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A TEST OF TWO PHOTOGRAMMETRIC MEASURING INSTRUMENTS USED TO DETERMINE DOLPHIN LENGTHS FROM VERTICAL AERIAL PHOTOGRAPHS

James W. Gilpatrick, Jr.
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U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Southwest Fisheries Science Center

NOAA Technical Memorandum NMFS

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Abstract

Two photogrammetric measuring instruments having different, yet complementary features are used to derive body length frequency data from vertical aerial photographs of eastern tropical Pacific (ETP) dolphins. Length frequency distribution data derived with these instruments are used to help describe and manage dolphin populations subjected to mortality in the ETP purse-seine fishery for tunas. Because these measuring instruments differed in design and image presentation, an experiment was conducted to test the hypothesis that there was no difference between instruments in dolphin image measurements. Results indicated no significant difference in length measurement values due to measuring instruments, readers, replicate measurements or interactions of these factors. Length measurements were precise (averaged < 1.0% coefficient of variation) and 95% confidence limits of the means (averaged ±1.2 cm) were within the range needed to detect the small length differences (minimum: 2 - 3 cm) found between certain ETP dolphin populations.

Introduction

Body length frequency data derived from vertical aerial photography has provided population biologists with information on reproductive parameters, social stratification and growth rates in mammal populations (Laws, 1969; Sinclair, 1969; 1973; Croze, 1972), including cetaceans (Sumich, 1986; Cubbage and Calambokidis, 1987; Scott and Perryman, 1991; Koski et al., 1992; Withrow and Angliss, 1992; Rugh et al., 1992; Perryman and Lynn 1993 and in press). This biological information is often used in formulating management policies for the conservation of exploited populations. At the Southwest Fisheries Science Center (SWFSC), dolphins are measured from large format aerial photographs with two photogrammetric measuring instruments: a video image-analyzer (VIA) and a stereo-comparator (STK). Length data derived with these instruments are used to help describe and manage dolphin populations subjected to mortality in the eastern tropical Pacific Ocean (ETP) purse-seine fishery for tunas (Perrin, 1975; Perryman and Lynn, 1993 and in press). For ETP dolphins, distinct populations within species have been described based on differences in biological parameters, including average differences in length frequency distributions. Precise measuring techniques are necessary in these length studies because average differences between certain populations are small (minimum: 2 to 3 cm; Perrin et al., 1985).

The VIA and STK function as complementary measuring systems at the SWFSC. The computer image enhancement features of the VIA make it possible to measure dolphin images when image resolution is reduced (e.g., for deep swimming dolphins, dolphin image contrast against the ocean background can be diminished due to loss of light with sea depth). In addition, the VIA's image storage, printing and monitor viewing capabilities make it possible to retrieve imagery from memory for ongoing analyses and for multiple workers to review the imagery simultaneously. The STK is an optical instrument whose design allows for rapid and successive measurements of dolphin images distributed throughout a large format photograph.

With the VIA, dolphin images are displayed and measured on a video monitor; with the STK readers view images through an ocular and measure images that are optically magnified. Because the two instruments differ in physical design and image presentation, we were concerned that there might be systematic differences between instruments in length measurements. Additionally, we wanted to know if measuring techniques (including reader error) were precise and reliable enough to detect the small length differences that differentiate certain ETP dolphin populations. In this report, differences between instruments in measurement values are tested in an experiment using analysis of variance (ANOVA). Additionally, to validate that our measurements were precise enough to discern length differences between dolphin populations, we also report the precision and confidence limits of replicate length measurements.

Materials and Methods

Vertical aerial photographs analyzed here were taken in the ETP from a Hughes 500D helicopter based aboard the National Oceanic and Atmospheric Administration (NOAA) research ship *David Starr Jordan* . Photographs were taken with a 12.6 cm (5 inch) format Chicago Aerial Industries, KA-45 military aerial reconnaissance camera equipped with a 15.2 cm (6 inch) fixed lens. To avoid distortion in photograph image resolution caused by the forward motion of the aircraft (i.e., the aerial camera views an area that is apparently moving), the KA-45 features "forward motion compensation" whereby the film in the camera is advanced along a stationary platten (while the shutter is open), at the same rate and direction as the image being recorded by the camera (Smith, 1968). All photographs were taken with Kodak Aerial Plus-X (3404) black and white film. Field methods followed those described by Perryman and Lynn (1993 and in press) and Gilpatrick (1993).

Measuring Instruments

The VIA system consisted of a Cohu Inc. CCD video camera linked by an adapter to a Bausch and Lomb dissection microscope having 1x to 7x objective. Dolphin photo transparencies were placed on a light table under the microscope and digital video images of the dolphins were stored on a Data Translation QuickCapture™ frame grabber board installed in a Macintosh IIci computer. The dolphin images were displayed on a high resolution 40.6 cm (16 inch) video monitor. Dolphin image magnification of 45X (range: 10X to 70X) was used for the experiment because of the ease with which images were viewed and measured on the monitor. Measurements were made using the image processing software NIH Image 1.41.[1] A computer mouse was used to set the location of the tip of the dolphin rostrum (snout) and the trailing edge of the tail flukes. The computer program then calculated the distance between the marked points and stored the data for later conversion to absolute dolphin length (see below).

The STK (Wild STK-820 model) was designed for stereophotogrammetry i.e., simultaneous measurement of coordinate points, which correspond to the same recorded image feature, on a stereopair of photographs (see Ghosh, 1988). This has the effect of adding depth to the photograph image; thus measurements can be made in three dimensions. For our study, the instrument was used as a monocomparator and measurements were made in two dimensions on single photographs. The photo-transparencies were placed on an illuminated, horizontal square glass plate or "stage" with calibrated X and Y axes. Two mechanical hand-wheels were used to move the stage in a horizontal plane until the dolphin image was observed under the viewing system. Because only the monocomparator capability of the instrument was used, the image was projected and viewed in one ocular of the binocular viewing system. Due to the unavailability of alternative ocular magnification components, image magnification was limited to 20X. Dolphin image endpoints were aligned with a fixed measuring point in the ocular; endpoints were marked

[1]Computer software provided by the National Institute of Health, Washington, D. C.

by depressing a foot pedal. Each marked point was stored as an X-Y coordinate on an IBM-PC XT computer. The dolphin image length was derived by calculation of the distance between X-Y coordinates and converted to actual length as described below. Prior to starting the experiment, a slide-micrometer of known length was measured using both instruments to validate their accuracy.

Experiment and Analyses

A standard sample of fifteen photographed ETP dolphins was selected for the experiment. The sample was representative of the types of dolphins currently under study in our laboratory and comprised photographs of the pantropical spotted dolphin (*Stenella attenuata*), eastern spinner dolphin (*S. longirostris orientalis*), and common dolphin (*Delphinus delphis)*. For each species, images of a calf, a cow and three other adult (or near adult) sized dolphins were selected. Only dolphins photographed while swimming normally parallel to the surface were used; measurements were done according to methods described by Perryman and Lynn (1993). The standard sample photographs were measured independently and in random order on both instruments by three readers. Replicate measurements of the sample were completed four times with replicates done several days apart. To minimize variability (in the statistical model) due to physical error associated with readers' unfamiliarity with the measuring instruments, the first replicate measurements were not included in the analysis.

To transform dolphin image measurements to actual dolphin lengths, the data were first converted from micrometers to centimeters. Actual lengths were then calculated by use of the scale factor equation :

$$I = (A/F)\,O$$

where A = altitude from which the photograph was taken (cm), F = focal length of the camera lens (cm), O = measurement of the object (dolphin) in the photograph (cm), and I = actual size of image (dolphin) photographed (cm; see Ghosh, 1988). A and F were constant at 24,384 cm (800 feet) and 15.24 cm (0.5 feet), respectively. Prior to ANOVA , using Levene's test, the variances in the data were found to be homogeneous ($F = 0.03$, $df = 1, 174$, $P = 0.8641$; BMDP7D, Dixon et al., 1988). The ANOVA was performed using the Abacus Concepts, SuperAnova™ (1990) computer software. The precision of replicate measurements is described using the coefficient of variation (CV) statistic and the reliability of the length measurements is described using 95% confidence limits (CL) of the means.

Results

Dolphin measurements made on the VIA averaged 185.9 cm (range: 103.8 - 229.6 cm) while measurements made using the STK averaged 184.7 cm (range: 105.6 - 229. 3 cm; Tables 1 and 2). The ANOVA revealed no significant difference between the two photogrammetric instruments in measurements of the same photographs ($F = .084$, $df = 1, 252$, $p = .7722$). The ANOVA also showed no significant effects due to readers, replicate measurements, or interactions of the three factors (Table 3). Measurements made on both instruments appeared equally precise: average precision for the VIA = 0.87% CV and average precision for the STK = 0.91% (Table 2). Reader precision averaged 0.67% CV for the VIA and averaged 0.70 % CV for the STK, thus indicating that readers were equally precise on both instruments (Table 4). Furthermore, levels of precision for individual readers were consistent between instruments indicating no reader bias (Table 4). The 95% CL of the means were similar averaging ±1.2 cm for both the VIA and the STK (Table 2).

Discussion

Dolphins were measured with precision similar to that reported from other vertical aerial photogrammetric studies of cetaceans. Davis et al. (1983) used an ocular micrometer in a dissection microscope and measured targets with average precision of 1.5% CV. Using a stereocomparator, Cubbage and Calambokidis (1987) measured ground targets with average precision of 1.7% CV while Best and Rüther (1992) measured images of southern right whales (*Eubalaena australis*) with average precision of 1.4% CV for cows and 1.5% CV for calves. Koski et al (1992) used a stereocomparator and an ocular micrometer in a stereo-microscope and measured bowhead whales (*Balaena mysticetus*) with precision ≤ 1.0% CV. Perryman and Lynn (1993), using the same measuring instruments as in this study, did replicate length measures of common dolphins (*Delphinus delphis*) with average precision ≈ 1.0% CV.

Our results suggest no difference in the accuracy and precision of dolphin lengths measured with both photogrammetric measuring instruments. Furthermore, analysis of replicate measurements showed 95% CL averaged within ≈ 1.2 cm of mean dolphin lengths. Our findings validate: 1) the use of both instruments as complementary measuring systems and 2) that the 95% CL of mean lengths reported here are within the range needed to detect population level differences in length frequency distributions of ETP dolphins.

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Table 1. Replicate dolphin length measurements (in cms) and CV of measurements derived using a Video image analysis system (VIA) and a Wild stereocomparatator (STK).

VIA

	READER 1					READER 2					READER 3				
DOLPHIN	R 1	R 2	R 3	MEAN	CV (%)	R 1	R 2	R 3	MEAN	CV (%)	R 1	R 2	R 3	MEAN	CV (%)
1	120.42	119.90	120.85	120.39	0.40	122.20	122.64	124.05	122.96	0.79	119.63	122.96	121.24	121.28	1.37
2	226.15	224.33	227.02	225.83	0.61	226.52	225.94	225.30	225.92	0.27	226.35	226.89	225.61	226.28	0.28
3	186.60	183.61	186.27	185.49	0.88	188.01	188.42	187.67	188.03	0.20	184.45	187.59	188.03	186.69	1.05
4	209.22	207.80	209.16	208.73	0.38	208.57	205.48	203.97	206.01	1.14	204.44	205.37	205.65	205.15	0.31
5	204.43	201.15	203.98	203.19	0.88	204.24	202.81	203.64	203.56	0.35	203.32	202.73	204.56	203.54	0.46
6	229.45	227.96	229.54	228.98	0.39	228.33	226.35	227.16	227.28	0.44	230.93	232.65	233.86	232.48	0.63
7	144.23	144.51	144.83	144.52	0.21	141.93	146.24	144.53	144.23	1.50	146.65	147.70	148.21	147.52	0.54
8	217.86	215.87	215.11	216.28	0.66	216.48	215.90	215.92	216.10	0.15	214.43	216.90	215.65	215.66	0.57
9	208.12	207.26	206.31	207.23	0.44	207.63	206.09	206.33	206.68	0.40	209.69	207.83	206.64	208.05	0.74
10	204.93	206.62	206.60	206.05	0.47	205.70	205.85	205.36	205.64	0.12	205.94	206.27	205.24	205.82	0.26
11	187.57	184.64	186.10	186.10	0.79	188.01	187.20	187.20	187.47	0.25	186.75	187.47	188.30	187.51	0.41
12	194.21	198.66	195.73	196.20	1.15	194.99	194.15	193.79	194.31	0.32	195.79	196.35	195.66	195.93	0.19
13	178.47	175.03	177.01	176.84	0.98	177.84	177.33	176.80	177.32	0.29	175.68	178.87	179.57	178.04	1.16
14	101.92	100.82	103.22	101.99	1.18	102.49	108.17	105.46	105.37	2.70	102.37	103.78	105.93	104.03	1.72
15	175.72	174.31	177.55	175.86	0.92	178.11	175.50	175.82	176.48	0.81	176.84	177.95	178.74	177.84	0.54
			MEAN =	**185.58**	**0.69**			MEAN =	**185.82**	**0.65**			MEAN =	**186.39**	**0.68**

STK

	READER 1					READER 2					READER 3				
DOLPHIN	R 1	R 2	R 3	MEAN	CV (%)	R 1	R 2	R 3	MEAN	CV (%)	R 1	R 2	R 3	MEAN	CV (%)
1	121.07	121.04	120.82	120.98	0.11	121.70	121.87	121.97	121.85	0.11	119.55	118.03	122.52	120.03	1.90
2	222.47	221.15	224.42	222.68	0.74	222.21	225.20	224.49	223.97	0.70	224.51	227.61	224.67	225.60	0.77
3	185.74	185.98	186.32	186.01	0.16	184.53	185.79	188.92	186.41	1.21	186.99	181.70	181.66	183.45	1.67
4	202.18	205.11	206.80	204.70	1.14	202.18	205.03	205.55	204.25	0.89	206.30	205.80	205.56	205.89	0.18
5	200.64	201.19	200.08	200.64	0.28	201.64	202.43	200.75	201.61	0.42	205.31	203.66	204.52	204.50	0.40
6	226.17	230.16	230.96	229.10	1.12	228.13	229.83	226.19	228.05	0.80	231.20	230.08	230.98	230.75	0.26
7	142.86	144.42	143.37	143.55	0.55	143.27	143.78	141.71	142.92	0.75	147.49	143.32	145.55	145.45	1.43
8	214.17	213.44	213.14	213.58	0.25	213.97	213.82	212.33	213.37	0.42	212.87	213.29	216.20	214.12	0.85
9	206.34	205.40	205.76	205.83	0.23	205.57	203.36	201.68	203.54	0.96	203.66	206.67	207.17	205.83	0.92
10	202.78	202.65	202.50	202.64	0.07	202.15	202.49	202.92	202.52	0.19	201.40	204.33	204.64	203.46	0.88
11	188.32	185.88	185.44	186.55	0.83	187.45	184.78	186.34	186.19	0.72	185.84	187.20	186.85	186.63	0.38
12	193.11	194.26	193.78	193.72	0.30	193.30	193.17	192.52	193.00	0.22	193.48	193.19	192.18	192.95	0.35
13	175.56	178.16	177.17	176.96	0.74	176.97	176.27	176.19	176.48	0.24	174.89	175.67	175.21	175.26	0.22
14	103.46	104.11	103.49	103.69	0.35	103.77	109.47	108.87	107.37	2.92	105.46	104.34	107.56	105.79	1.55
15	175.21	178.22	175.51	176.31	0.94	175.00	174.87	174.56	174.81	0.13	174.57	175.07	179.29	176.31	1.47
			MEAN =	**184.46**	**0.52**			MEAN =	**184.42**	**0.71**			MEAN =	**185.07**	**0.88**

* R1 = Replicate 1, R2 = Replicate 2, R3 = Replicate 3

Table 2. Mean lengths, 95% confidence limits of the means, and cvs for replicate dolphin length measurements (in cms) made using two different photogrammetric measuring instruments.

	VIA			STK		
DOLPHIN	**MEAN**	**95% CL**	**CV (%)**	**MEAN**	**95% CL**	**CV (%)**
1	121.54	± 1.16	1.24	120.95	± 1.07	1.15
2	226.01	± 0.65	0.37	224.08	± 1.47	0.85
3	186.74	± 1.30	0.91	185.29	± 1.82	1.28
4	206.63	± 1.58	1.00	204.95	± 1.28	0.81
5	203.43	± 0.83	0.53	202.25	± 1.43	0.92
6	229.58	± 1.92	1.09	229.30	± 1.53	0.87
7	145.43	± 1.51	1.35	143.97	± 1.30	1.17
8	216.01	± 1.51	0.46	213.69	± 0.85	0.51
9	207.32	± 0.89	0.56	205.07	± 1.38	0.88
10	205.83	± 0.46	0.29	202.87	± 0.78	0.50
11	187.03	± 0.81	0.59	186.46	± 0.55	0.59
12	195.48	± 1.14	0.76	193.22	± 0.48	0.32
13	177.40	± 1.13	0.83	176.23	± 0.80	0.59
14	103.80	± 1.78	2.23	105.61	± 1.84	2.26
15	176.73	± 1.13	0.83	175.81	± 1.32	0.98
MEAN =	185.93	**± 1.19**	**0.87**	184.65	**± 1.19**	**0.91**

Table 3. Results of three factor analysis of variance (ANOVA).

Type III Sums of Squares:

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
INSTRUMENTS	1	4321.440	4321.440	0.0840	0.7722
READERS	2	1027.283	513.641	0.0100	0.9901
REPLICATES	2	270.490	135.245	0.0030	0.9974
INSTRUMENTS * READERS	2	38.868	19.434	0.0003	0.9996
INSTRUMENTS * REPLICATES	2	85.027	42.514	0.0010	0.9992
READERS * REPLICATES	4	594.795	148.699	0.0030	1.0000
INSTRUMENTS* READERS * REPLICATES	4	881.562	220.391	0.0040	1.0000
Residual	254	12971337.653	51473.562		

Table 4. Reader precision in replicate dolphin length measurements (in cms) made using two different photogrammetric measuring instruments.

READER PRECISION

	VIA		STK	
	CV(%)		CV(%)	
	MEAN	RANGE	MEAN	RANGE
READER 1	0.69	(0.21-1.18)	0.52	(0.07-1.14)
READER 2	0.65	(0.12-2.70)	0.71	(0.11-2.92)
READER 3	0.68	(0.19-1.72)	0.88	(0.18-1.90)
MEAN =	**0.67**	**(0.12-2.70)**	**0.70**	**(0.07-2.52)**

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