A RANGE FINDER FOR PELAGIC BIRD CENSUSING

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Use of the line-transect method for the estimation of pelagic densities of seabirds is becoming common. Line-transect models require that the distance to each bird be measured, either radially from the observer or perpendicularly from the transect line (Anderson et al. 1979). However, it is difficult to obtain perpendicular distances at sea. Therefore, the radial distance must be estimated at the time of observation. This requires a distance-measuring device that is (1) small, (2) hand-held, (3) able to measure distances quickly, and (4) accurate within the detection range of most birds. When I began censusing pelagic birds in 1974, I was unable to find a device that conformed to these specifications.

RANGE FINDER DESCRIPTION

A fixed-interval range finder that I designed in 1975 and a continuous-scale model that was built in 1976 are described (Fig. 1). The latter is an inexpensive slide caliper modified by grinding the jaws thinner, and adding a handle and a larger friction knob on the slide. The range finder is held vertically at arm's length, in either hand, with thumb on the friction knob. The tip of the lower jaw is placed in line with a bird on the water, or on the water directly beneath a flying bird, and the tip of the upper jaw is placed in line with the horizon. The caliper is read and the value recorded. The distance (d) to the bird can be calculated from the equation:

$$d = \frac{h(bv - hc)}{bh + vc}, \qquad (1)$$

where v is the distance from the observer to the visual horizon, h is the height of the observer's eyes above the water, c is the caliper reading, and b is the distance from the observer's eye to the upper jaw of the caliper (Fig. 2). The derivation of Eq. (1) is given in the Appendix.

ERROR ANALYSIS

With practice, an observer can obtain distance estimates within 2–4 sec. The user should be aware of potential sources of error and their relative magnitudes. Estimations of the magnitudes of errors occurring at the time of observation were derived from a sensitivity analysis of Eq. (1). The effect on d of a 10% error in a given parameter was determined with all other parameters held constant. This analysis was conducted for heights of 2–20 m, and for radial distances of 25–1,000 m.

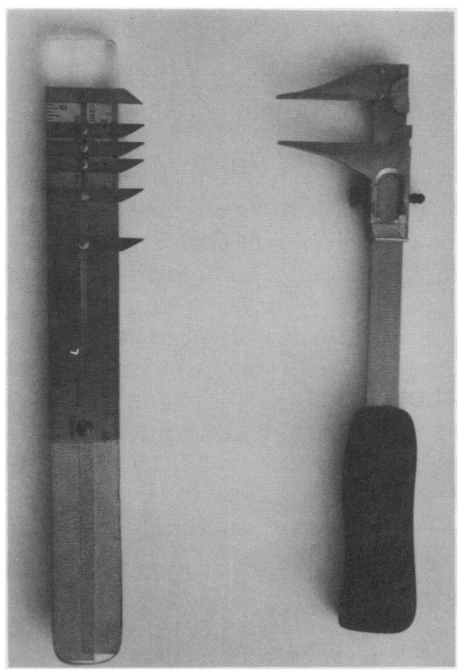

Fig. 1. Fixed-interval (left) and continuous-scale (right) range finders.

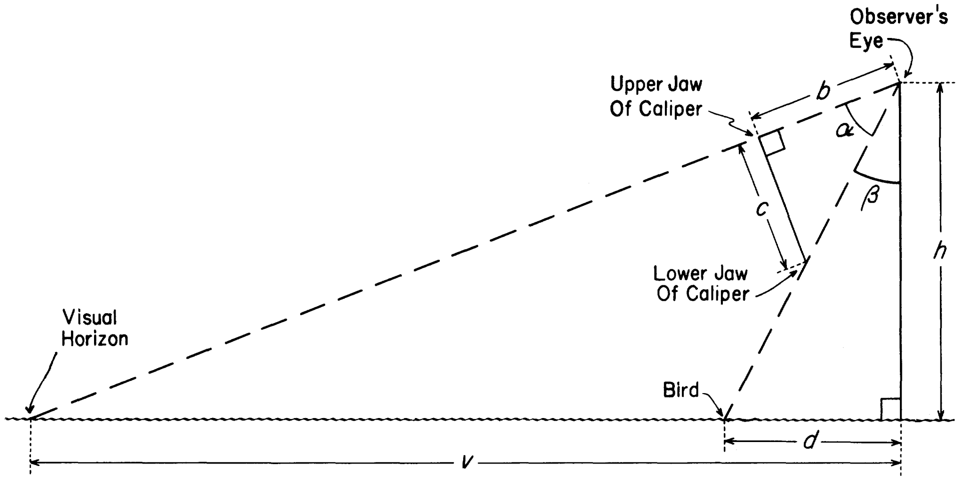

Fig. 2. Diagrammatic representation of an observer *v* m from the visual horizon, whose eyes are *h* m above the water, estimating the distance (*d*) to a bird on the water, using the caliper range finder. The observer sights past the upper jaw of the caliper to the horizon and past the lower jaw to the bird. The caliper's reading (*c*) can be used along with *v*, *h*, and *b* (the distance from the upper jaw to the observer's eye) to estimate *d*.

Parameter Estimation and Sources of Error

Eye Height (h).—Eye height is unique for each observer and position on the ship, and it changes as fuel and supplies are expended, when fuel or water is taken on, or when cargo is loaded or unloaded. Thus, h must be adjusted during a cruise to compensate for changes in the ship's displacement. Ocean swells and waves cause h to oscillate around the value used by the observer. Swell and wave heights can vary from zero to several meters, but the amount of variation in h is also affected by the size and heading of the ship, and thus is difficult to measure. A 10% error in h yields an 8.3–10.0% error in d.

Visual Horizon (v).—The following equation can be used to determine v in meters:

$$v = 3{,}838(h^{1/2}), \qquad (2)$$

where h is expressed in meters. If other units are used, then the constant in the equation must be changed. Equation (2) gives the distance to the visual horizon as a function of the observer's height under average atmospheric conditions (Bowditch 1966:1187). When the atmosphere's index of refraction of light is different from its average value, an error in v will result. This causes only minor error in d, as a 10% error in v yields only a 0.0–2.1% error in d.

Caliper Reading (c).—Errors in the caliper reading can arise from: (1) misreading the caliper, (2) missetting the jaws on the horizon and/or on the bird due to movement of the observer (wind-, wave-, or swell-induced) and/or of the bird, (3) misselecting the spot on the water directly beneath a flying bird, and (4) obscuring of the horizon. The last 2 are the largest potential sources of error. These errors can be reduced through precise and careful use of the range finder. A 10% error in c results in a 7.6–9.1% error in d.

Eye-to-Range Finder Distance (b).—Once b has been measured it remains constant, although it is subject to error due to variation in the observer's posture. A 10% error in b yields an 8.4–10.0% error in d.

The sensitivity analysis indicates that estimates of d are most severely affected by errors in h, c, and b. The smallest errors occur at low observation heights and long distances, and the magnitude of the errors increases as height increases and/or distance decreases. For v, the smallest errors occur at great observation heights and short distances, and the magnitude increases as height decreases and/or radial distance increases.

Monte Carlo Simulation

I conducted a Monte Carlo simulation to identify the potential error in the estimation of d. Error in the estimation of each parameter was assumed to be normally distributed around the true value. Variances were chosen somewhat arbitrarily from my knowledge of pelagic censusing and 100+ hours of field experience with the range finders. Variances chosen were larger than usually observed, to be conservative in my assessment of the range finder.

I conducted 25,000 iterations of the equation separately for heights of 2–20 m and distances of 25–1,000 m. For each iteration the true parameter values, given the values of h and d, were calculated, and error factors were chosen at random from each parameter's normal error distribution. These were added to the parameters' values, and an estimated d was calculated and compared to the actual d. The simulation provided average error in d when errors occur randomly in all the parameters simultaneously.

The following standard deviations were used to describe the error distribution of the parameters: 1.0 m for h, 10% of the parameter's value for v and b. The absolute magnitude of the error in the placement of the jaws increases as c increases; however, when c is small (<0.005 m), the error can be quite large relative to c. Therefore, the standard deviation of the error in c was varied linearly from 150% of c at $c = 0.001$ m to 10% of c at $c = 0.150$ m. This made c the largest possible source of error in d, except for error in h at low heights. With error in c varying in this manner, the sensitivity analysis showed error in d from 5.3%, at high observation heights and short radial distances, to 56.4%, at low heights and long distances.

The average error in d varies directly with distance, and inversely with observer height, with the latter affecting d most severely (Fig. 3). Above a certain height the error is roughly constant and varies little with distance. However, error increases as observer height increases. Most line-transect models make the critical assumption that all individuals are detected on the transect line (Anderson et al. 1979). Because detection probability decreases with observer height, fewer individuals are detected. Because this error introduces a negative bias in density estimates, it is potentially more damaging.

A FIXED-INTERVAL RANGE FINDER

The fixed-zone range finder (Fig. 1) has an upper jaw and several lower jaws. The body is made from wood or plastic with a lengthwise slit. The sheet-metal jaws are attached to the body by screws through the slit. The jaws are fixed in place while the range finder is in use, but can be adjusted by loosening the screws and moving the jaws up or down the slit.

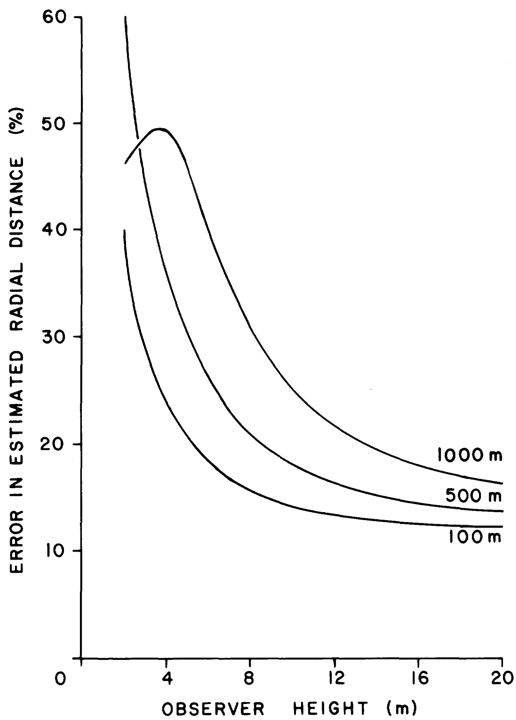

Fig. 3. Error in the estimated radial distance, as determined from Monte Carlo simulation, as a function of observer height. The different curves are for different actual radial distances.

The upper jaw is used to sight on the horizon and the lower jaws mark a series of distances (d_i). For example, if there are 3 lower jaws set to mark distances of 100, 200, and 300 m, then with the range finder held out in position, a bird that appears between the 1st and 2nd jaws down from the upper jaw would be between 200 and 300 m from the observer. For a given observer, with a unique h and b, the values of c needed to set the lower jaws to conform to the radial distance intervals required can be calculated from the equation (derivation similar to that for d in the Appendix):

$$c_i = \frac{bh(v - d_i)}{(h^2 + vd_i)}.$$

CONCLUSION

When checked against RADAR, the range finders gave estimates within the error ranges presented and were quick and easy to use. An important exception occurs when high bird density leaves insufficient time between observations to operate the continuous-scale range finder. Because the fixed-interval range finder does not require adjusting a slide or reading a scale when estimating d, it requires less time to operate, and thus can be used at higher densities than can the continuous-scale model. At still higher densities, the observer must mentally estimate radial distance. Use of the fixed-interval range finder quickly enables the observer to make surprisingly accurate mental estimates.

Although use of the range finders will increase the precision of density estimates, the observer should not use them when they may introduce a bias in density estimates. I recommend that the range finders be used above 6–8 m to minimize error in the estimation of d, while staying as low as necessary to avoid missing birds on the transect line. Also, estimates should be made with the fixed-interval range finder or mentally when densities increase to the point that birds may be missed while using the range finder. They should not be used when the horizon is foreshortened by fog, rain, or land, as this will result in a positive bias in the estimate of d, and hence negatively biased density estimates.

Although the continuous-scale range finder is not suitable for aerial censusing, the fixed-interval model can be adapted for aerial use. A hand-held model would be large and slow to use, but marks could be placed on a window or wing strut to mark the distance intervals (Pennycuick and Western 1972).

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APPENDIX

Equation (1) was derived from Fig. 2 as follows:

note that

$$d = h(\tan \beta),$$

and that β can be obtained from

$$\tan(\alpha + \beta) = \frac{v}{h},$$

$$\beta = \arctan\left(\frac{v}{h}\right) - \alpha,$$

and α from

$$\alpha = \arctan\left(\frac{c}{b}\right).$$

Substituting for α and β gives

$$d = h\left\{\tan\left[\arctan\left(\frac{v}{h}\right) - \arctan\left(\frac{c}{b}\right)\right]\right\}. \tag{3}$$

With the following identity:

$$\tan(m - n) = \frac{\tan(m) - \tan(n)}{1 + \tan(m)\tan(n)},$$

and some rearranging, Eq. (3) simplifies to

$$d = \frac{h(bv - hc)}{(bh + vc)}, \tag{4}$$

which is the equation presented in the text. If desired, the equation for v ($v = ah^{\frac{1}{2}}$, where $a = 3{,}838$ when h is expressed in meters) can be incorporated in Eq. (4) to give

$$d = \frac{h(ba - h^{\frac{1}{2}}c)}{(bh^{\frac{1}{2}} + ac)}.$$

EVALUATION OF TWO DEVICES FOR SAMPLING NEKTONIC INVERTEBRATES

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Waterfowl biologists have recently acquired a better understanding of the feeding ecology of wild breeding ducks. Swanson et al. (1979) demonstrated that aquatic invertebrates are dominant constituents in the diets of ducks during the breeding season, especially of females during laying. Of major importance is the relationship between environmental levels of invertebrates and use of the resource by ducks. Numerous apparatuses and methods have been developed to quantify invertebrate resource levels in a variety of aquatic habitats (e.g., Merritt and Cummins 1978); however, few pa-