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ABSTRACT

Large and small-scale fishery experiments have demonstrated that attaching acoustic devices (pingers) on gill nets reduces harbor porpoise *(Phocoenaphocoena)* entanglement and mortality. However, the mechanism for mortality reduction is unknown. We conducted shore-based observations of a set gill net that was alternately set with and without alarms for 2- to 5-day periods during 27 days between 11 July - 6 August 1996. When the acoustic alarms were attached to the net, harbor porpoise were displaced by an acoustic buffer with a radius of at least 125 m around the net (P <O.Ol), which demonstrated the effectiveness of pingers in reducing entanglement.

CONTENTS

INTRODUCTION

Pingers have dramatically reduced incidental harbor porpoise *(Phocoena phocoena)* mortality in experiments conducted with the sink gill net fishery in the Gulf of Maine (Kraus et al. 1997) and the Makah Tribal set gill net fishery (Gearin et al. 1996) off the coast of Washington State. However, the mechanism for mortality reduction is unknown. The report of the Workshop on Acoustic Deterrence (Reeves et al. 1996) concludes:

> *Although it is clear that the pingers significantly reduced the harbor porpoise bycatch in the [Gulf of Maine] experiment, it is not clear why they worked. For example, it is not clear whether porpoises were alerted or repelled by the sounds made by the pingers; their prey responded by moving away from the sounds and the porpoises followed; or other factors were involved.*

The workshop recommended conducting “studies of the fine-scale distribution of porpoises in areas where pingers are used, to look for signs of displacement and other effects”.

To address the workshop recommendation, we repeated the work of Gearin et al. (1996) to assess the effectiveness of pingers at reducing incidental mortality and included the following additional objectives: 1) measure the effects of pingers on the fine-scale distribution of porpoise by observing surfacing harbor porpoise in relation to a set gill net that was alternately set with pingers (alarmed) and without pingers (unalarmed); and 2) determine signal to noise ratios of the pinger frequencies in the region surrounding the net by recording acoustic measurements when the net was alarmed and unalarmed. We report here on the study of the effects of pingers on the fine-scale distribution of harbor porpoise.

METHODS

Study Area Description

The Spike Rock Fishery Area, seaward of Shi Shi Beach, is within the Olympic Coast National Marine Sanctuary in the Pacific Ocean at the northwestern edge of the Olympic National Park in Washington State (Fig. 1). Water depths do not exceed 20 m within the study area at mean tide levels. During the survey period, 11 July to 6 August, daily differences between low and high tides ranged from as little as 1.6 m up to 4.4 m (from -1 .0 m to +3.4 m).

Observations of the Spike Rock Fishery Area were made from a site on an exposed bluff northeast of Shi Shi Beach (48°6.5’N, 124°40.7’W). The observation site was located on the Makah Indian Reservation, adjacent to the Olympic National Park. Vegetation at the observation site limited the field of view of the Spike Rock Fishery area to 56° (magnetic 202.5° to 259.2° for the inshore observer, and 197.2° to 253.5° for the offshore observer; magnetic declination was +21.3°). The site altitude, 46.8 m (149 A) above sea level at a 0 m tide, was determined by using triangulation with a pair of targets at sea level separated by a known distance (Appendix A). Distances based on vertical angles from the horizon or horizontal used the 46.8 m height adjusted for tide height at the time of the measurement, which was interpolated between extremes from a tide table.

Net Array

Four set gill nets (Nos. 10-13) were deployed with net No. 12 and No. 13 (183 m long by 10 m deep) placed near the south side of the Spike Rock Fishery Area, and net No. 10 and No. 11

(183 m long by 16 m deep) placed opposite the shore-based observers (Fig. 1, Table 1). The ends of each net were marked by orange buoys attached to the cork line. Theodolite bearings to each buoy were recorded at low and high tides each day, providing a record of net locations relative to porpoise sightings. Daily measurements were used to construct an average position of each net. The theodolite (Nikon NT2A) was accurate to 0.006° with a 19 power lens and an optical field of view of 1.50°. Vertical readings were determined relative to a precisely leveled bubble; horizontal bearings were determined relative to magnetic north. A distinctive notch on Spike Rock, at the far end of the survey area, was used to calibrate the horizontal bearings (set at 211°OO'OO"). Buoy locations were also determined using a Global Positioning System (GPS), aboard the fishing vessel that attended the nets.

Experimental Design/Survey Protocol

Eleven pingers, built to the specifications of John Lien (Fullilove 1994) were placed on the corkline of each net at 16.6 m intervals to create an acoustic alarm (Gearin et al. 1996). Initially we intended to place pingers on one net within each of the two pairs No. 10 - No. 11 and No. 12 - No. 13. The pingers were to be rotated between nets within each pair every 2 days. This design was followed for the first week of the 1996 study; however, as we collected acoustic measurements, it became clear that the lower tonal component (3Hz) of the pings was discernible between nets within the same pair (Bowles, unpub. data). Therefore, we modified the original design such that both nets in each pair were either alarmed or unalarmed. Inclement weather sometimes prevented changing the pingers between nets every 2 days. When this occurred, the following period was matched in length of days to the previous observation period (e.g., a 3-day alarmed period was followed by a 3-day unalarmed period). Pingers were switched between nets when the nets were checked to remove fish and any entangled porpoise. The nets were checked once each day during mid-morning to late afternoon by the fishing crew unless weather conditions compromised the crew's safety. Any missing or defective pingers were replaced. Each net required about 20-30 minutes to be checked.

An observation team, which was unaware of the status (i.e., alarmed or unalarmed) of the nets, conducted 30- to 45minute systematic watches of the field of view. One observer scanned the inshore area while another scanned the offshore area, and a third person recorded data. The primary focus of the observation effort was net No. 10 which was closest to the observation site. The four-person team included a rest position, rotated every 45 minutes. This fourth position was also used to track net buoy locations via theodolite bearings. When only 3 observers were available, rotations were made every 30 minutes. Rotations allowed a rest from the search effort with every other change in position (Appendix B).

Searching was conducted through 7 x 50 binoculars (Fujinon), which have a 5.44° optical field of view with 14 vertical reticle marks which measure the vertical angle from the horizon (0.283" per reticle mark). An internal magnetic compass provided 360° horizontal bearings. Tripods were used to steady the binoculars and provide a smooth sweep as observers scanned the field of view. Observers continuously scanned horizontally across the survey area. One observer scanned left to right and the other right to left. Each horizontal scan required 6-8 minutes. To minimize redundant observations of the same surfacing, upon completion of a scan the observer switched back to the beginning point of the scan (i.e., left or right) instead of scanning back and forth. The field of view was divided vertically at 7 reticles (i.e., 1,190 m from the site) to define the inshore and offshore areas.

When one or more marine mammals were seen at the surface, the observer announced the sighting and provided the vertical angle (estimated to tenths of retitles), horizontal bearing (via the internal magnetic compass in each binocular), species, count, and any comments about behavior, etc. The recorder transcribed those data and the time of sighting to the closest second and the observer's initials on the data forms (see Appendix B for details). Observers made no attempt to avoid re-sighting the same porpoise. Porpoise may have been recorded multiple times on different viewing sweeps. Nor was there any attempt to track porpoise though the field of view.

Environmental conditions (i.e., visibility, wind, weather and glare) were recorded at the beginning of each watch period and whenever conditions changed during the watch (Appendix B). Watch effort was generally suspended when visibility was less than fair or when more than 20% of the field of view was obscured by glare.

Analysis

Our primary interest was whether harbor porpoise were displaced from the region surrounding the net when pingers were attached. For each observation of porpoise, we computed the closest distance between the porpoise and net No, 10, which was closest to the observation site. Because multiple observations of surfacing harbor porpoise through time will obviously not be independent, standard statistical distribution tests (e.g., Kolmogorov-Smirnov) that assume independence would be invalid. Instead, we constructed distributions for the distance from each surfacing to net No. 10, when it was either alarmed or unalarmed. Based on a graphical examination of the distributions, we chose a distance of 125 m as the radius for a potential displacement region and defined the random variable $y_i = 1$ if harbor porpoise were seen surfacing once or more within the displacement region during day *i* and $y_i = 0$ if they were not seen in the displacement region. If the proportion of days in which $y_i = 1$ ($p = Pr\,[y_i, = 1]$) were significantly different between alarmed (p_a) and unalarmed (p_u) periods, we would conclude that the alarms displaced the porpoise. If the amount of observation time and conditions were the same for each day and the occurrence of harbor porpoise in the displacement region was independent between days, a simple test of equality of binomial proportions could be conducted with Fisher's exact test for a 2 x 2 contingency table (Fleiss 1973).

Unfortunately, weather conditions varied substantially during our survey, resulting in large daily differences in the amount of observation time and visibility conditions. This did not preclude performing a valid test because the alarm status of the net was independent of the weather conditions except that alarmed or unalarmed periods were sometimes extended when the net could not be checked. However, variation in weather conditions could decrease the power of the test. If observations between days were assumed to be independent, we could have used logistic regression to account for variation in observation effort and test for an alarm effect. However, we were not entirely satisfied with the assumption of independence between days, so we used hidden-Markov chain models (Satten and Longini, 1996; Zucchini and Guttorp, 1991) to allow for possible dependence in the observed sequence y_1, y_z,. ..,y_n.

A hidden Markov-chain model assumes that the true state of the system is a Markov-chain, but the observed state of the system is subject to measurement error. In this case, the true state of the system is s_i =l if porpoise surfaced within the displacement region at some point during day *i* but the observed state of the system y_i is 1 if the porpoise are seen and 0 if the porpoise are not seen. Clearly, if $s_i = 0$, then $y_i = 0$. If the sequence of s_i are assumed to be first-order Markov, then s_i depends on s_{i-1} but no other states. However, the y_i do not satisfy the Markov property, and y_i is dependent on $y_1, y_2, \ldots, y_{i-1}$-, because of measurement error, even if the errors are independent. Dependence in the errors (e.g., contiguous bad weather days) creates further dependence in the y_i. The probability of seeing harbor porpoise in the displacement region ($y_i = 1$) given they surfaced within the region ($s_i = 1$) was formulated as a logistic equation :

$$p^*(h) = \frac{e^{\gamma_0+\gamma_1 h}}{1+e^{\gamma_0+\gamma_1 h}} \quad , \qquad (1)$$

where *h* is a covariate. We examined the amount of observation time and the average visibility condition (weighted by search time) during the day as potential covariates.

We considered five different models to describe the state of the system .(s_i) (Table 2) to account for differences in dependence assumptions and a potential alarm effect ($x_i = 1$ if net No. 10 was alarmed on day *i* and 0 if it was unalarmed) . Models 1 and 2 assume independence between days, and Models 3 to 5 allow for dependence between days. Likelihood ratio tests were used to test the significance of the covariates and between hierarchical models to test for dependence and for an alarm effect. More specific details of the models and the likelihoods and computations are given in Appendix C.

RESULTS

Harbor porpoise groups were sighted on 501 occasions in our 135.7 hours of observation effort during 27 days (Table 3). Group size varied from 1 to 10 porpoise with 72% either one or two porpoise. The amount of observation time varied between 0.3 and 9 hours/day in excellent to fair visibility conditions. When the alarm status of net No. 10 changed mid-day, shown as two entries for the same date in Table 3, we excluded the afternoon portion of the observation from the analysis so we did not have to model dependence within a day as well as between days. This excluded 14.3 hours of observation effort, resulting in 50.4 hours of observation effort during the 13 days when net No. 10 was unalarmed and 7 1 hours during the 14 days when net No. 10 was alarmed.

All of the measurement of buoy positions for net No. 10 were within 40 m of the average position. However, it was apparent that on 23 July the inner buoy had shifted and remained 50 m to the southeast from its original position. Using separate averages for 11-22 July and 23 July - 6 August, 96% of the positions were within 20 m of the average, and no measurement exceeded 30 m from the average. Therefore, distances between harbor porpoise sightings and net No. 10 were computed using the average position of net No. 10 during the respective two periods.

Harbor porpoise sightings were primarily clustered to the north of net No. 10 (Fig. 2) but when net No. 10 was unalarmed, harbor porpoise were seen closer to the net. The distribution of distances between sightings and net No. 10 (Fig. 3) suggested porpoise were displaced 100 to 150 m from the net. We chose 125 m as the radius of the displacement region for testing the significance of an alarm effect.

Harbor porpoise were seen within the displacement region on 5 of the 13 days when the net was not alarmed, but on only 1 of the 14 days when the net was alarmed (Table 4). Without considering the influence of the length of the observation effort and visibility, this is not a significant result (P = 0.08, Fisher's exact test), But, during seven unalarmed and five alarmed days when fewer than four observation hours were conducted (Table 4), harbor porpoise were never seen within the displacement region. Whereas, during days in which four or more hours were observed, harbor porpoise were seen in all but 1 unalarmed day, but on only 1 of 9 alarmed days. Fisher's exact test yields a significant result (P = 0.01) when the analysis is restricted to days with four or more hours of observation effort. Visibility does not appear to be an important variable, except that there were fewer hours of observation on days when observations were halted because of poor visibility conditions.

Given the clear pattern presented in Table 4, it was not surprising that examining the data based on parametric models produced the same conclusions. Each of the five models was fit to the observed sequence and included the hours of observation as a covariate in Equation (1) (Table 5). In each model, the estimated intercept for Equation (1) was the lower bound of -100, . and the slope coefficient for hours was 24.5. Decreasing the lower bound would change the highly correlated parameter estimates, but it did not substantially affect the log-likelihood value or model predictions. The logistic curve effectively separated the data into two classes as in Table 4: 1) for days with fewer than 4 hours of observation effort observers had nearly zero probability of seeing a harbor porpoise that entered the displacement region sometime during the day, and 2) for days with more than 4 hours the observers almost certainly saw porpoise that entered the region. We expect that a smoother curve would be observed if the sample size was larger. The number of observations hours was a very important covariate when tested for model 2 and 4 (Model 2: $x^2 = 13.02$, df= 1, $P < 0.001$, Model 4: $x^2 = 15.7$, df = 1, $P < 0.001$). A comparison of Models 2 and 4 does not give strong evidence for dependence ($x^2 = 3.92$, df = 2, $P = 0.14$); therefore, Model 2 is the most parsimonious model. However, whether we assumed independence between days (Model 1 vs. Model 2: $x^2 = 6.82$, df = 1, $P = 0.009$) or used the hidden Markov-chain model with first-order dependence (Model 3 vs. Model 4: $x^2 = 10.7$, df = 2, $P = 0.005$), the presence of pingers significantly reduced the probability a harbor porpoise surfaced within 125 m of net No. 10.

DISCUSSION

Our finding that harbor porpoise were seen less frequently in the vicinity of a net with acoustic alarms was the most logical explanation for the reduction in entanglement and subsequent mortality in experiments conducted with pingers. We expected harbor porpoise to avoid the nets by a considerable distance because the work of Kastelein et al. (1995) demonstrated that captive harbor porpoise kept in close proximity of a net became entangled in a net even when they were aware of its presence. The captive porpoise eventually learned to avoid the net after repeated entanglements, but in a natural setting, learning is not possible because the initial entanglement will most likely result in death. While our result refines the possible set of explanations, it does not entirely elucidate the mechanism for mortality reduction.

Whether the porpoise are repelled or alerted by certain pinger frequencies or whether they are following their primary prey, herring (Gear-in et al. 1994), that are repelled remains uncertain. Differentiating between these mechanisms has important implications on the effectiveness of pingers and the available management options to reduce entanglement mortality. If harbor porpoise are repelled, the potential exists for habituation to the sound and a decline in the effectiveness of pingers. However, habituation may not be an important concern for the Makah setnet fishery because the fishing season only lasts 2 to 3 months during the summer. If porpoise are following herring that are repelled, presumably habituation is less likely. However, reductions in herring abundance and availability could reduce the effectiveness of the pingers if the porpoise switch to different prey that could be unaffected by the pingers.

Displacement of porpoise from the area around the net results in mortality reduction, but also reduces the available porpoise habitat. We have demonstrated that alarmed nets changed the distribution of porpoise within at least 125 m of the net. This area could be potentially larger, and we note that the encounter rates of porpoise were also substantially lower when net No. 10 was alarmed. We did not analyze these data because it can be easily explained by porpoise moving to the north out of the observer's field of view. While this loss of habitat may not be important for the current size of the Makah setnet fishery, historically nets were set throughout the Spike Rock Fishery Area and would likely exclude porpoise from the entire area if each net was alarmed.

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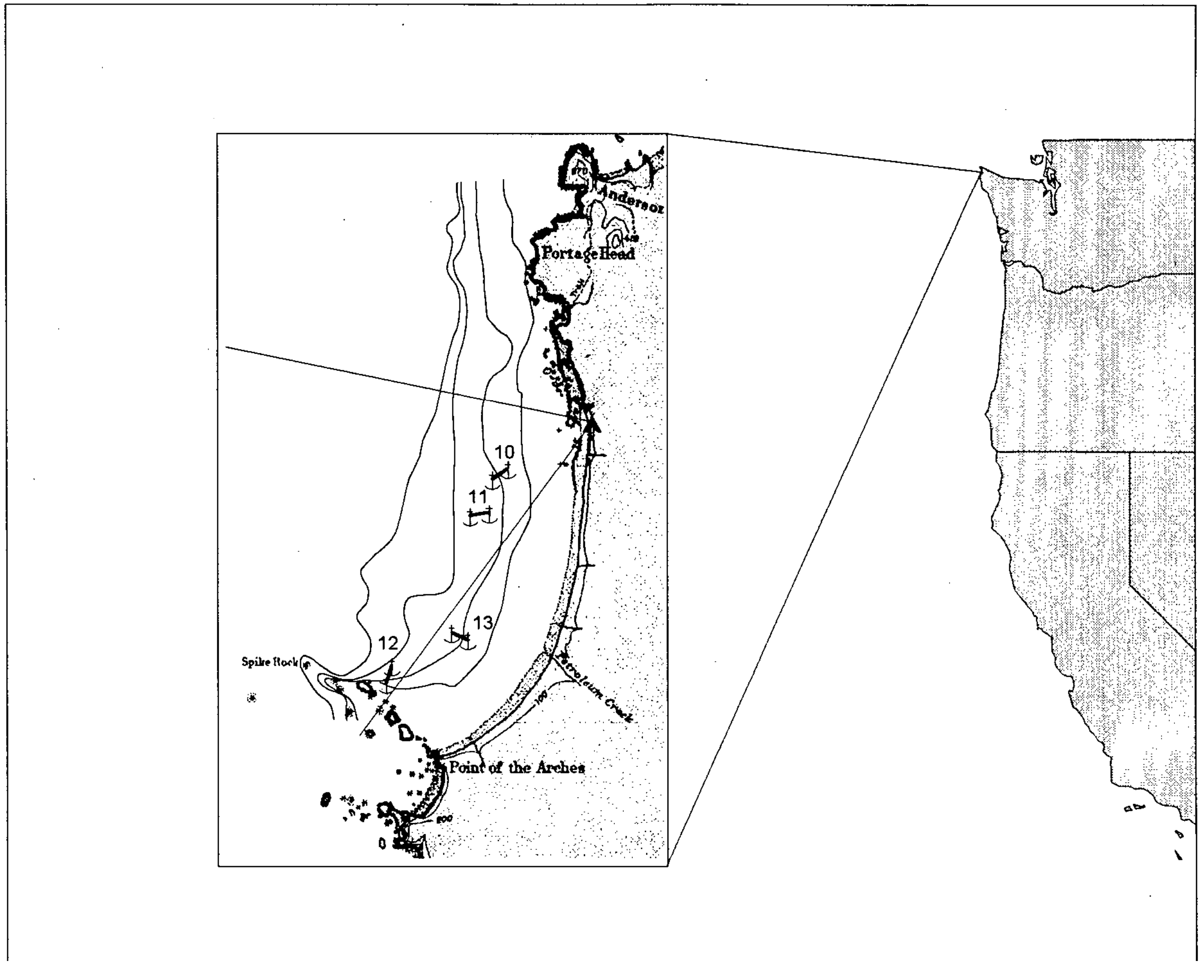


Figure 1. -- Spike Rock Fishery area. Approximate field of view (56° indicated by lines emanating from base camp position. Net positions (Nos. 10-13) are indicated by anchors. Approximate bathymetric contours are indicated for 4,6,8, and 10 fathoms.

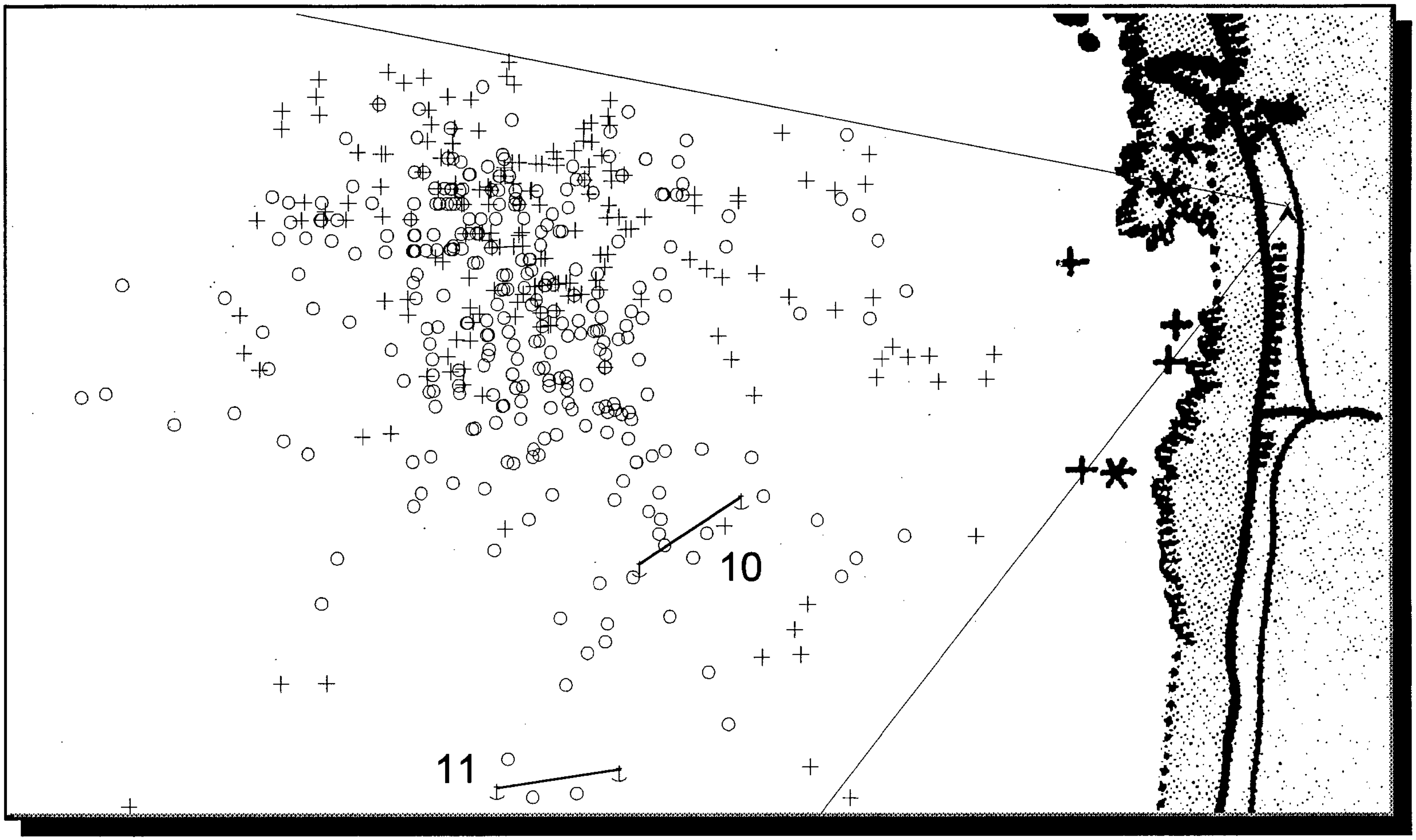


Figure 2. -- Positions of harbor porpoise sightings when net No. 10 was unalarmed (circle) and alarmed (+).

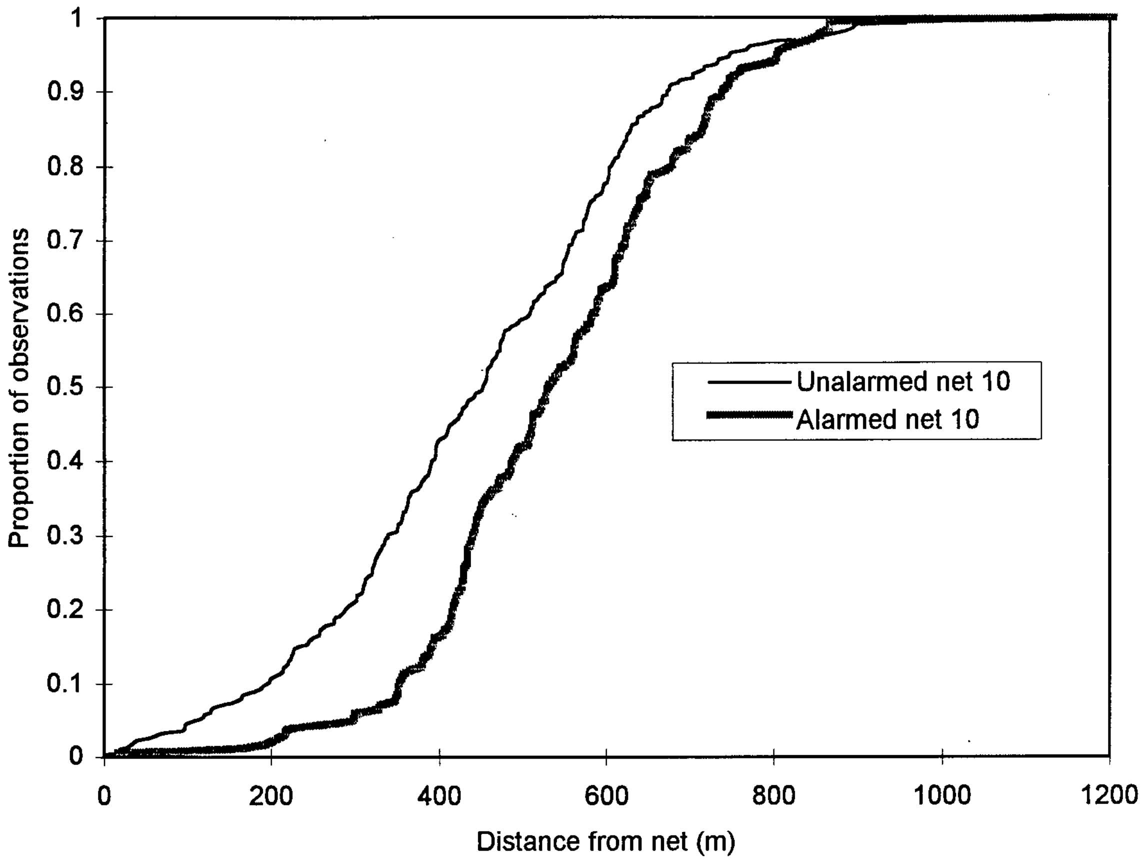


Figure 3. -- Cumulative distributions of distances between harbor porpoise sightings and net No. 10 when the net was alarmed and unalarmed.

Table 1. -- Distances between nets (using the center of each net) and the observation site (camp).

Net	Distance (km) to:			
	Camp	Net 10	Net 11	Net 12
No.10	1.04	--	--	--
No.11	1.41	0.42	--	--
No.12	3.06	2.16	1.74	--
No.13	2.34	1.54	1.14	0.79

Table 2. -- Potential models, their dependence assumptions, and number of parameters needed to describe the state of the system (s_i).

Model	s_n dependent on:			No. of parameters
	s_{n-1}	x_n	x_{n-1}	
1	No	No	No	1
2	No	Yes	No	2
3	Yes	No	No	2
4	Yes	Yes	No	4
5	Yes	Yes	Yes	8

Table 3. -- Summary of hours watched and number of harbor porpoise observations classified by date, pinger state for net No. 10 and visibility code (excellent (l), very good(2), good(3), fair(4)). Rows marked with an asterisk were excluded from the analysis to reduce dependence. A superscript 1 indicates that one or more observations were made within 125 m of net No. 10. An asterisk represents an observation period that was excluded during the latter portion of the day after alarm status changed.

		Hours Watched by Visibility					Average	No. of Observations by Visibility					No. of Observations/hr by Visibility				
Pinger	Date	Ex(1)	VG(2)	G(3)	F(4)	Total	Visibility	Ex(1)	VG(2)	G(3)	F(4)	Total	Ex(1)	VG(2)	G(3)	F(4)	Average
on	7/11/96			2.9	2.8	5.7	3.5			7	5	12			2.45	1.77	2.11
off [1]	7/12/96		0.7	3.0	1.9	5.6	3.2		0	26	6	32		0.00	8.72	3.14	5.75
off	7/13/96			2.5	1.3	3.8	3.3			0	3	3			0.00	2.37	0.79
on	7/14/96		0.3	4.5		4.8	2.9		0	1		1		0.00	0.22		0.21
on	7/15/96				1.0	1.0	4.0				0	0				0.00	0.00
on	7/16/96		0.8	4.2	3.7	8.6	3.3		0	3	1	4		0.00	0.72	0.27	0.46
on	7/17/96		1.8	1.0	0.3	3.1	2.5		15	4	0	19		8.51	3.82	0.00	6.09
off *	7/17/96			0.6	2.2	2.8	3.8			0	1	1			0.00	0.45	0.36
off [1]	7/18/96		0.8	2.5	1.8	5.1	3.2		14	4	0	18		18.28	1.60	0.00	3.55
off [1]	7/19/96			4.4	4.5	9.0	3.5			4	12	16			0.90	2.66	1.79
off [1]	7/20/96	0.7	3.1	1.6	2.5	7.8	2.8	45	86	4	3	138	66.61	28.17	2.52	1.21	17.70
off	7/21/96		1.0	1.0		2.0	2.5		34	4		38		34.42	3.91		18.90
off	7/22/96			0.6	0.3	0.9	3.4			1	0	1			1.76	0.00	1.12
on *	7/22/96		0.2	4.4	1.4	5.9	3.2		0	9	3	12		0.00	2.07	2.21	2.05
on	7/23/96			5.0	1.6	6.5	3.2			2	0	2			0.40	0.00	0.31
on [1]	7/24/96			5.6	3.4	9.0	3.4			2	1	3			0.36	0.29	0.33
on	7/25/96			2.1	1.5	3.6	3.4			0	0	0			0.00	0.00	0.00
on	7/26/96			2.4	5.5	7.9	3.7			6	3	9			2.51	0.54	1.13
off	7/27/96		0.5	0.2	0.7	1.4	3.1		0	0	2	2		0.00	0.00	2.74	1.39
off	7/28/96				0.3	0.3	4.0				0	0				0.00	0.00
off	7/29/96		0.7	0.4	1.1	2.2	3.2		4	0	0	4		6.00	0.00	0.00	1.78
off [1]	7/30/96		1.5	2.4	0.3	4.2	2.7		6	14	0	20		3.96	5.88	0.00	4.74
on *	7/30/96			0.9	2.4	3.3	3.7			0	0	0			0.00	0.00	0.00
on	7/31/96	0.4	1.0	4.0	1.4	6.9	2.9	3	6	7	2	18	6.81	5.74	1.75	1.44	2.62
on	8/1/96		0.2	1.4	1.0	2.6	3.3		0	0	0	0		0.00	0.00	0.00	0.00
on	8/2/96	0.1	1.1	1.9	1.3	4.5	3.0	0	7	1	0	8	0.00	6.61	0.51	0.00	1.78
off *	8/2/96				0.3	0.3	4.0				0	0				0.00	0.00
off	8/3/96			2.8	3.2	6.0	3.5			3	3	6			1.08	0.94	1.00
off	8/4/96			1.3	0.8	2.1	3.4			4	2	6			3.14	2.37	2.83
on *	8/4/96				0.3	0.3	4.0				0	0				0.00	0.00
on	8/5/96		0.1	0.8	1.6	2.5	3.6		0	0	0	0		0.00	0.00	0.00	0.00
on	8/6/96	1.3	1.7	1.0		4.0	1.9	0	0	23		23	0.00	0.00	22.42		5.73
off *	8/6/96		0.5	1.3	0.2	2.0	2.8		44	25	1	70		88.00	18.78	5.91	34.99
	Total	2.5	15.8	66.7	50.8	135.7	3.2	77	216	154	54	501	30.64	13.70	2.31	1.06	3.69

Table 4. -- Proportion of observation days in which harbor porpoise were seen within 125 m of net No. 10, classified by alarm state of net No. 10, number of observation hours, and visibility conditions.

	Hours Watched	Average Visibility: Ex-Good (<3)	Average Visibility: Good - Fair (≥3)	Total
Alarm Off	< 4	0/1	0/6	0/7
	≥ 4	2/2	3/4	5/6
	Total	2/3	3/10	5/13
Alarm On	< 4	0/1	0/4	0/5
	≥ 4	0/4	1/5	1/9
	Total	0/5	1/9	1/14

Table 5. -- Log-likelihood values and estimated state model parameters (see Appendix C for definitions) for models l-5 with hours of observation as a covariate.

Model	- Log-likelihood	State Model Parameter Estimates (θ)
1	9.08	0.54
2	5.67	0.17, 0.87
3	9.08	0.55,0.53
4	3.71	0.42 , 0.00 , 0.37, 0.00
5	3.69	0.24, 0.00, 0.00, 1.00, 0.15, 0.00, 0.36, 0.99

Appendix A

Details of Cliff-height Computation

The height of the cliff was determined from a known beach measurement and alternatively from a known distance between the survey site and a landmark, Spike Rock. Points near the waterline were marked on the beach at the northernmost (N) and southernmost (S) limits of the field of view from the survey cliff-site (C) (Appendix Fig. A-l). The distance between the beach points, *a*, was measured with a tape. A theodolite positioned on a tripod 1.45 m above the cliff was used to measure vertical angles **(δ and ϵ)** and the horizontal angle a. The theodolite was then positioned at each of the beach points to measure the horizontal angles (B and y). The sides b and c were computed with the following trigonometric relationships for the oblique triangle BSN:

$$c = \frac{a\sin(\gamma)}{\sin(\alpha)} \qquad b = \frac{a\sin(\beta)}{\sin(\alpha)} \quad .$$

From the vertical angles **δ and ϵ**, t the height of the cliff, *h*, can be computed based on the right triangles CBN and CBS using:

$$h = \frac{c}{\tan(\delta)} \qquad h = \frac{b}{\tan(\epsilon)} \quad .$$

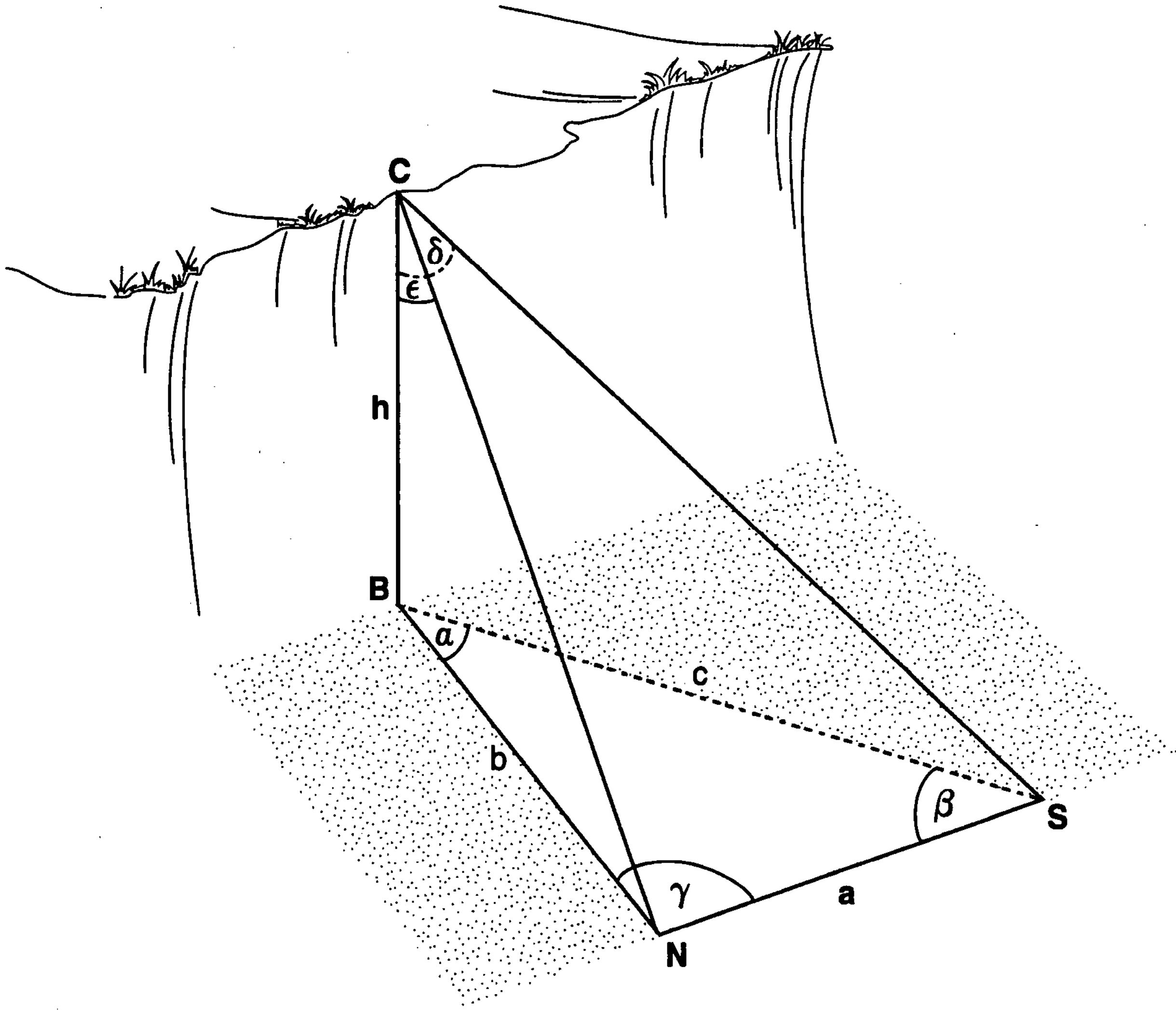
From the measurements made (Appendix Table A-l), determinations for *h* of 44.85 m and 44.78 m were made based on the vertical angles for the south and north points respectively for an average of 44.82 m. The beach measurements were made on 9 July 1996 between 1130 and 1200 h. The high tide at 0848 h was +2.07 m and low tide at 1410 h was +0.58 m. The tide at the time of measurement was approximately +1.3 1 m. The beach points were slightly above sea level to avoid working in the surf Using the theodolite, the height of the points above sea level was measured as the difference in the height of the theodolite above the beach point and a parallel height above a tidepool at sea level. The average height of the beach points above sea level was 1 m. Thus, the height of the theodolite above sea level for a 0 m tide was 47.13 m.

Alternatively, the height, *h*, can be computed from the known distance, *d*, to an object and the vertical angle <BCK denoted ζ (Appendix Fig. A-2) with the following equation:

$$h = \frac{d}{\tan(\zeta)} - 1000*\left(R - \sqrt{R^2 - \left(\frac{d}{1000}\right)^2}\right) \quad ,$$

where R = 6,366 km is the Earth's radius. The second term in the above equation makes a correction for the Earth's curvature. We used this approach by obtaining the distance from an imaginary point below the cliff-site position (B) and the base of Spike Rock (K) as *d* and measured the vertical angle, ζ, from the cliff-site to the water level at the base of Spike Rock. From this computation, the height of the theodolite above sea level at the time of the measurement was 44.90 m. The vertical angle measurement was taken at 1127 h on 9 July, so the correction of +1.3 1 m for the tide, provides a height of the theodolite above sea level for a 0 m tide of 46.21 m.

The difference in these estimates is easily explained when you consider the difficulty of determining the base of Spike Rock at a distance of nearly 2 nautical miles (nmi). We believe the beach measurement approach provides an inherently more accurate measurement of the cliff height. The observer's eye level varied somewhat and was about 0.3 m below the theodolite because the observers were sitting in chairs. Therefore, for observations a height of 46.83 m was used for a 0 m tide. Adjustments to the height from tide variations were made by linear interpolation between the daily highs and lows.



Appendix Figure A- 1. -- Geometric representation of cliff-height measurement (h) at point C to beach positions N and S.

Vertices

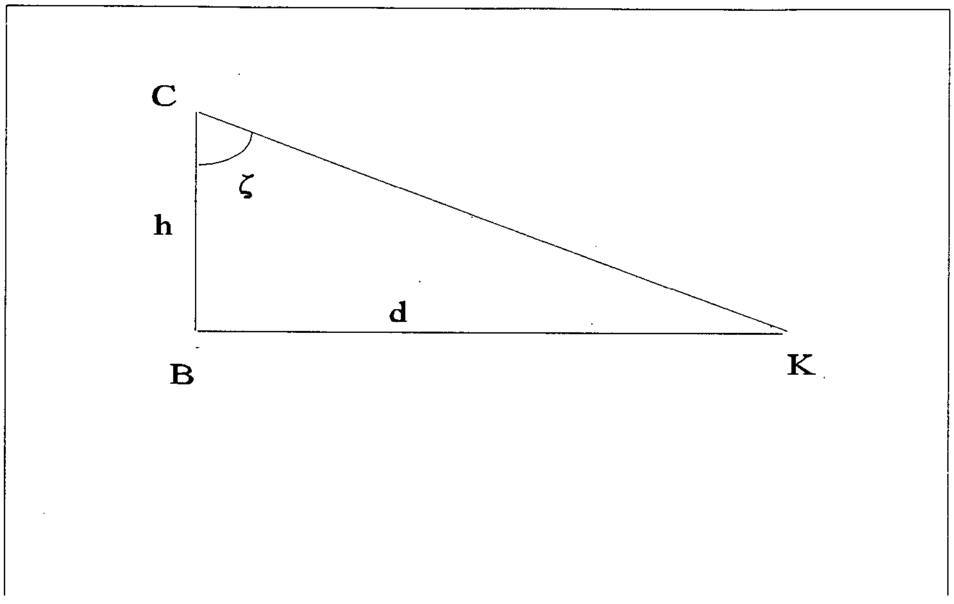
C - survey site on the cliff above the beach
N - north marker on the beach
S - south marker on the beach
B - point beneath C, such that the plane containing B, S and N is perpendicular to the line CB

Angles

a - the horizontal angle, <NBS
B - the horizontal angle <BSN
y - the horizontal angle < SNB
δ - the vertical angle < SBC
e - the vertical angle <NBC

Sides

a - measured length of side NS
b - length of side BN
c - length of side BS
h - length of side CB, the cliff height above sea level



Appendix Figure A-2. -- Geometric representation of cliff-height measurement (h) at point C (survey site) to position K (Spike Rock) at known distance *d*.

Appendix Table A-l. -- Geometric measurements and computed values for height determination.

Angle or Distance	Measured or Computed Value
a	47.77 m
b	117.20 m
c	119.36 m
α	23.2789°
β	75.8411°
γ	80.9194°
δ	69.4061°
ϵ	69.0911°
ζ	89.2667°
d	3586 m

Appendix B

Field Procedure Details

PROCEDURES FOR RECORDING HARBOR PORPOISE SIGHTINGS
FROM A SHORE-BASED OBSERVATION SITE

Use the OBSERVATION EFFORT form to record systematic search effort. Use the SIGHTING FORM to systematically record observations of marine mammals as seen from a shore-based site. Use the TRACKING FORM for logging locations of the buoy markers. Use the “Green Book” to record general descriptions of daily events, including personnel changes at the observation site, problems encountered, and summary notes.

OBSERVATION EFFORT

Location: Enter “Boundary” for the observation site on the bluff northeast of Shi Shi Beach (height 46.8 m). If alternate sites are used, give them descriptive names and establish their altitudes.

Date. Enter date as indicated. Only one date per page.

Page / : Show which page and number of pages in a series. A series consists of all hand-logged data from the same day. Pagination should start with “Observation Effort,” then “Sighting Form,” then “Tracking Form.” This helps keep track of how many pieces of paper are associated with each day’s effort.

Time: Use militaty hours (1:00 pm = 13:00:00). Each day, synchronize time with the acoustic team. Record time to the second. Indicate the time a systematic watch is truly in effect, not the time an observer is in place starting to prepare for a watch.

Observer: Enter initials (see attached listing).

Position: Record the role the observer is taking, as determined by the field needs (i.e, inshore vs. offshore). When the entry is for the end of a watch, write “OFF” in the “Position” column.

Recorder: Initials of the data recorder.

[update the following entries each watch rotation or with each significant change of conditions. Sea state and visibility conditions are recorded separately for the inshore-offshore observers.]

Viz: Visibility is a sightability index; it is a record of how well you can see porpoise, not the visibility of the horizon. Primary considerations in establishing visibility are 1) an observer’s attentiveness, 2) light level and direction, 3) rain or fog, and 4) sea state.

EX = excellent: Clear skies or high clouds; no problem with light or glare; horizon is visible; sea state does not compromise sightability of porpoise. The effective sighting range is >l mni (<7 retitles).

VG = very good: Clear skies or some cloud cover; very little problem with light level, glare, or sea state. The effective sighting range is out to nearly 1 mni (7 retitles) with hardly any interference.

GO = good: Weather may be cloudy, hazy, light fog, or clear; some visibility interference with low light level, flat light, glare, or sea state (choppy or large swells). The effective sighting range is out to 0.5 mni (14 retitles) without any interference.

FA = fair: Weather may be cloudy, very hazy, foggy, rainy, or clear; visibility interference is occurring because of low light level, glare, fog, rain, or sea state (Beaufort 2 or higher). The sighting range out to 0.5 mni (14 retitles) is somewhat compromised.

PO = poor: Visibility is badly compromised by near darkness, extreme glare, rain, fog, choppy seas, or a high surf. Effective sighting range is under 0.3 mni (>21 reticles).

UL = useless: The watch effort is ineffective due to darkness, heavy rain, thick fog, or a wind storm.

Wind. Beaufort Scale.

WX: Weather that affects the standard viewing area; indicate only the condition which affects the view the most. CL = clear (0-10% overcast); **HOV** = high overcast, such as cirrus (indicate percent); **LOV** = low overcast, such as cumulus (indicate percent); **LF** = light fog; **HF =** heavy fog; **LR =** light rain; **HR =** heavy rain.

Glare: Describe glare only as it affects the standard search area. N = none; M = moderate; X = extreme.

Comments: Note any elements that might affect the search other than those recorded above.

SIGHTING FORM

Observers are searching different parts of the study area. We are not conducting a "double-blind" study; therefore, we have an open communication about sightings. However, if one observer calls out a sighting, the other observer should not change their search routine.

Each sighting is treated as a new entry. If links between sightings are evident, note them in the "Comments" column. If there is a rapid series of surfacings in view, try to record the minutes and seconds of each surfacing with locations on as much of the group as is possible.

Time: Record time to the second when making sightings.

Vertical: Use the 14 vertical reticle marks in the 7x50 Fujinon binoculars (17' per reticle mark). the marks are of two different widths, treat them as equal, running from 0 at the topmost to 14 at the bottom. Subdivide to tenths of an increment as best you can. Count retitles from the sighting up to the horizon. If horizon is not clear (i.e., obscured by haze, fog or rain), estimate the number of retitles and write "E" next to the reticle reading.

Bearing: Give the magnetic bearing to the target (as read in the binocular).

Sp: Enter **PP** for harbor porpoise; **EL** for sea otter; **ER** for gray whale; **ZC** for California sea lion; **EJ** for Steller sea lion; **PV** for harbor seal. Also use this column when making entries of other targets, such as boats or buoys.

Count: How many of the target species occurred at the given time and location? separated sightings, they should be entered on different data rows and each recorded as a count of 1, even though the two animals appeared to be traveling together. Use the "Comments" column to note your observations of apparent associations.

Obsv: Record the initials of the observer who called the sighting.

Comments: Make long comments on the back of the form, and write "Over" in the "Comments" column. Comments may include animal's direction of travel (in magnetic bearing from 0° to 360°) behavior (slow, fast, milling, pop-splash, etc.), apparent group size (if a group was too far apart in time or space to be combined in the "Count" column), etc.

TRACKING FORM

Entries are self-explanatory. Include instrument height and station altitude in the "Alt" entry. Record buoy positions at the start of each day and approximately every two hours afterwards.

[The NT2A theodolite is accurate to 20" with a 19-power lens and an optical field of view of 1.50°.]

OBSERVERS

LB = Lisa Baraff	MD = Melissa Dolan	BH = Brad Hanson	SH = Scott Hill
RH = Rod Hobbs	JL = Jeff Laake	SM = Sally Mizroch	MM = Marcia Muto
DR = David Rugh	KS = Kim Shelden	JW = Janice Waite	

ROTATION SCHEDULE

4 person team - 45 minute periods - 2 observers; 1 recorder; 1 rest

Pattern: Observer -> Rest -> Observer -> Recorder

3 person team - 30 minute periods - 2 observers; 1 recorder

Pattern: Observer 3 Recorder -> Observer

Rotate through this pattern for 3 periods, and then the entire team rests for 30 minutes. After each set of 4 periods, observers should have rotated through the starting positions. This does mean each person will have 1 hr search periods when 2 observation periods are contiguous.

TRACKING FORM

Location: **Alt:** **Observer:** **Recorder:** **Date:** **Page /**

TIME hr: min: sec	VERTICAL deg: min: sec	HORIZONTAL deg: min: sec	TARGET	COMMENT

OBSERVATION EFFORT

Location: ____________________________ **Date:** __________ **Page** ____/ ____

Time	Observer	Position	Recorder	Viz	Wind	WX	Glare	Comments

SIGHTING FORM

Location: ____________________________ Date: ______________ P a g e /

Time	Vertical	Bearing	Sp	Count	**Obsv**	Comments

Appendix C

Analysis Details

The state of the system s_i on day *i* is either 1 if porpoise used the defined region around the net, or 0, if porpoise did not use the region. For day *i*, $x_i = 0$ if the net was not alarmed and $x_i = 1$, if the net was alarmed and h_i is the number of hours the net was observed. The observed state of the system y_i at time *i* is either 1 if porpoise were observed in the defined region around the net, or 0 if the porpoise did not use the region or used the region but were not seen. The relationship between the true and observed system states can be expressed as:

$$Pr[y_i|s_i=1]=\begin{cases} p^*(h_i) & y_i=1 \\ 1-p^*(h_i) & y_i=0 \end{cases}$$

$$Pr[y_i|s_i=0]=\begin{cases} 0 & y_i=1 \\ 1 & y_i=0 \end{cases} ,$$

where $p^*(h_i)$ is the probability that porpoise are observed using the region with h_i hours of observation, modeled as a logistic:

$$p^*(h) = \frac{e^{\gamma_0+\gamma_1 h}}{1+e^{\gamma_0+\gamma_1 h}}$$

Each y_i is a Bernoulli random variable that has probability p_i that $y_i = 1$ and probability $1-p_i$ that $y_i = 0$. The y_i are assumed to be conditionally independent given the values of p_i. Depending on the assumptions, p_i may depend on the previous values of y, ,..., y_{i-1} as influenced by the true states of the system, s_i, the alarm states of the net, x_i, and the hours of observation (h_i) at each previous day:

$$p_i = Pr(y_i=1|y_1,\ldots,y_{i-1},x_1,\ldots,x_{i-1},h_2,\ldots,h_{i-1})$$

The likelihood function conditioned on the first observation is:

$$\mathcal{L}(\theta,\gamma_0,\gamma_1|y_1,\ldots,y_n,x_1,\ldots,x_n,h_2,\ldots,h_n) = \prod_{i=2}^{n} p_i^{y_i}(1-p_i)^{1-y_i} .$$

For a model which assumes that the s_i are independent:

$$p_i = p^*(h_i)\, Pr[s_i=1\,|x_i] \quad .$$

For Model 1, with no alarm effect

$$Pr[s_i|x_i]=Pr[s_i]=\begin{cases}\theta_1 & s_i=0\\ 1-\theta_1 & s_i=1\end{cases} \quad ,$$

and for Model 2 with an alarm effect:

$$Pr[s_i|s_{i-1},x_i,x_{i-1}]=Pr[s_i|x_i]=\begin{cases}\theta_{1+x_i} & s_i=0\\ 1-\theta_{1+x_i} & s_i=1\end{cases} \quad ,$$

where $0 < \theta_i < 1$. The independence models could use all ***n*** observations, but the first observation was dropped to allow comparisons with the dependence models.

For a hidden Markov-chain model with first-order dependence

$$p_2 = Pr[y_2=1\,|y_1=s_1,x_1,x_2,h_2] = Pr[s_2=1\,|s_1,x_1,x_2]p^*(h_2) \quad ,$$

and for i>3,

$$\begin{aligned}p_i = {} & p^*(h_i)\,Pr[s_i=1\,|s_{i-1}=1,x_i,x_{i-1}]\,Pr[s_{i-1}=1\,|y_1,\ldots,y_{i-1},x_1,\ldots,x_{i-1},h_2,\ldots,h_{i-1}]+\\ & p^*(h_i)\,Pr[s_i=1\,|s_{i-1}=0,x_i,x_{i-1}]\,(1-Pr[s_{i-1}=1\,|y_1,\ldots,y_{i-1},x_1,\ldots,x_{i-1},h_2,\ldots,h_{i-1}])\end{aligned}$$

where

$$_{-1}=1\,|y_1,\ldots,y_{i-1},x_1,\ldots,x_{i-1},h_2,\ldots,h_{i-1}] = \frac{Pr[y_{i-1}|s_{i-1}=1]\,Pr[s_{i-1}=1\,|y_1,\ldots,y_{i-2},x_1,\ldots,x_{i-1},h_2,\ldots,h_{i-1}]}{\sum_{s_{i-1}=0}^{1} Pr[y_{i-1}|s_{i-1}]\,Pr[s_{i-1}\,|y_1,\ldots,y_{i-2},x_1,\ldots,x_{i-1},h_2,\ldots,h_{i-1}]} \quad ,$$

and,

$$Pr[s_{i-1}=1|y_1,\ldots,y_{i-2},x_1,\ldots,x_{i-1},h_2,\ldots,h_{i-1}] = \sum_{s_{i-2}=0}^{1} Pr[s_{i-1}=1|s_{i-2},x_{i-2},x_{i-1}]\,Pr[s_{i-2}|y_1,\ldots,y_{i-2},x_1,\ldots,x_{i-2},h_2,\ldots,h_{i-2}]$$
$$Pr[s_{i-1}=0|y_1,\ldots,y_{i-2},x_1,\ldots,x_{i-1},h_2,\ldots,h_{i-1}] = 1 - Pr[s_{i-1}=1|y_1,\ldots,y_{i-2},x_1,\ldots,x_{i-1},h_2,\ldots,h_{i-1}] \quad .$$

For Model 3 with first-order dependence of s_i but no alarm effect:.

$$Pr[s_i|s_{i-1},x_i,x_{i-1}]=Pr[s_i|s_{i-1}]=\begin{cases}\theta_{1+s_{i-1}} & s_i=0\\ 1-\theta_{1+s_{i-1}} & s_i=1\end{cases} \quad .$$

For Model 4, with first-order dependence of s_i and an alarm effect:

$$Pr[s_i|s_{i-1},x_i,x_{i-1}]=Pr[s_i|s_{i-1},x_i]=\begin{cases}\theta_{1+2x_i+s_{i-1}} & s_i=0\\ 1-\theta_{1+2x_i+s_{i-1}} & s_i=1\end{cases} \quad .$$

For Model 5, with first-order dependence of s_i and alarm effect for current and previous states:

$$Pr[s_i|s_{i-1},x_i,x_{i-1}] = \begin{cases}\theta_{1+4x_{i-1}+2x_i+s_{i-1}} & s_i=0\\ 1-\theta_{1+4x_{i-1}+2x_i+s_{i-1}} & s_i=1\end{cases} \quad .$$

Allowing for dependence on the previous state requires some assumption regarding the beginning of the experiment to compute the likelihood. The options are either to condition on the first state or to assume the process has been going for an infinite amount of time and is at equilibrium. We chose the former because the pingers had been used for a short time prior to initiating observation. Conditioning on the first state requires knowing the true value of the first state, s_1. If $y_1 = 0$, as it was in this particular case, s_1, is unknown. However, we have assumed that $s_1 = y_1 = 0$ in this case because $h_1 = 5.7$ hours and $p^*(5.7) = 1$ for our data. We fitted models that assumed that s_1 was 0 and 1, effectively treating s_1 as a parameter, and $s_1 = 0$ was more likely.

The calculation of the p_1 is recursive. To take advantage of the recursiveness the likelihood was re-written as:

$$\mathcal{L}(\theta,\gamma_0,\gamma_1 | y_1,\ldots,y_n,x_1,\ldots,x_n,h_2,\ldots,h_n) = \prod_{i=2}^{n} Pr[y_i | y_1,\ldots,y_{i-1},x_1,\ldots,x_i,h_2,\ldots,h_i]$$
$$= \pi(y_1 = s_1, y_2,\ldots,y_n,x_1,\ldots,x_n,h_2,\ldots,h_n) \quad ,$$

where

$$\pi(s_{i-1},y_i,\ldots,y_n,x_i,\ldots,x_n,h_i,\ldots,h_n) = \begin{cases} Pr[s_i=0 | s_{i-1},x_i,x_{i-1}]\ \pi(s_i=0,y_{i+1},\ldots,y_n,x_{i+1},\ldots,x_n,h_{i+1},\ldots,h_n)\ + & \\ Pr[s_i=1 | s_{i-1},x_i,x_{i-1}]\ \pi(s_i=1,y_{i+1},\ldots,y_n,x_{i+1},\ldots,x_n,h_{i+1},\ldots,h_n)(1-p^*(h_i)) & y_i=0 \\ Pr[s_i=1 | s_{i-1},x_i,x_{i-1}]\ \pi(s_i=1,y_{i+1},\ldots,y_n,x_{i+1},\ldots,x_n,h_{i+1},\ldots,h_n)\,p^*(h_i) & y_i=1 \end{cases}$$

These recursive computations were used to compute the likelihood of the parameters for the observed data vector with Splus routines. The parameter values that maximized the likelihood were obtained using the Splus routine NLMINB.

RECENT TECHNICAL MEMORANDUMS

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