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Bias and variability in distance estimation on the water: implications for the management of whale watching

Robin W. Baird
Biology Department, Dalhousie University, Halifax, Nova Scotia, B3H 4J1, Canada
(e-mail: rwbaird@is.dal.ca)

Stephanie M. Burkhart
Pacific Whale Foundation, 101 North Kihei Road, Kihei, Hawaii 96753, USA

ABSTRACT

Distance regulations or guidelines are the most common method used by regulatory agencies to manage interactions between whale watching vessels and whales. In Hawaiian waters, a distance rule prohibits vessels from approaching humpback whales (*Megaptera novaeangliae)* closer than 100 yards (91 m). Vessel captains and government enforcement agents rely almost entirely on estimating distance to whales, yet research on distance estimation abilities on land suggest a large degree of variability associated with such estimation. In 1999, we used laser range finders (accurate +/- 1 yard) to measure the distance between whale watching boats and whales, and obtained estimates of distances from vessel captains, naturalists, and members of the general public (702 estimate/measurement pairs from 106 individuals). We found a high degree of variability associated with distance estimation to whales on the water, more so than had been documented in land-based studies or controlled ship-based distance estimation experiments with highly experienced observers. A general bias towards under-estimating distance (ie., estimating that the vessels are closer to whales than they actually are) suggests that the distance rule is likely conservative, in terms of encouraging vessel operators to stay at least 100 yards from whales. Distance estimation abilities seem to improve with experience: estimates of vessel captains were less variable than estimates of naturalists or passengers. However, given the overall high degree of variability in estimating distance to whales, combined with the ease of use and relatively low cost of commercially available laser range finders, we suggest that such instruments should be incorporated into both whale watching and management of whale watching activities.

INTRODUCTION

With the rapid growth of whale watching worldwide, there is increasing concern over the short- and long-term impacts of vessel activity on whales (e.g., Bauer and Herman 1986; Duffus and Dearden 1993; IFAW et al. 1996). Since little information is available on the impacts of whale watching activities on whales, management agencies are faced with the difficult task of promulgating and enforcing regulations which will continue to allow whale watching, but which minimize disturbance to the animals. Distance guidelines or restrictions are the primary management tool used by agencies around the world to mitigate impacts of vessel activity around marine mammals (Carlson 1996). Although in many areas of the world only voluntary guidelines exist, distance approach regulations have been implemented in parts of Australia, New Zealand, the West Indies, South Africa and the United States. It is important to see not only how well these regulations are being enforced, but also how effectively vessel captains and enforcement personnel, as well as the general public, are able to interpret and follow these rules. This includes determining how well people are able to accurately estimate distance on the water, as well as examining the factors influencing people's perception of distance.

Several studies have been undertaken examining the biases in estimating distance on land, including the effect of training in increasing accuracy in distance estimation (Gibson and Bergman 1954; Gibson et al. 1955). Such studies have been undertaken in a controlled manner, using subjects of the same sex and age (usually young adult males), and examining distance estimation over land surfaces with a clear textural gradient. On the water, similar controlled experiments have been undertaken using experienced observers from ship-board surveys for cetaceans, with estimates made as a ship approaches floating radar buoys (Oien and Schweder 1992; Schweder 1996; 1997). Results from such studies are interesting, but it remains difficult to assess how the controlled and somewhat unrealistic circumstances presented (compared with an actual encounter with a whale in the wild) can be applied to real-life situations. Our study was developed to investigate the accuracy of distance estimation to whales by those directly involved in whale watching activities, including vessel captains, naturalists, and passengers. In particular, we have focused on the bias and error in distance estimation to whales as they relate to the effectiveness of distance regulations in the management of whale watching.

STUDY SITE

Each year, humpback whales migrate between summer feeding areas in high latitudes and winter mating and calving areas in low latitudes (Clapham 2000). In the North Pacific, the main (SE) Hawaiian Islands are one of the primary wintering grounds for humpback whales (Baker et al. 1986). While wintering in Hawaii, concentrations of humpback whales can be consistently found off the leeward (south and west) sides of the main Hawaiian Islands. Whale watching activities in Hawaii focus on humpback whales, and last from mid-December through April. During the 1999 season (mid-December 1998 through mid-April 1999) there were a total of 52 commercial vessels running an average of 87 whale watching trips per day in Hawaii (Utech 1999). Utech (1999) estimated that almost 370,000 individuals went whale watching in Hawaii during the 1999 whale watching season, generating between \$11 and \$16 million dollars in direct revenue. Of the four islands where whale watching activities are based, the majority of vessels operate from the island of Maui (Utech 1999).

The humpback whale is listed as an Endangered species under the U.S. Endangered Species Act of 1973, and within 320 km (200 nautical miles) of the Hawaiian Islands is protected by a number of federal laws and regulations. Regulations prohibit the operation of aircraft within 305 m (1000 feet) of humpback whales, and restrict vessels from approaching closer than 91 m (100 yards), as well as prohibiting any act which would cause a vessel or other object to approach closer than 91 m (Nitta 1997).

METHODS

From January-May, 1999, passengers, captains and naturalists onboard whale watching vessels operating out of 2 ports (Lahaina and Ma'alaea) on the island of Maui were asked to volunteer as part of a research study looking at people's perception of distance on the water. In order to determine whether any of the passengers had substantial prior experience with estimating distances on the water, passengers were asked to provide basic background information, including occupation (and if retired, their previous occupation) and sports that they play, and were asked questions related to prior distance estimation experience (e.g., boating activities). All volunteers were at least 20 years of age.

Each volunteer was asked to estimate the distance (in yards) between him/herself and a whale, while an independent observer simultaneously measured the actual distance (in yards) with laser range finders. Bushnell Yardage Pro 800 laser range finders were used to obtain measurements to whales at distances of up to 600 m (with a stated accuracy of ± 1 m). Each volunteer and rangefinder operator stood side by side, so no correction for difference in distance was required. Measurements obtained from different range finders off the same target were identical.

For each volunteer, the height of the boat platform from which the observer was viewing the whales was noted (3 different boats, one with 2 decks, were used, giving two general heights, from 1-1.8 m above sea level, and approximately 5.5 m above sea level). The behavior of the whale 30 seconds prior to the estimate/measurement was recorded, and behavior was later divided into two categories: surface-active groups (involving breaches, lunges, tail-lobbing, etc), or non-surface-active groups. We attempted to get 10 measurements per volunteer. Estimates/measurements were made at least 5 minutes apart except when whales surfaced on opposite sides of the boat, so that volunteers were not influenced by their prior estimate. Volunteers were not given feedback on how close their estimates were to the measured distance, so as to not bias their future estimates.

When describing the results we refer primarily to two different attributes of the data: the magnitude and direction of bias, and the amount of variability. The magnitude of bias describes the accuracy of estimates compared to measurements, and is calculated as the percentage of the actual distance (see Table 1). The direction of bias refers to the tendency to overestimate or underestimate distance. The variability indicates the scatter in estimated values for the same true distance, and is calculated as the percentage error (see Table 1). For measures of central tendency, we present both mean and median values, since the parameters are not always normally distributed (as no estimates can be less than 0% of the true distance, yet estimates can be greater than 200% of the true distance). In general we use all samples from all individuals, rather than use mean values for each individual, as the variability between individual means was far lower than the variability between samples. To test the effect of this on our conclusions, we compared treatments based on individual means for some tests, and found no difference in significance.

RESULTS

One hundred and six people participated in the study (58 men; 48 women) and 702 estimates/measurements were recorded. While some of the passengers sampled had some prior boating experience, none had previously spent time attempting to estimate distance to whales, so for the purposes of examining experience level, we have simply compared three groups: whale watch captains, naturalists and passengers.

Overall, observers showed a bias towards underestimating distance, with mean and median estimates of 89% and 77% of the true distance, respectively (SD 60%, see Figure 1). The distance between the observer and whales did not affect this tendency (regression of percentage error versus measured distance, r^2=0.0058, slope= -0.00057). The magnitude of bias and level of variability were both affected by gender (Figure 1), with women being less accurate (more bias), but also showing less variability in their distance estimates than men.

Experienced observers (naturalists and captains combined) of both sexes exhibited the same direction and magnitude of bias as inexperienced observers, though estimates were less variable (Figure 2; Table 1). Vessel captains were slightly better at estimating distances than naturalists, and both groups showed far less variability in their distance estimates than people with less experience (Table 1; Kruskal-Wallis one-way ANOVA on all samples, $p < 0.001$, on individual means, $p < 0.001$).

Estimates made at a greater height above water were generally more accurate and less variable (Table 1), however these differences were not significant (Mann-Whitney U-tests on all samples, accuracy, $p = 0.29$; variability, $p = 0.45$). To rule out the potential influence of gender and/or experience, we also compared estimates for a subset of the data (the group with the largest sample size, male passengers - 46 individuals and 284 samples), and found similar results (Mann-Whitney U-tests, accuracy, $p = 0.85$, variability, $p = 0.55$). The general behavior of the whales (surface-active or not) did not appear to influence the variability of the estimates (Table 1; Mann-Whitney U-test, $p = 0.36$), however it did affect the accuracy of the estimates (Table 1; Mann-Whitney U-test, $p = 0.001$).

Taking into account only those individuals where at least five samples were obtained and averaging the percentage error values for each individual, the mean level of variability was 37% (SD 20%, n=73 individuals). Some observers were relatively good at estimating distance (mean ± SD: 10%±7%), while others had much higher levels of variability (mean ± SD: 117%±60%). Twenty-seven percent of these observers always underestimated, while 10% always overestimated. Sixteen percent of the observers were just as likely to underestimate as they were to overestimate.

DISCUSSION

There is clearly a high degree of variability associated with distance estimation on the water (Figure 1). The degree of error found with both inexperienced passengers and experienced naturalists and vessel captains on the water (Figure 2) appears to be greater than distance experiments with individuals on land (Gibson and Bergman 1954), and prior controlled experiments on the water (Oien and Schweder 1992), although the bias in each case (a tendency to underestimate) was the same. In terms of distance regulations, such a bias towards underestimating results in a tendency to err on the side of caution, that is, individuals are likely to be greater than 100 yards from a whale when they think they are at 100 yards distance. This suggests that distance regulations may be a conservative approach to managing boat/whale interactions (assuming that keeping people a set distance away from whales is the management goal).

Experience on the water was expected to make one better at estimating distance (Gibson and Bergman 1954; Gibson et al. 1955) and, not surprisingly, captains had the least variability and bias in their estimates (Table 1). Gender was another factor that influenced both the magnitude of bias and degree of variability of distance estimates, though it is unclear why females would be less variable (and less accurate) than males (cf. Kimura 1999). When individuals were at a higher platform on a boat, they were less variable in their estimates, and less likely to overestimate, though these differences were not significant. Behavior of the whales (surface-active versus non-surface active) seemed to influence the magnitude of bias, with observers being more accurate with surface-active groups. Whales which are surface-active tend to show more of their bodies above the water, and observers might thus be able to use the whale's size as a reference in estimating distance.

In general, people are relatively poor at estimating distances to whales. Given that estimating distance is currently the main way vessel captains try to comply to distance regulations, this should be a matter of concern, both to management agencies and to vessel captains. The range finders we used were relatively inexpensive and easy to use, and we recommend that whale watching operators purchase such range finders for use on the water. Alternatively, given that distance estimation abilities improve with experience, on-the-water training and practice using range finders could be done with vessel captains throughout the whale watching season. Problems in whale watching management associated with distance estimation are not limited to vessel captains, however. Enforcement agents of the National Marine Fisheries Service, or deputized agents from other federal (e.g., Coast Guard) or state agencies (e.g., the Department of Land and Natural Resources in Hawaii) all rely on estimating distances between boats and whales when determining whether a violation of distance regulations has occurred, and in most cases such agents likely have far less experience at judging distances to whales than do captains of whale watching vessels. Given the tendency of all groups to underestimate distance (Table 1), it is likely that in many cases vessels may actually be compliant with regulations when enforcement agents think otherwise. The problems with whale watching management do not stop there. Members of the general public, particularly those on shore, often view near-shore interactions between boats and whales. We suspect that the error in estimating distance between two objects offshore is even greater than what we have reported here, thus land-based reports of vessels violating distance regulations should be viewed with particular caution.

The majority of boat-based whale watching that occurs in the nearshore-waters of Maui, Hawaii, appears to occur from commercial whale watching vessels, but our results are also relevant to recreational whale watching. In some parts of the United States, private recreational boaters make up a substantial proportion of the boats found around whales (e.g., off San Juan Island in Washington state, at times over two-thirds of the boats with killer whales, *Orcinus orca,* are recreational, R. Otis and R.W. Osborne, personal communications). Given the relatively poor abilities of inexperienced individuals (a category which we suspect the majority of recreational boaters fall into) in estimating distances to whales, we believe it is doubly important that tools such as range finders be used in educational programs and management efforts.

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Table 1. Comparison of distance estimate characteristics for different treatments.

Treatment[1]	Variability [2] Mean/Median (SD)	Accuracy[3] Mean/Median (SD)	Under-estimates (%)	Number of measurements per treatment
All females (n = 48)	35/33 (24)	78/71 (36)	77	317
All males (n = 58)	44/34 (58)	98/83 (73)	68	385
Female passengers (n = 41)	38/37 (25)	76/68 (39)	78	244
Male passengers (n = 46)	52/42 (65)	100/80 (83)	67	284
All captains (n = 6)	19/17 (15)	89/88 (22)	77	57
All naturalists (n = 13)	25/24 (15)	89/87 (27)	65	117
All passengers (n = 87)	45/39 (51)	90/72 (68)	73	528
Close to water (1-1.8 m)	43/36 (53)	95/80 (68)	67	185
High above water (5.5 m)	38/33 (44)	87/77 (57)	74	517
Surface-active whales	40/35 (49)	97/82 (54)	66	195
Non-surface-active whales	39/31 (38)	86/75 (62)	74	507

[1]Sample sizes given indicate number of individuals. [2]Variability calculated as (Absolute(Measured Distance – Estimated Distance)/Measured Distance)*100). [3]Accuracy (percentage of true distance) calculated as ((Estimated Distance /Measured Distance)*100).

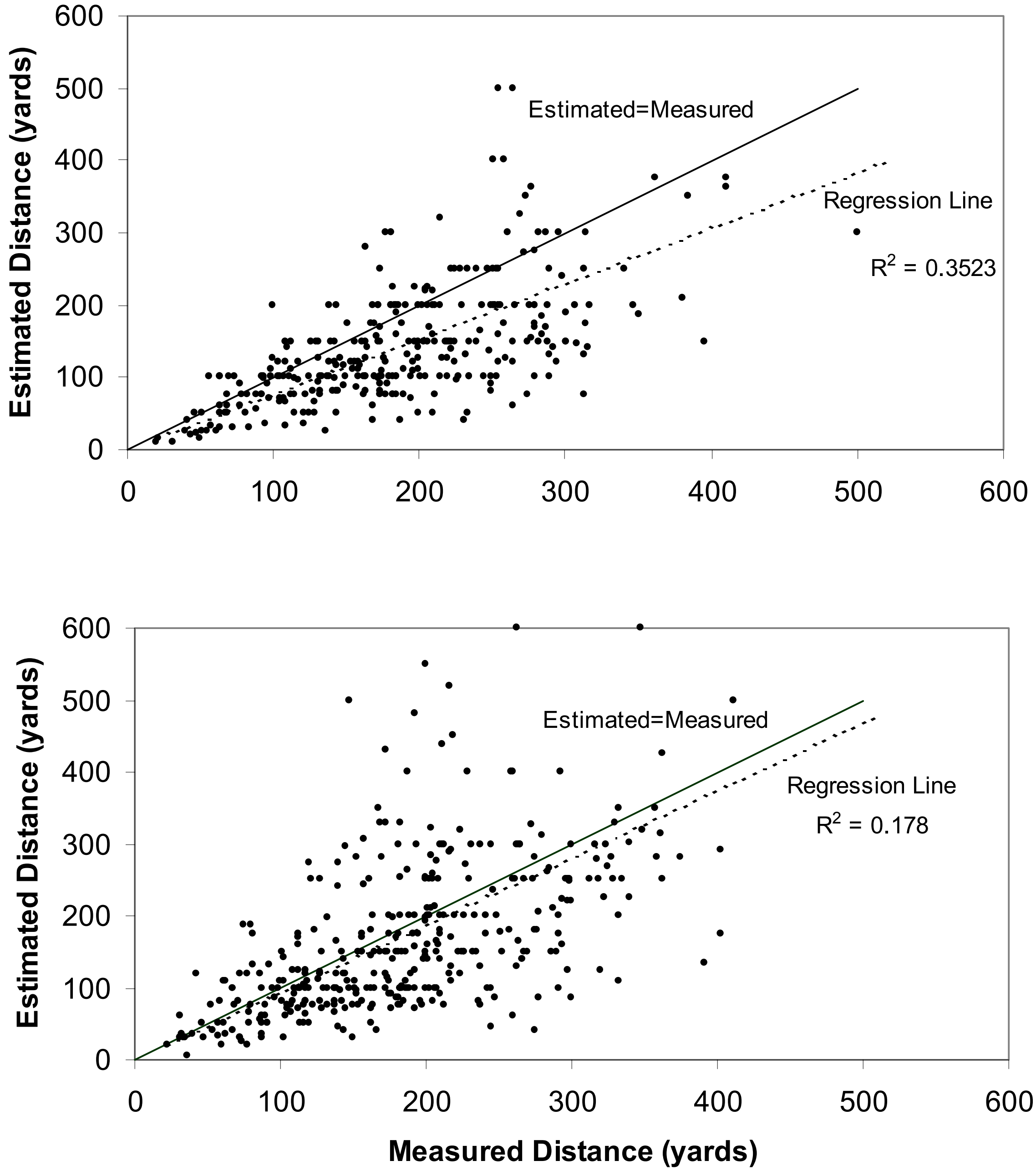

Figure 1. Scatter plots of measured distances versus estimated distances (both in yards) for all females (top) and all males (bottom). The line of equality (measured = estimated) is shown, as well as the best fit lines for least squares regression. In both cases distance tends to be underestimated.

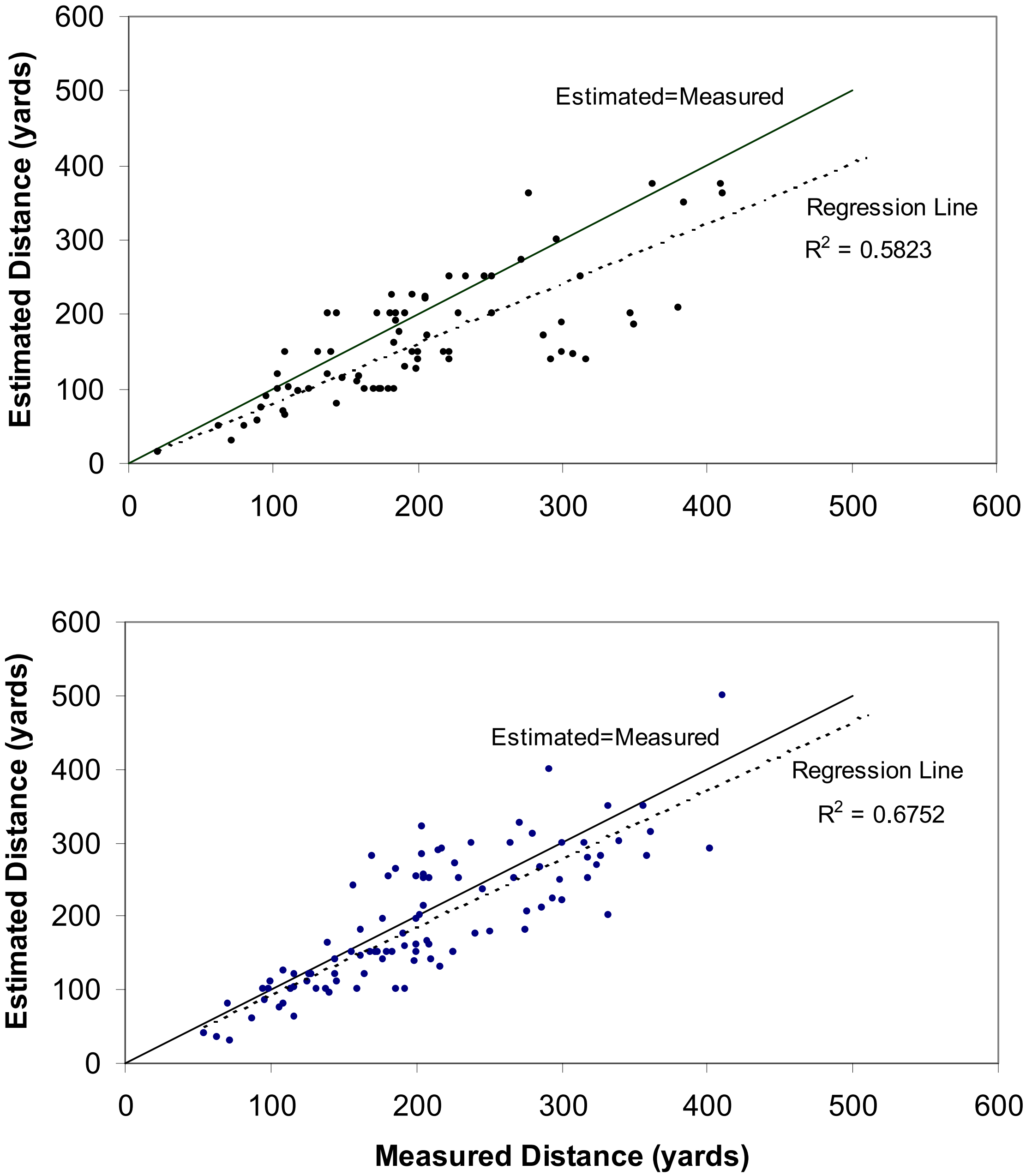

Figure 2. Scatter plots of measured distances versus estimated distances (both in yards) for individuals with experience at distance estimation (females shown at top, males at bottom). The line of equality (measured = estimated) is shown, as well as the best fit line for a least squares regression. Direction and magnitude of bias is similar in both cases, though the fit to the regression is much stronger for experienced individuals than for inexperienced individuals (cf. Figure 1).