mean survival rate with a coefficient of variation of 0.05. A shorter program would require a larger sample size to achieve the same level of precision. If a lower level of precision is acceptable, additional analysis would be needed to estimate sample size. However, a lower level of precision is not recommended.

2. Prior to the planning of mark-resighting studies, better estimates of rates of emigration and sighting are needed. If emigration is high and probability of sighting is low, an unreasonable number of manatees would need to be marked to obtain estimates with the desired coefficient of variation. Under conditions of low emigration and high sighting probability, about 20 to 30 manatees would need to be captured during each of five periods for Jolly-Seber estimates of manatee abundance and survival at a warm-water refuge. Under similar favorable conditions, about 35 to 40 manatees would need to be marked at the beginning of the season if marking occurred during only one capture period.

3. Due to the relatively high numbers of animals that would need to be marked at warm-water refuges, the possibility of using natural scar patterns as marks needs to be further examined. However, since not all animals can be identified in this manner, it would involve some changes in assumptions and definitions of variables in the models currently used. Appropriate models should be developed to approximate sample sizes required for mark-resighting studies based on scar patterns.

INTRODUCTION

Approximate sample sizes that would be required to estimate abundance and survival rates are needed to plan mark-recovery studies of manatees (Trichechus manatus) in Florida (Eberhardt 1982). Computer programs that have been developed to estimate sample sizes required for waterfowl studies are generally applicable to this question. Using these programs, sample sizes have been estimated for three potential research projects: (a) estimates of annual survival rates based on recovery of tagged manatees via the salvage of carcasses, (b) estimates of abundance and short-term survival based on repeated marking and resighting of manatees at a warm-water refuge, and (c) estimates of abundance and short-term survival based on one marking effort and subsequent resightings at a warm-water refuge.

METHODS

Computer programs used in this analysis have been developed and are available at Patuxent Wildlife Research Center (J. D. Nichols and J. E. Hines, May 6, 1981 and August 27, 1979 Memoranda to Chief, Game Section, Migratory Bird Habitat Research Laboratory). The analyses performed for each potential project are as follows.

Tags Recovered in Carcasses

Models of bird-band recoveries used to estimate survival rates of waterfowl have been described by Brownie et al. (1978). The model used in the present analysis (Model 1) is based on the situation where a sample of adults is tagged and released into the population at roughly the same months, for each of several successive years. Models permitting the inclusion of young animals are also available, but we consider only the single-age model for simplicity. The model also assumes that survival (S) and tag recovery rates (f) are year-specific but independent of the year of tagging.

Application of this model to the manatee situation is based on recovery of tags by salvage of carcasses. Therefore, in the manatee situation, recovery rate (f) is the product of annual mortality (1-S) and a salvage rate (q = probability that a dead manatee is salvaged). Salvage rates are not precisely known and are likely to vary in different areas of Florida (O'Shea, pers. comm.), so a range of values was used (q = 0.6, 0.7, 0.8). Survival rates of manatees are not known, but probably are above 90% (Eberhardt 1982). A range of survival rates (S = 0.80, 0.85, 0.90, 0.95) was used in this analysis. Thus, the recovery rates (f = q(1-S)) ranged from 0.03 to 0.16. It is not necessary to specify expected population size when planning band recovery experiments designed to estimate survival rates.

Estimates were calculated for research projects of three durations (4, 7 and 10 years). The sample sizes were computed to yield a desired coefficient of variation (($\hat{CV}(\hat{S}_i)$ = 0.10) for estimates of survival rates corresponding to specific years. Sample sizes required to estimate the mean survival rate over all years were computed to yield a coefficient of variation ($\hat{CV}(\hat{\bar{S}})$) of 0.05. The coefficient of variation of an estimator is the standard error of the estimator divided by the estimator itself, so CV (S) = SE (S)/S. A small coefficient of variation indicates a narrow confidence interval on the estimator, while a large value indicates a wide confidence interval.

Multiple Tagging Periods and Resighting

To evaluate sampling intensity needed to estimate average population size (N) using the Jolly-Seber model (Jolly 1965, Seber 1965), coefficients of variation for this parameter ($\hat{N}$) were determined for a range of capture probabilities (PC = 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0) and population sizes (N = 100, 200, 300, 400, 500). The population sizes were chosen to correspond to the number of manatees that might be present at a warm-water refuge. Maximum aerial counts at six sites over five years ranged from 30 to 270 manatees (Eberhardt 1982). Considering that methods independent of aerial surveys have yielded preliminary estimates nearly double the maximum aerial count (Shane 1981, Packard 1981), the potential range of population sizes could thus be 60 to 540 manatees, and we rounded it to a range of 100 to 500 manatees.

The model assumes that manatees can be marked with individually recognizable tags at five periods during a winter (assuming there will be five cold spells) and that sampling is done by sighting of marked and unmarked individuals at these periods. The probability of sighting is unknown, but will presumably be a function of effort, so a range of values was used (PS = 0.2, 0.4, 0.6, 0.8). The rate at which manatees leave warm-water refuges (via death or emigration) between sampling periods is also unknown, so calculations were performed for two short-term survival rates (PHI = 0.7, 0.9). Note that PHI corresponds to short time periods between samplings and includes emigration loss, whereas S corresponds to 1 year and includes only mortality.

For each value of survival (PHI) and population size (N), the coefficient of variation of $\bar{N}$ (the mean estimate of population size) at each of the values of sighting probability (PS) was plotted against sample size (N * PC). A level of precision indicated by a coefficient of variation less than 0.10 is generally acceptable for such studies. Therefore, values yielding an estimated coefficient of variation of 0.08 or less were considered within the desired level of precision. Approximate sample sizes required to obtain the desired coefficient of variation were identified by interpolation of the point where the line (CV = 0.08) intersected the curve for each probability of sighting (PS = 0.2, 0.4, 0.6, 0.8). These minimum sample sizes were plotted against population size for each value of survival rate (PHI = 0.7, 0.9). Sample sizes are the number of manatees that must be captured for tagging at each cold spell, not all of which will be unmarked.

Single Tagging Period and Resighting

The computer program used was the same as for the multiple-tagging project described above, but it was assumed that marks were applied on only the first capture (cold spell) and only resightings were obtained at subsequent cold spells. The same values for parameters were used. Rather than extrapolating minimum sample sizes from plots as described above, the lowest (to the nearest 0.01) capture probability (PC_m) with a coefficient of variation less than 0.10 was identified from examination of the output tables. The minimum sample sizes were thus calculated as the product of the population size and the capture probability ($N * PC_m$).

RESULTS

Large sample sizes would be required to estimate survival by means of carcass recovery, but the sampling effort per year may be reduced by extending the tagging and recovery over a longer period. Sample sizes required for Jolly-Seber estimates of abundance and survival at warm-water refuges are dependent on the probability of sighting and survival rate (the probability that an animal in the area at sampling period i is still in the area in period i + 1). Thus, possible values for these variables should be determined prior to designing mark-resighting programs.

Tags Recovered in Carcasses

For annual survival estimates from a 4-year tagging and recovery program (Table 1), sample sizes range from 380 to 2200 animals for first year estimates, depending on salvage and survival rates. If a precise estimate of survival rate for the final year of the program (i.e. the survival rate for year 3) is desired, then thousands of animals would have to be marked each year. If an average survival estimate over all years is desired, annual sample sizes would range from 450 to 2360 animals.

If tagging and recovery are extended over 7 years (Table 2), the range of sample sizes for first year survival rate estimates drops to 180-1090 animals tagged annually. Sample sizes required for a mean estimate of survival range from 100 to 500 animals.

Over a 10-year period (Table 3), sample sizes required for a first-year estimate would range from 130 to 730 manatees. Sample sizes required to estimate survival rate for the last year of a 10-year study would range from 870 to 5090 manatees. For an estimate of the mean survival rate over 10 years, annual sample sizes would range from 40 to 210 animals.

Multiple Tagging Periods and Resighting

For fixed PS, N, and PHI, the coefficient of variation of N declines as a curvilinear function of sample size (Figure 1). The range of the coefficient of variation is greater for small populations (N = 100) than for large populations (N = 500) at capture probabilities between 0.1 and 1.0 ($0.1 \leq PC \leq 1.0$). If a coefficient of variation less than 0.1 is desired, the probability of sighting is a critical variable. With a sighting probability of PS = 0.2, the desired level of precision can not be achieved within the ranges of parameters specified in this model. At a higher survival rate (Figure 2), sample sizes can be smaller to achieve the desired coefficient of variation.

When the sighting probability is high ($PS \geq 0.6$), the size of the population has little influence on the minimum sample size required to obtain the desired level of precision (Figure 3). At a low survival rate (PHI = 0.7) and sighting probability (PS = 0.4), required sample sizes range from about 140 to 180 manatees, depending on population size. If the probability of sighting is as high as 0.6 or 0.8, sample sizes must be about 60 or 20 manatees, respectively. At a higher survival (PHI = 0.9), required sample sizes range from about 10 to about 90, depending on the sighting probability (Figure 3).

Table 1. Number of tags required for a 4-year recovery program at several rates of survival (S) and carcass recovery (q)[a].

YEAR (i)	SALVAGE RATE(q)	REQUIRED TAGS S = 0.80	S = 0.85	S = 0.90	S = 0.95
1	0.6	570	740	1100	2200
2		740	980	1480	3000
3		1330	1790	2700	5470
Mean		640	820	1200	2360
1	0.7	460	610	910	1860
2		600	810	1240	2540
3		1110	1500	2290	4660
Mean		530	690	1020	2010
1	0.8	380	510	770	1600
2		500	690	1060	2200
3		950	1290	1980	4060
Mean		450	590	880	1750

[a]To obtain estimates for each year with a coefficient of variation of 0.10 and mean annual estimates with a coefficient of variation of 0.05. The sample sizes corresponding to the annual estimates (e.g. for year i) reflect the number of animals to be marked in each year of the study in order to estimate S_i with the desired level of precision. For example, if S = 0.80 and q = 0.60, then approximately 570 animals should be marked during each of the 4 years of the study in order to estimate S_1 such that $\widehat{CV}(\hat{S}_1) = 0.10$. To estimate S_3, approximately 1330 animals should be marked during each of the 4 years of the study.

Table 2. Number of tags required for a 7-year recovery program at several rates of survival (S) and carcass recovery (q)[a].

YEAR (i)	SALVAGE RATE(q)	REQUIRED TAGS S = 0.80	S = 0.85	S = 0.90	S = 0.95
1	0.6	310	380	550	1090
2		320	410	610	1240
3		370	490	740	1510
4		470	630	960	1960
5		680	910	1380	2820
6		1250	1680	2550	5180
Mean		140	180	260	500
1	0.7	240	300	440	910
2		250	330	500	1040
3		290	390	610	1260
4		380	510	790	1650
5		550	750	1150	2390
6		1050	1410	2160	4410
Mean		120	150	220	430
1	0.8	180	240	360	770
2		190	260	410	880
3		230	320	510	1080
4		310	420	670	1420
5		460	630	990	2060
6		890	1210	1860	3840
Mean		100	130	190	370

[a]To obtain estimates for each year with a coefficient of variation of 0.10 and mean annual estimates with a coefficient of variation of 0.05. The sample sizes corresponding to the annual estimates (e.g. for year i) reflect the number of animals to be marked in each year of the study in order to estimate S_i with the desired level of precision. For example, if S = 0.80 and q = 0.60, then approximately 310 animals should be marked during each of the 7 years of the study in order to estimate S_1 such that $\widehat{CV}(\hat{S}_1) = 0.10$. To estimate S_6, approximately 1250 animals should be marked during each of the 7 years of the study.

Table 3. Number of tags required for a 10-year recovery program at several rates of survival (S) and carcass recovery (q)[a].

YEAR (i)	SALVAGE RATE(q)	REQUIRED TAGS S = 0.80	S = 0.85	S = 0.90	S = 0.95
1	0.6	230	270	370	730
2		230	270	390	780
3		240	300	440	880
4		260	340	500	1010
5		300	390	590	1200
6		360	480	720	1480
7		460	620	940	1920
8		660	890	1360	2770
9		1230	1650	2500	5090
Mean		60	80	110	210
1	0.7	170	210	290	590
2		160	210	310	640
3		180	230	340	720
4		200	260	400	840
5		230	310	470	1000
6		280	380	590	1240
7		370	500	780	1620
8		540	730	1130	2350
9		1030	1390	2120	4330
Mean		50	60	90	180
1	0.8	120	150	230	490
2		120	160	240	540
3		130	170	280	610
4		150	200	320	710
5		170	240	390	850
6		220	310	490	1060
7		300	410	650	1390
8		450	620	970	2030
9		870	1190	1830	3760
Mean		40	50	80	150

[a]To obtain estimates for each year with a coefficient of variation of 0.10 and mean annual estimates with a coefficient of variation of 0.05. The sample sizes corresponding to the annual estimates (e.g. for year i) reflect the number of animals to be marked in each year of the study in order to estimate S_i with the desired level of precision. For example, if S = 0.80 and q = 0.60, then approximately 230 animals should be marked during each of the 10 years of the study in order to estimate S_1 such that $\widehat{CV}(\hat{S}_1) = 0.10$. To estimate S_9, approximately 1230 animals should be marked during each of the 10 years of the study.

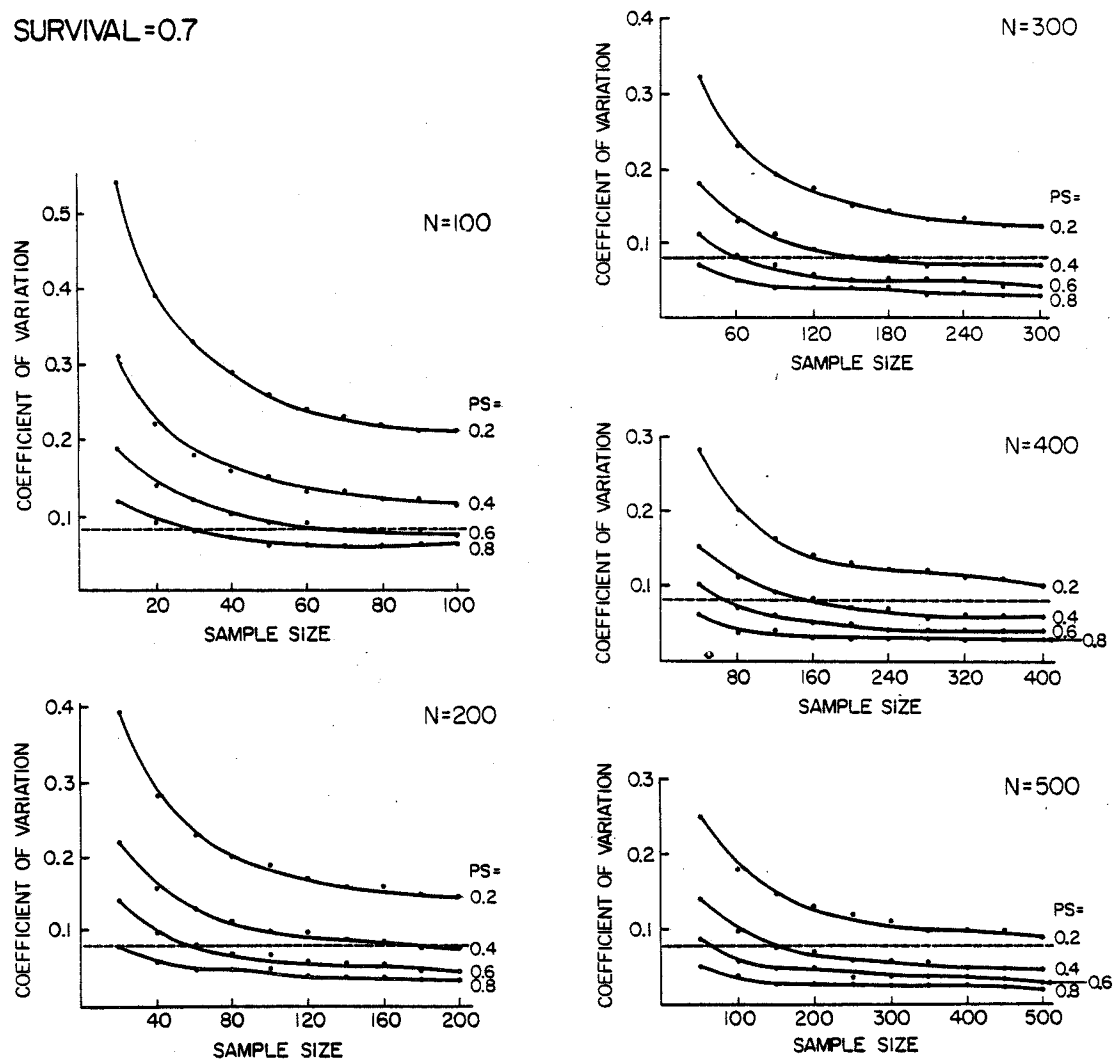

Figure 1. Assuming manatee survival rate of 0.7, curves show the relation of sample size to the coefficient of variation of population estimates, dependent on population size (N) and probability of sighting (PS).

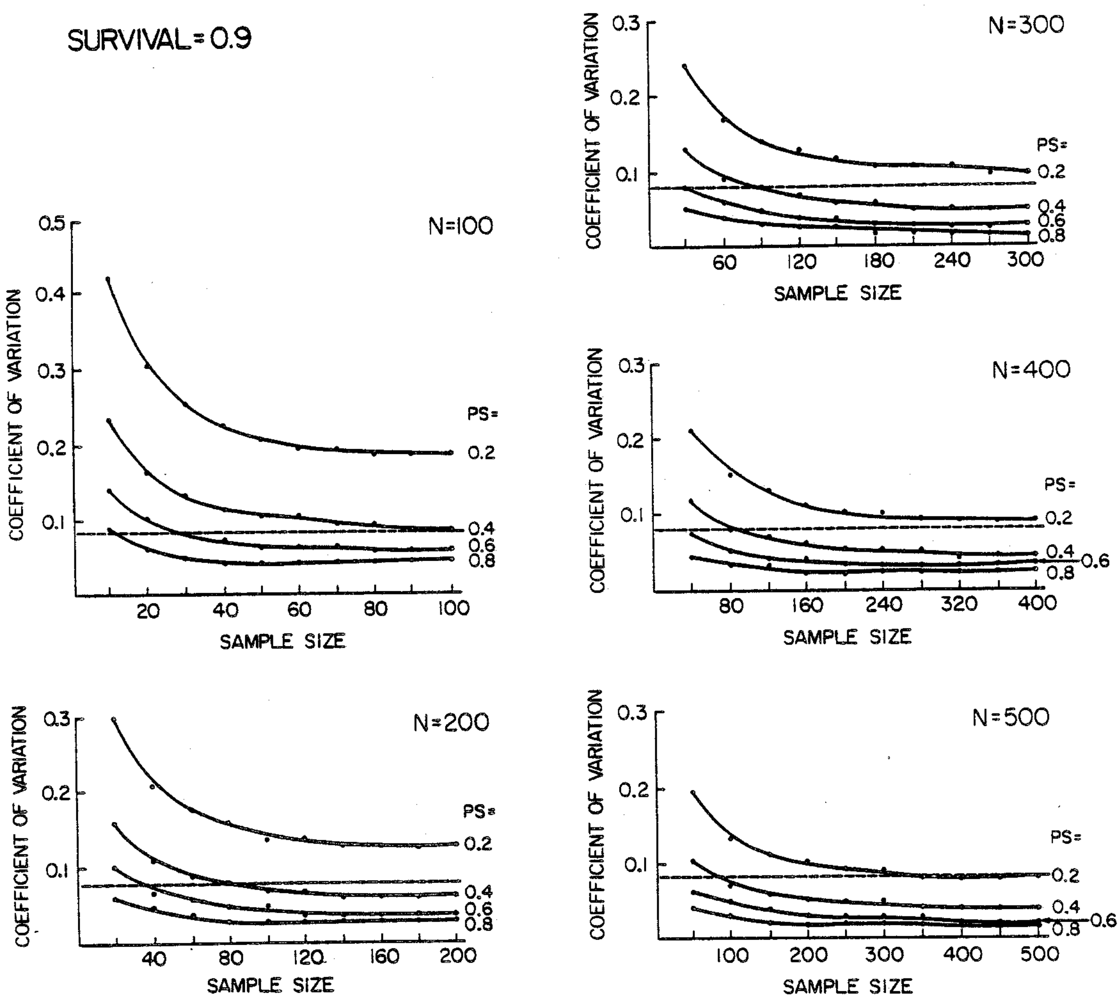

Figure 2. Assuming manatee survival rate of 0.9, curves show the relation of sample size to the coefficient of variation of population estimates, dependent on population size (N) and probability of sighting (PS).

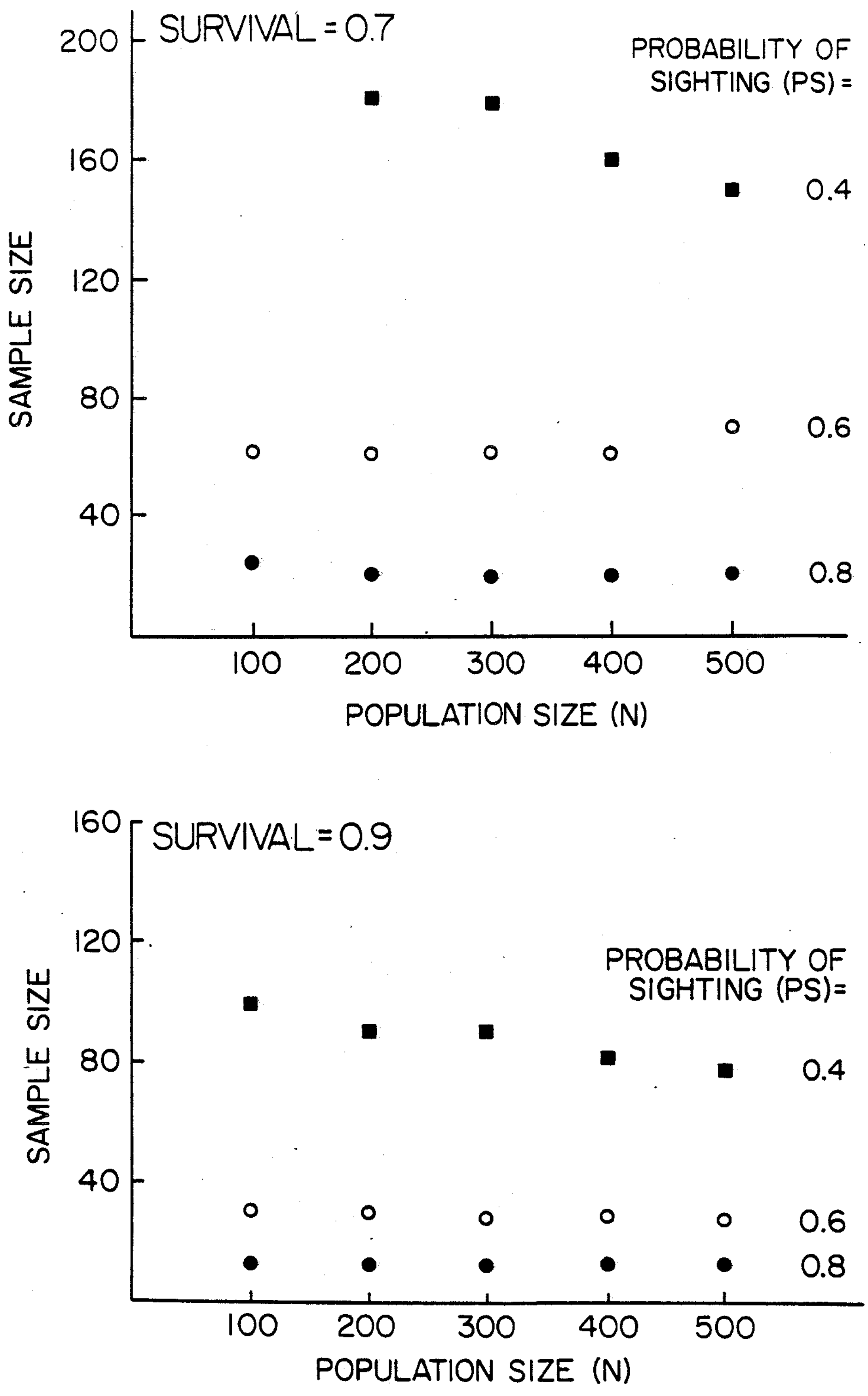

Figure 3. Sample sizes required to obtain population estimates with a coefficient of variation below 0.1, dependent on survival rate and probability of sighting.

Single Tagging Period and Resighting

To obtain the desired coefficient of variation, sample sizes would need to be higher if manatees are tagged during one period at the beginning of a winter compared to multiple tagging periods during the winter. At a high sighting probability (PS = 0.8), an initial sample of about 15 manatees would have to be marked at a high survival rate (PHI = 0.9) and about 35 manatees for a lower survival rate (PHI = 0.7) (Table 4). Required sample sizes increase substantially as the probability of sighting decreases.

DISCUSSION

Sample sizes calculated in these analyses indicate that under certain conditions, it will be impractical to tag enough manatees to obtain estimates of population parameters that are within the desired level of precision. For example, under the best recovery conditions (S = 0.8, q = 0.8) large numbers of manatees (950 manatees per year) would have to be marked over 4 years to obtain precise annual survival rate estimates for all years of a 4-year program of carcass recovery. Over 10 years, annual sample sizes for estimates of annual survival rate through the eighth year will still be large (450 manatees per year) to obtain the same level of precision. Because the total population may be as low as 1,000 to 3,000 manatees (Eberhardt 1982), annual estimates of survival rates within the desired coefficient of variation (CV = 0.1) may not be feasible. Because of the low tag recovery rates and relatively small population size, band recovery models such as those used for waterfowl populations will not provide precise annual survival rate estimates for Florida manatees.

If a mean estimate of survival is adequate and recovery conditions are good, about 40 manatees would need to be tagged each year of a 10-year program, and 450 manatees would need to be marked each year of a 4-year program. However, if recovery conditions are poor (q = 0.6, S = 0.95), it would not be possible to mark enough manatees to obtain mean survival estimates with the desired precision. Therefore, before initiating a program of tag-recovery via salvage of carcasses, it is necessary to decide whether a lower level of precision is acceptable and whether estimates of mean annual survival rates will yield the information needed for management purposes.

Emigration rates (1 - PHI) and probability of sighting (PS) need to be determined before evaluating the feasibility of obtaining estimates of population parameters via tagging and resighting at warm-water refuges. If emigration is high (PHI = 0.7), the probability of sighting must be as high as PS = 0.8 for a multiple-tagging program to be feasible; about 20 animals would have to be captured at each tagging period. If emigration is low (PHI = 0.9) it might be possible to conduct the studies even if the sighting probability is as low as PS = 0.6; however, sample sizes would need to be about 30 manatees. At sighting probabilities lower than PS = 0.6, sample sizes would have to be too large to be feasible.

If tags are put out only at the beginning of a season, the probability of sighting must be high (PS = 0.8) for the project to be feasible. At a low rate of emigration (PHI = 0.9), at least 15 to 20 manatees should be tagged. If the emigration rate is higher (PHI = 0.7), at least 35 to 40 manatees should be tagged.

Table 4. Sample sizes (N*PC) required for a range of population sizes (N), probabilities of sighting (PS) and survival rate (PHI)[a].

N	PS = 0.2		PS = 0.4		PS = 0.6		PS = 0.8	
	PC	(N*PC)	PC	(N*PC)	PC	(N*PC)	PC	(N*PC)
PHI = 0.9								
100	-		-		.38	38	.16	16
200	-		.55	110	.20	40	.07	14
300	-		.39	117	.14	42	.05	15
400	-		.30	120	.11	44	.04	16
500	-		.24	120	.09	45	.03	15
PHI = 0.7								
100	-		-		-		.34	34
200	-		-		.49	98	.16	32
300	-		-		.33	99	.11	33
400	-		.76	304	.25	100	.08	32
500	-		.62	310	.20	100	.07	35

[a]Calculated from the minimum probability of capture (PC) that will yield an estimate of mean population size with a coefficient of variation less than 0.10.

The potential disturbance associated with tagging large numbers of manatees at a warm water refuge should be considered, because mark-recovery models assume the behavior of marked animals (specifically, probability of emigrating and of being sighted) is not changed. Under optimal conditions, the number of tagged manatees required may be within the range that could be obtained by recognition of distinct scar patterns. However, slightly different assumptions would be involved in a mark-recognition program based on distinct scar patterns, and sample sizes would need to be calculated specifically for such a program.

CONCLUSIONS

1. Precise estimation of annual survival rates by tag recovery from carcasses is not feasible due to the large sample sizes that would be required.

2. An estimate of the mean annual survival rate over 10 years would be feasible by means of tag recovery in carcasses if the recovery rate (product of mortality and salvage rates) is high. About 40 to 210 manatees would need to be tagged each year.

3. A high rate of emigration and low probability of sighting tags would make a program involving multiple marking periods infeasible, due to large sample sizes. However, if the probability of sighting is high, about 10 to 30 manatees would need to be captured at each marking period, depending on emigration rates.

4. If sighting probability is high, about 15 to 40 manatees would need to be marked for estimates from a mark-resighting program that involved only one initial tagging period. When total marking effort is considered, a single-tagging-period program is more efficient than a program relying on multiple tagging periods. However, the potentially greater disturbance associated with tagging many manatees at one time should be considered.

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