Evaluation of high-powered binoculars to detect inter-year changes in offshore distribution of eastern North Pacific gray whales

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ABSTRACT

Paired, independent searches for gray whales (*Eschrichtius robustus*) were conducted through fix-mounted, 25-power binoculars during January 1995 and 1996 at Granite Canyon, California. The study was a test of an efficient method for documenting inter-year changes in the offshore distribution of the migration. The research site has been used most years since 1975 by the National Marine Mammal Laboratory to make counts for abundance estimates of gray whales. Matching sightings between the paired observation efforts showed a very high agreement between observers (detection probability 0.97) for whale groups apparently of more than one animal within 1-3 n.miles of shore and a fairly high agreement (0.87) for animals travelling alone (5% of the sampled population) within 1-3 n.miles of shore. Sighting probability thus remained high up to 3 n.miles, a distance which includes most (98.7%) of the whale migration. For the critical sighting range of 1-3 n.miles, the method applied here is considered a feasible, cost-effective technique for detecting inter-year differences in the offshore tail of the distribution.

KEYWORDS: GRAY WHALE; SURVEY-SHORE-BASED; DISTRIBUTION; NORTH PACIFIC

INTRODUCTION

The National Marine Mammal Laboratory (NMML) has been conducting shore-based counts of southbound migrating gray whales most winters over the past four decades. Since 1975, all of these counts have been made at Granite Canyon, near Carmel, central California (Reilly, 1992; Shelden *et al.*, 1997). The counts have formed the basis for estimates of and trends in abundance for this species (e.g. Buckland *et al.*, 1993; Buckland and Breiwick, 2002). The estimates are corrected for whales missed during watch periods using a sight-resight (double count) analysis of information from independent observers (Rugh *et al.*, 1990; 1993). However, the validity of the abundance estimates depends on the assumption that the sight-resight model incorporates all variables affecting detection probability. If whales pass at distances which effectively make them undetectable, abundance will be underestimated. Trend analysis assumes that there is no time dependence in any bias (Buckland *et al.*, 1993). If the offshore distribution of gray whales was to shift significantly beyond the shore-based observers' visual range (approximately 3 n.miles), bias could develop. Aerial surveys have been used to measure offshore distribution in the vicinity of the counting station (Reilly *et al.*, 1983; Withrow, 1990; Shelden and Laake, 2002) because there has been concern that the migratory corridor shifts significantly between years and needs to be assessed during each survey (Reilly, 1981).

Prior to using reticled binoculars (in 1985), distances to whale sightings were simply estimated. Results suggested there were large inter-year variations in offshore distribution (Reilly, 1981); however, on closer examination there appears to be little basis for using the estimated values as they were not calibrated. For example, from 1967-1980, observers estimated that 13.0% to 62.8% of the whale groups passed within 0.25 n.miles of shore (Reilly, 1981, table 7); yet, after reticled binoculars were in use, no more than 7% were sighted that close to shore (NMML, unpubl. data). Buckland and Breiwick (2002), in their analysis of gray whale counts from Granite Canyon, concluded 'that estimated distances offshore from shore-based observers are suspect'. It seems that offshore distances were grossly underestimated by shore-based observers before the use of reticled binoculars.

Six seasons of aerial survey effort near Granite Canyon showed that the nearshore (< 2.25 n.miles) and offshore (> 2.25 n.miles) distribution of gray whale pods did not differ significantly among survey years (Shelden and Laake, 2002). Only 4.76% of the pods were beyond 2.25 miles, and only 1.28% were beyond 3 miles (Shelden and Laake, 2002). Aerial surveys are clearly the most accurate method of assessing the offshore distribution of gray whales because the probability of detection is constant for all offshore distances, whereas shore-based observers will have a loss in detection probability as distance increases. However, aerial surveys are very costly, requiring approximately 40% of the annual survey budget and sample size may be limited. As a cost-effective replacement for aerial surveys, this study evaluated 25-power, reticled binoculars as a technique for detecting inter-annual changes in the offshore tail of the whale distribution. Because most (approximately 99%) of the gray whales passing Granite Canyon have been within 3.0 n.miles of shore (Shelden and Laake, 2002), 25-power binoculars may be a useful tool if the probability of detecting surfacing whales is high and relatively uniform up to 3 n.miles. This study estimates the detection probability of observers using 25-power binoculars with sight-resight data collected from paired, independent counts.

METHODS

The paired, independent observer effort using two fix-mounted, 25-power binoculars ('Big Eyes') was conducted 6-25 January 1995 and 7-25 January 1996 during the gray whales' southbound migration past Granite Canyon (elevation 20.5m). Concurrent with the high-powered binocular study, standard counts were made for abundance estimations as in previous surveys (Rugh *et al.*, 1990; 1993). During the standard count effort, searches for whales were made across a 40-50° field of view, primarily without optic aids but assisted by handheld 7-power binoculars with compasses and reticles. In addition to the shore-based studies, an aerial survey was conducted in January 1996 (Shelden and Laake, 2002). Results from the 1995/96 standard counts are reported in Hobbs *et al.* (1996).

Paired binoculars

Each 25-power binocular was housed in a separate observation shed. These sheds were approximately 2m apart and separated from sheds used for the standard census. The binoculars were supported on 1.2m wooden frames so that observers could view through them while comfortably seated. Fine vertical and horizontal adjustments allowed the binoculars to be set to nearly identical fields of view, which was critical for the paired effort. The horizontal orientation was along the 241° magnetic line, equivalent to the primary sighting angle on the standard watch. The 25-power magnification and narrow field of view (2.7°) made the system very sensitive to misalignment. Slow moving targets, such as distant ships, were used to check horizontal alignment and make adjustments if necessary. Alignment of the two binoculars was kept accurate to within 0.03° (1% of the field of view).

Horizontal sectors

The horizontal field of view in the binoculars was divided into 6 *ad hoc* sectors. This provided an assessment of the horizontal component of a sighting. As the sectors were not etched onto the eyepieces, they had to be approximated by observers with the assistance of a drawing (Fig. 1). Whales seen to the extreme left or right (sectors 1 or 6) may have been missed by one of the two observers if the two binoculars were not exactly aligned; in the paired-record analysis, these entries were examined relative to sightings made in the mid-range (sectors 2-5).

Vertical increments

The binoculars had scribed marks to delineate most of the vertical field of view. These showed whole and half increments for each of 20 reticles (0.077° each; Kinzey and Gerrodette, 2001), with the uppermost reticle sub-divided into fifths (Fig. 1). The uppermost line was set on the horizon, and the vertical angle was established as the number of reticles counted from the horizon down to the waterline where a whale surfaced. The vertical viewing perimeter of the search effort ranged from 9.0 n.miles (the horizon) to <0.4 n.miles, the closest perimeter in which a whale may have been seen. Calculations for offshore distance included a correction for dip to the horizon (the angle between absolute horizontal and the apparent horizon) and curvature of the earth. Distances were checked with an array of calibrations conducted in cooperation with a US Coast Guard vessel.

Observers

At different times during the two research seasons, 12 observers took part in the study. All were experienced cetacean survey observers, and several had previous experience with gray whale counts at Granite Canyon. During periods with acceptable sighting conditions, standard and fixed-binocular watches were conducted continuously and simultaneously such that two to four observers were on effort at a time. Effort on the fixed-binoculars was divided into 45min watches and generally ran from 07:30 to 16:30.

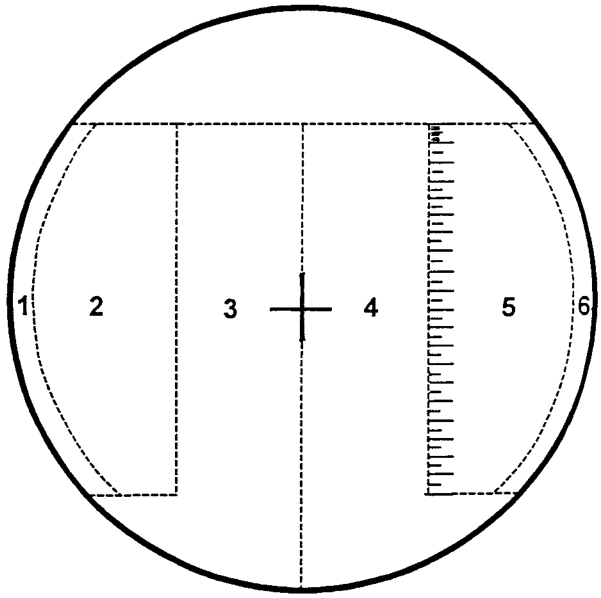

Fig. 1. Horizontal sectors (bordered by dashed lines) and vertical reticle marks (solid bars) used to describe locations of whale sightings in fix-mounted, 25-power binoculars. The dashed line across the top of the field of view demarks the horizon. Other dashed lines represent subjective borders. Solid lines represent marks permanently etched in the binocular optics.

Watch rotations gave each observer equal pairing with all other available observers over the respective season. Observers were given at least a 1.5hr rest before and after each standard watch and a minimum of 45min rest between watches on the fixed binoculars.

Independent effort

To keep the search efforts independent, no cues were communicated between observers while on watch. Visual isolation was provided by the walls of the observation sheds. Surf and wind noise or portable headsets blocked out other observers' voices. In an attempt to maximise search effort through the binoculars and minimise the time spent looking away, data were collected through voice-actuated tape recorders. After each 45min observation period, data were transcribed from tapes onto standard recording forms.

Timing

Precise timings of surfacings were required to minimise discrepancies and potential ambiguities when making matches between the paired observers' records. At the start of each day, time pieces were synchronised to within 1sec. During the search through the binoculars, whale surfacings were recorded on audio tapes along with information on the vertical reticles and horizontal sectors in which the sightings occurred. The exact time was then reported to the second by a glance at a nearby digital watch. Pod sizes were estimated after each whale group left the field of view. During data transcription, the exact time of each surfacing was back-calculated from the recorded times. The precision in recording time was within 6sec. When an observer felt a time could not be estimated to within 10sec, a 'T' was entered to indicate 'time estimated'. When time could not be estimated closer than 60sec, a 'U' was entered for 'unknown time'. Only one surfacing per whale group was recorded in the primary dataset; other surfacings were usually tallied and later aided in the matching process. The surfacing tally was a record of the number of times each whale in the respective pod was visible.

Visibility

Visibility was recorded as the apparent sightability of whales. It was subjectively appraised into one of six categories from excellent (1, an uncompromised view of the search area) to useless (6, very low likelihood that a surfacing whale could be seen). Because visibility through the binoculars often changed dramatically as a function of distance, the first 4 reticles below the horizon (> 0.5 n.miles) were each assigned separate visibility ratings, while all distances inshore of reticle 4 (< 0.5 n.miles) were given a single rating; therefore, there were five visibility zones designated from the horizon down.

Establishing matches between paired sighting records

The paired records were manually searched for matches (i.e. whale groups recorded by both observers). To establish parameters in which a pair of sightings might be considered a match, several people independently reviewed each season's data, looking for sightings that were within a few seconds, reticles and sectors of each other. This *ad hoc* process also allowed for the possibility that different sightings were recorded of the same whale group as it passed southward through the viewing area. The independent reviews were then compared, first to establish obvious matches (within 6sec, 1 reticle and 1 sector) and then to work out appropriate rulings for ambiguous cases. Most matchings (98.3%) were unequivocal. Surfacing times proved to be the most important data used for recognising matches. Vertical measures (reticles) and horizontal sectors were used to locate positions of sightings, while information on group size, behaviour (e.g. breaching or fluking) and number of sighting cues, helped support decisions on matches.

Only periods when two observers were systematically searching were reviewed. When an entry had time recorded as estimated (T) or unknown (U), the observer's record was treated as 'off watch' for the time between the previous timed entry and the following timed entry. Sightings within the corresponding time period in the paired observer's record were also deleted. Summarising both sets of records for both years, 88 sightings were deleted because of time recording problems. That represents only 4% of the recorded sightings, so any potential bias in terms of a higher probability of deleting matched rather than unmatched records is minimal.

Analysis

Once the matching record was established, a sight-resight type analysis was performed using the logistic regression approach of Buckland *et al.* (1993). With this method, the sensitivity of the sighting probability to different covariates can be reviewed.

For the 1995 dataset, the covariates considered were horizontal sector, pod size, distance offshore (expressed in reticles), visibility, observer and location (south or north sheds) (Table 1). The visibility code for a sighting was the single visibility code assigned to the reticle range within which the sighting was made. Counts of sighting cues were considered to approximately equate pod size estimates and therefore were not treated separately in the covariate analysis. All covariates were treated as categorical data. All covariates were entered into the model, and a backward step-wise model selection was used until no step decreased the Akaike's Information Criterion (AIC).

The 1996 data were analysed as for 1995 except that horizontal sector was dropped as a covariate (parts of sectors 1 and 6 were potentially not in view in both binoculars, so they were not used in the analysis), sea state and wind direction were added, and distance was treated as distance offshore rather than reticles below the horizon, thus increasing compatability with other studies (Table 1). All covariates were initially examined individually as categorical data, with numeric covariates treated as binned data. Numeric data were then assigned a functional form, or bins were combined to represent the data with as few parameters as possible. A visibility threshold was determined from the result of this categorical analysis; sightings from effort periods with lower than the threshold visibility were removed, while higher visibilities were uniformly included, without separate treatments for each visibility category. All covariates were then entered into the model and a backward step-wise model selection was used until no step decreased the AIC.

Table 1

Data collected while using paired, high-powered binoculars to observe gray whales migrating south past the shore-based station at Granite Canyon, California.

Data fields	Covariates analysed[1] 1995	1996	Covariates included in the model
Location (N or S Shed)	2	2	-
Date	-	-	-
Observer	7	13	-
Effort (start and stop time)	-	-	-
Visibility	6	6	6 *vs* <6
Wind direction	-	16	-
Wind force	-	5	-
Sighting time	-	-	-
Sighting sector (horizontal)	6	-	sectors 1 and 6 *vs* 2-5
Sighting reticle (vertical)	>20	>20	reticles 0-2 *vs* 2-3 *vs* >3
Size of whale group	5	8	1 *vs* >1
Presence of a calf	-	-	-
Travel direction	-	-	-
Behaviour	-	-	-
Number of sighting cues	-	-	-
Comments	-	-	-

[1] Column entries are the number of categories recorded for each covariate.

RESULTS

Watch effort

During 6-25 January 1995, there was a total of 76.3 hours of observation in the south binocular and 74.7 hours in the north (of which 69.7 hours were paired). During 9-25 January 1996, there was a total of 124.9 hours in the south binocular and 119.1 hours in the north (of which 108.9 hours were paired). Effort was greatly compromised by weather conditions in 1995; unusually intense winds, rains and flooding dominated portions of the season. Weather in 1996 was considered fairly typical for winters in the study area.

Sample size

In 1995, 381 pods (543 whales) were seen from the south binocular and 360 pods (502 whales) from the north. In 1996, 631 pods (1,038 whales) were seen from the south binocular and 613 pods (981 whales) from the north. Between the two seasons, peak counts reached 21 pods/hr but averaged 2.4 pods/hr, and on 20 of the 45-minute watches (8 in 1995; 12 in 1996) no whales were recorded. Based on the recorded number of sighting cues, whales surfaced an average of 1.7 times through the field of view.

Table 2 shows the number of sightings in each distance bin (0.25 n.miles) as used in the analysis after removing sightings from sectors 1 and 6, entries with timing problems, data collected during low visibility periods and any but unequivocal matches between observers' records.

Table 2

Number of gray whale sightings made during a study with high-powered binoculars at Granite Canyon, California. Sightings are shown as a function of distance from shore (n.miles) and observation shed. When paired observers recorded different offshore distances for a sighting they made in common, the data were split between the respective distance bins in this table.

	1995			1996			Both sheds in both years (%)
Distance offshore	North shed	South shed	Both	North shed	South shed	Both	
0-0.5	0	0	0	0	0	0	0.0
0.5	1	1	1	5	6	4	0.8
0.75	10	11	9	16	17	15	3.5
1.0	9	10	7	61	54	53	8.6
1.25	27	45	29	99	105	95.5	17.6
1.5	68	53	51.5	108	106	97.5	21.4
1.75	71	71	57.5	75	79	72	18.9
2.0	49	49	43.5	74	66	65.5	15.2
2.25	24	17	18	22	25	21	5.6
2.5	12	9	7	9	15	10.5	2.9
2.75	3	10	4.5	8	8	6.5	1.9
3.0	8	6	4	5	6	5.5	1.6
3.25	4	3	2.5	1	1	0.5	0.6
3.5	0	0	0	1	0	0.5	0.1
3.75	2	2	0.5	1	0	0	0.3
4.0	0	3	1	1	2	1	0.4
4.25	0	0	0	0	0	0	0.0
4.5	3	0	1	0	0	0	0.2
4.75	1	1	1	0	0	0	0.1
5.0	0	1	0.5	0	0	0	0.1
5.25	0	0	0	0	0	0	0.0
5.5	2	1	0.5	0	0	0	0.2
>5.5	0	0	0	0	1	0	0.1
Totals	294	293	239	486	491	448	

Of the sightings matched between paired records, most (87%) were < 6sec apart, 96% were within 1 sector of each other and 96% were within 1 reticle. Of the sightings seen while two observers were on watch in 1995, 239 pods were recorded by both observers and 109 pods were recorded by only one. In 1996, 448 sightings were matched and 81 unmatched. This makes a total of 687 pods seen by both observers compared to 190 seen by only one observer.

Covariates

The significant covariates in the logistic regression of the 1995 data were horizontal sector, pod size, distance offshore and visibility. To keep the model simple and relatively easy to interpret, no interaction terms were considered. Horizontal sectors (1 and 6 *vs* 2-5), pod size (1 *vs* > 1) and visibility (6 *vs* < 6) were each separated into two different categories, while distance offshore was divided into three categories (reticles 0-2, 2-3 and > 3). The extreme horizontal sectors (1 and 6) had some distortion, therefore the associated sightings (58 unmatched pods and 30 matched pods) were removed from further analysis, increasing the probability that both observers were studying the same viewing area.

Analysis of the 1996 data indicated a significant drop in sighting probability with visibility > 4, which was chosen as the visibility threshold. The seven pods sighted at visibility 5 were discarded from the analysis; none were seen in visibility 6. The significant covariates in the logistic regression were pod size, distance offshore and observer. Interactions of these three terms were considered and none were significant. A functional form was assigned to distance offshore which was modelled with linear, quadratic and inverse terms. The inverse of distance was included to model a steep drop in sightability near shore. The squared term dropped out and the linear and inverse terms remained. The detectability of pods of size one was significantly less than that of pods of size two or greater, but no significant difference in detectability occurred among the categories for pods > 1, so bins of 1 and > 1 were used. Observers were treated individually and were found to be significant covariates as a group, though no observer was found to be significantly different from the average observer; observer was thus dropped as a covariate.

Detection probabilities

In 1995, the proportion of sightings seen by an average observer was 0.87 when pod size was = 1 (visibility < 6; sectors 2-5; distance < 1.88 n.miles) and 0.95 when pod size was > 1. In 1996, the proportion of sightings seen by an average observer was 0.87 when pod size was = 1 (visibility < 5; sectors 2-5; distance 1-3 n.miles) and 0.97 when pod size was > 1. Detection probabilities are shown as a function of distance offshore (Fig. 2), with pod sizes = 1 and > 1 segregated. The mean offshore distance of pod sightings, when visibility was < 5, was 1.94 n.miles ($n = 302$ pods; SD = 0.66 n.miles) in January 1995 and 1.72 n.miles ($n = 667$ pods; SD = 0.53 n.miles) in January 1996. These mean distances are not comparable to those obtained from aerial surveys because the nearshore sighting probability is low within the binoculars' field of view. In summary, then, the paired-observer sighting records showed a very high agreement between observers (detection probability 0.97) when whale group size was > 1 within 1-3 n.miles of shore and a fairly high agreement (0.87) for single whales (5% of the sampled population) within 1-3 n.miles of shore. Sighting probability thus remained high up to 3 n.miles, a distance which includes most (98.7%) of the whale migration (Shelden and Laake, 2002).

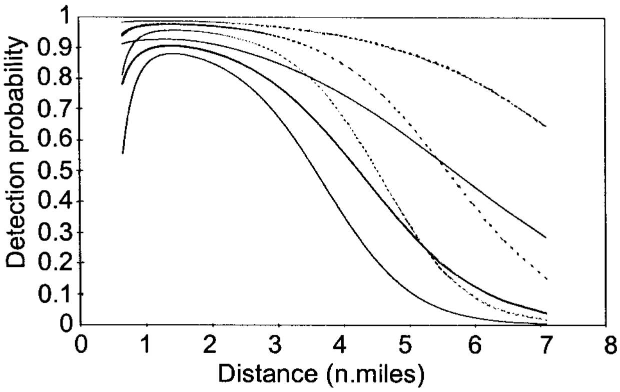

Fig. 2. Detection probabilities of gray whale pods migrating south past Granite Canyon, California, shown as a function of distance offshore. Detection is determined through rates of sightings matched or not matched between independent, paired observations on high-powered binoculars. The solid lines ($\bar{x}$ with 95% CI) show sightings where pod size = 1, and the dashed lines ($\bar{x}$ with 95% CI) show pod size > 1. Data are from all but the extreme horizontal sectors (1 and 6) and from all but the worst visibilities (5 and 6).

DISCUSSION

The process of comparing paired, independent observation records is not new (e.g. Magnusson *et al.*, 1978; Maxim *et al.*, 1981; Rugh, 1984; Rugh *et al.*, 1990; 1993), but the application of this process to determining probability of detection in high-powered binoculars led to greater precision. The field of view for an observer on the standard watch was approximately 160° while the field of view through the 25-power binoculars was less than 3°. Although observers on the standard watch had many more opportunities to see each whale group passing through the search area, the likelihood that two observers would be looking in the same direction was small relative to two observers looking through the two aligned binoculars. The test with fix-mounted binoculars was therefore a relatively accurate assessment of sightability of whales in the common field of view (detection probability > 0.9) in comparison with the paired standard watch (0.8; Rugh *et al.*, 1993). By locking down the binoculars on their frames and making fine adjustments for alignment, both observers should have been studying the same area. In the analysis, small amounts of misalignment were compensated for by removing records of sightings made in the extremes of the field of view (sectors 1 and 6). By using tape recorders and keeping the search effort to only 45 minutes at a time, the chance that one observer would have been looking away when the other made a sighting was minimised. The system improves the likelihood of detecting distant whales and increases the precision of location data. Through sight-resight type analysis, detection probability as a function of distance from shore may be calculated, and significant shifts in offshore distribution of the migratory corridor should be evident. With these refinements, paired binoculars provide an accurate mechanism for monitoring the offshore distribution of gray whales within the viewing area.

Detection probabilities calculated here might be overestimated as they do not account for all sources of heterogeneity, such as differences in number and size of sighting cues per whale at a given distance. Some surfacings are high, and the blows are distinct, while others are low and cryptic. However, even if this bias is significant (as much as 20%), the detection probability is sufficiently high for high-powered binocular surveys to be used instead of aerial surveys in detecting inter-year shifts in the offshore tail of the distribution of migrating gray whales.

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