

## A simple and low-cost method to estimate spatial positions of shorebirds: the Telescope-Mounted Angulator

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**ABSTRACT.** Estimating the spatial position of birds in open habitats like intertidal mudflats is important for many studies, for example, detailed density estimates or linking predation pressure to resource availability. To date, several methods have been used to estimate the positions of birds, including density counts in predetermined plots, range finders, photography, and tracking individuals tagged with GPS-equipped transmitters, and each method has advantages and shortcomings. Counts in premarked plots are possible over relatively long distances, but small-scale information is lost due to within-plot averaging. Other methods accurately determine the position of individuals, but can only be used at relatively short distances or involve capturing birds. We describe a simple and low-cost method to estimate the spatial position of individual birds in open habitats using a telescope-mounted instrument that measures the scope's viewing angle. Using this Telescope-Mounted Angulator (TMA), the distance to focal birds can be calculated by simple trigonometry, requiring only the viewing angle and mounting height of the telescope. Laboratory tests revealed that the TMA was most accurate when calibrated for individual observers. Field experiments performed on a 4-m high observation platform showed that the TMA can estimate the position of shorebirds with an accuracy of 18 to 36 m up to a distance of 500 m. By also including the direction, determined with a compass, the spatial position of birds can be reliably estimated. The TMA can be a valuable tool for estimating the spatial position of animals in various flat landscapes, providing detailed measurements in a relatively short period of time.

### RESUMEN. Un método sencillo y de bajo costo para estimar la posición espacial de playeros: un angulador montado en un telescopio

El estimar o determinar la posición espacial de aves en hábitats abiertos como lodazales, es importante para muchos tipos de estudios, ej. estimados detallados de la densidad o asociar presión de depredadores a la disponibilidad de recursos. Hoy en día, han sido utilizados diversos métodos e instrumentos para determinar la posición de aves, tales como medidores a distancia (range finders), fotografía, conteos de densidad en parcelas premarcadas, y el rastreo con GPS, de individuos que han sido marcados con radiotransmisores. Cada método tiene sus ventajas y problemas. Los conteos en parcelas premarcadas son posibles sobre distancias relativamente grandes, pero la información a pequeña escala se pierde al tener que promediar entre lotes. Otros métodos determinan con precisión la posición de individuos, pero solamente pueden ser utilizados para distancias relativamente cortas o envuelven la captura del ave. Describimos un método sencillo y de bajo costo para estimar la posición espacial de individuos particulares en hábitats abiertos, utilizando un instrumento montado en un telescopio (TMA), que mide el ángulo de visión del instrumento. Utilizando un TMA, se puede calcular la distancia focal del ave utilizando trigonometría simple, solamente requiriendo determinar el ángulo de visión y la altura de la montura del telescopio. Las pruebas de laboratorio revelaron que el TMA era más exacto cuando era calibrado para observadores particulares. Experimentos de campo llevado a cabo en una plataforma elevada de 4 metros demostraron que el instrumento puede estimar la posición de un playero a una distancia de 500 metros con una exactitud de 18 a 36 metros. Si se incluye la dirección, con un compás, la posición espacial del pájaro puede ser estimada confiablemente. El TMA puede ser una herramienta de gran valor para estimar la posición espacial de animales en diferentes escenarios, proveyendo medidas detalladas en un periodo corto de tiempo.

*Key words:* distance estimation, intertidal mudflat, oystercatcher, triangulation, viewing angle, wader

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In intertidal areas, large-scale counts of shorebirds may involve simultaneous observations by sometimes hundreds of observers using spotting scopes (Rappoldt et al. 1985, Cayford and Waters 1996). Often, however, more detailed information on the spatial position of shorebirds is needed, particularly for studies focusing on species-specific foraging or predator-prey interactions. In such cases, counting with a spotting scope in premarked plots is an often-used method (Ens and Alting 1996, Zwarts et al. 1996), but other approaches, like angulation based on observations with a riflescope (Folmer et al. 2010), photography or video (Gordon 2001), distance measurements with laser range finders (Piersma et al. 1990, Ransom and Pinchak 2003) or tracking with radio-transmitters (Warnock and Takekawa 2003, Fukuda et al. 2004, van Gils et al. 2006) have also been used.

All methods used for estimating spatial positions have advantages and limitations. Counts in premarked plots are possible over relatively long distances, but small-scale information (i.e., variation within plots) is lost due to within-plot averaging. Distance measurements with a mil dot riflescope (Folmer et al. 2010) or range finders can provide more accurate estimates of a bird's or flock's position (Heinemann 1981, Piersma et al. 1990, Ransom and Pinchak 2003), whereas video-camera monitoring can provide both high spatial and temporal resolution (Gordon 2001). However, compared to spotting scopes, these devices typically provide less optical quality and, as a result, individual identification and spatial precision are difficult at greater distances ( $>200$  m). Finally, GPS loggers/transmitters can in principle provide both high-resolution spatial data as well as detailed information about migration routes (Fukuda et al. 2004), but, at present, this sophisticated method is expensive and can only be used with larger species (Warnock and Takekawa 2003). Additionally, birds must be captured to attach GPS tags, possibly resulting in altered behavior (Calvo and Furness 1992, Phillips et al. 2003).

Here we present a simple and low cost alternative method to accurately estimate spatial positions of shorebirds on a tidal flat, water surface, or other flat area using a Telescope-Mounted Angulator (TMA)—an instrument that measures the viewing angle of a telescope. First, we explain the construction, theory, and methodology be-

hind this telescope-mounted device. Next, we investigate its accuracy using a combination of laboratory and field experiments. Finally, we discuss the usefulness of the TMA for bird surveys and experiments compared to other methods.

## METHODS

**Device description.** The device was mounted to a tripod and telescope (zoom ocular 20–60  $\times$ ; ATM 80 HD, Swarovski, Absam, Austria). To keep the design simple and avoid excessive weight, the TMA was constructed primarily using lightweight aluminum parts obtained at low cost ( $< \$100$  U.S. for the entire device). The device was mounted to the tripod in such a way that the tripod and scope did not have to be modified.

The TMA consists of four main components. (1) The frame is mounted to the rotating, but not tilting, part of the tripod (Fig. 1: 1), by clamping the 0.55-m long supporting bar of the frame (width and height: 25 mm; thickness: 2 mm; Fig. 1: 1a) to the tripod using a galvanized steel strip (Fig. 1: 1b). The steel strip is bent around the tripod head and screwed to the supporting bar. (2) A 0.5-m long rod (width and height: 15 mm; thickness: 1.5 mm) with a ball-and-socket joint at the end (Fig. 1: 2 and 2a) is screwed to the tilting part of the tripod head and moves together with the scope. To do this, we used the screw hole already present on the tripod that is used to clamp the tripod's moving handle. (3) A 0.35-m long needle/indicator (6-mm diameter; Fig. 1: 3) is screwed onto the rod by the ball-and-socket joint and to the frame by sliding through a heim, or rose, joint (Fig. 1: 1c). Because the rod is mounted close to the frame ( $< 10$  mm), the needle is extremely sensitive to changes in the viewing angle of the scope. (4) A self-constructed indicator board (width  $\times$  height: 100  $\times$  1500 mm; thickness: 1 mm; Fig. 1: 4) is screwed to the frame through a 0.53-m long rod (width and height: 15 mm; thickness: 1.5 mm). The scale on the board was drawn with a permanent marker. It is a part of a circle subdivided into arbitrary units (here, we used a 1-cm distance between the ticks). The radius of the circle is equal to the length of the needle. Finally, a compass (Fig. 1: 5) was fixed to the frame with double-sided tape to obtain the heading that, together with distance, can be used to calculate the position of a focal bird.

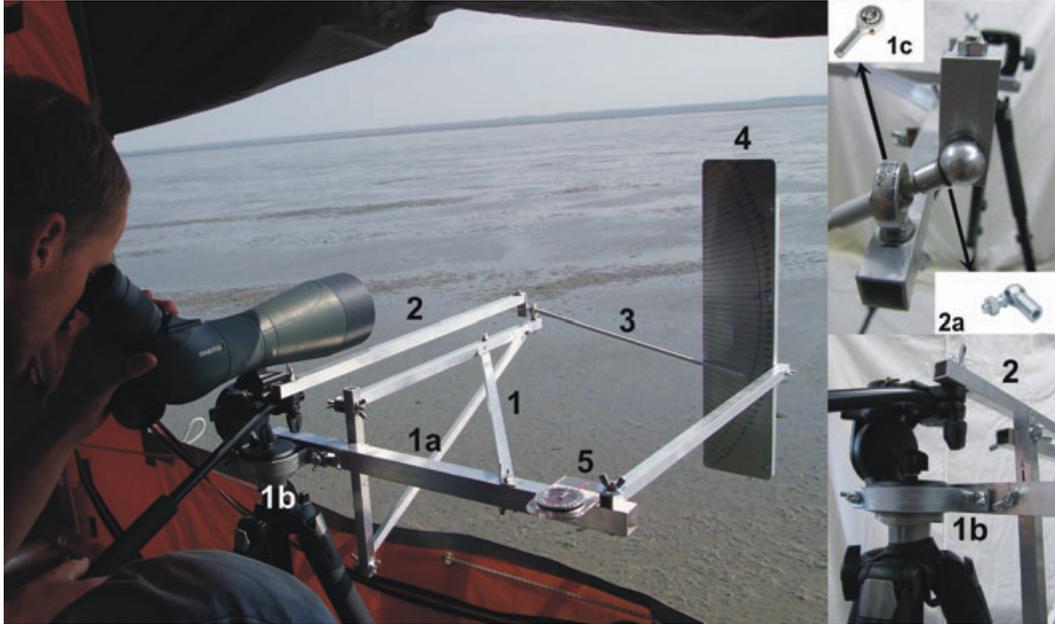


Fig. 1. The Telescope-Mounted Angulator. (1) The supporting bar (1a) of the aluminium frame is mounted on the rotating, but not tilting part of the tripod with a galvanizing steel strip (1b). (2) An aluminium square rod, moving with the telescope. (3) The needle/indicator, fixed to the rod by a ball-and-socket joint (2a) and to the frame by sliding through a rose joint (1c). (4) Aluminium indicator board for indicating the direction of the needle. (5) Compass attached to the frame.

**Theory.** An angulator is an instrument that, for various purposes, estimates angles. The TMA is an angulator that, when mounted to a field scope, provides a relative measure that relates to the viewing angle of a scope by a simple linear equation

$$\alpha = \alpha_0 + bx, \quad (1)$$

where  $\alpha$  is the viewing angle (degrees  $^{\circ}$ ; Fig. 2a),  $x$  is the relative indicator value from the TMA,  $\alpha_0$  is the angle at  $x = 0$ , and  $b$  is a constant ( $^{\circ}$ ). The relation between viewing angle and distance to the study-object can be calculated using basic trigonometry

$$D = \tan(\alpha)b, \quad (2)$$

with  $\alpha$  as the viewing angle,  $b$  as the mounting height of the scope (m), and  $D$  as distance (m). Combining Equations 1 and 2, the relation between distance  $D$  and TMA value  $x$  can be described as

$$D = \tan(\alpha_0 + bx)b. \quad (3)$$

In the field, the accuracy of TMA readings and parameter settings will depend on a number of factors. Sensitivity is dependent on the ratio between the mounting height of the scope and the distance (a higher value for  $b/D$  increases sensitivity) and increases with the scope's magnification (that must be fixed during measurements). Furthermore,  $\alpha_0$ ,  $b$ , and the TMA's sensitivity will depend on the distance between the frame and the rod moving with the scope (sensitivity is high when this distance is small). Finally, although  $\alpha_0$  can correct for tilting of the base of the tripod and the slope of the surface (Fig. 2b), the accuracy of TMA readings decreases substantially when random spatial variation in elevation of the landscape increases (Fig. 2c). Therefore, our device can only be used in areas with relatively flat surfaces. However, the required flatness of the surface depends on both the accuracy needed and the maximum viewing distance.

**Testing.** Variation between observers was tested in the laboratory. A tripod with scope and TMA was placed 6 m from a vertical ruler,

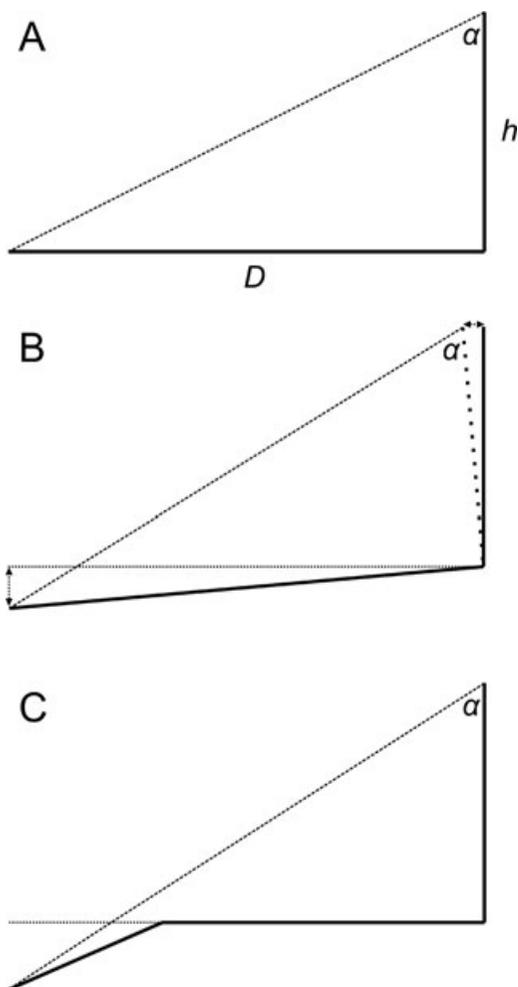


Fig. 2. (A) Estimation of distance ( $D$ ; base of the triangle) using height ( $h$ ; triangle's altitude) and the viewing angle (angle  $\alpha$ ). (B) The method of estimating distance using the TMA is quite robust to the slope of the surface because this can largely be corrected by adjusting parameter  $\alpha_0$  (tilt of the device). For instance, use of the TMA in an area with a slope of 0.1% (0.5 m change in height per 500 m), common for intertidal mudflats, would result in an error of only 0.7 m at 500 m. Variation in elevation of the landscape can, however, result in a great loss of accuracy (C). For example, a sudden decrease of 0.5 m in height at 500 m results in an underestimation of distance by 55.6 m.

with a scope height of 0.9 m. TMA values were determined by three observers at a fixed 60 $\times$  magnification of the scope for 16 preselected angles varying between 90 $^\circ$  and 88.5 $^\circ$  (heights

0.8 to 0.65 m on the ruler). The relation between the angle and TMA value was analyzed for all three observers by linear regression and the standard error for parameters  $\alpha_0$  and  $b$  was calculated.

To determine if an average calibration line could be applied for different observers, we calculated the observer error of the predictions at 100 and 500 m. We calculated the "mean" (a) and the "mean + standard error" (b) settings for both  $\alpha_0$  and  $b$ . For this purpose, Equation 3 can be rewritten as

$$x = \frac{\arctan(D/b) - \alpha_0}{b}. \quad (4)$$

We assumed a height ( $h$ ) of 4 m that was identical to the observation height in field tests we conducted. Subsequently, we calculated the observer error by substituting the obtained  $x$ -values from (a) into the parameterized Equation 3 of (b).

Following the laboratory tests, we tested the TMA in the field. First, we determined the TMA's accuracy by measuring distances and compass headings to fixed positions on a mudflat. Second, to illustrate possible applications, we assessed the spatial distribution of Eurasian Oystercatchers (*Haematopus ostralegus*) on and around a mussel (*Mytilus edulis*) bed in the intertidal zone of the eastern Dutch Wadden Sea (south of the island of Schiermonnikoog). We chose the oystercatcher-mussel bed system as a model because foraging oystercatchers are typically associated with mussel beds in this area during low tide, and the distribution of oystercatchers is often studied using spotting-scope observations (Ens and Alting 1996, Zwarts et al. 1996).

The scope's tripod was leveled and fixed to a 3.2-m high observation platform. The scope was set at a height of 0.8 m above the floor, resulting in a total height of 4 m above the tidal flat. The platform was placed on the tidal flat so that it allowed viewing of: (1) a 7-yr-old mussel bed, (2) an area with mussel spat (<1-yr old), and (3) a sandy area dominated by lugworms (*Arenicola marina*), all within a radius of 500 m (Fig. 3). We tested the TMA at low tide during four tidal cycles over a one-month period.

To calibrate the TMA-values to the observation angle and distance, we placed 0.5-m high PVC poles at fixed distances of 100, 200, 300, 400, and 500 m along a straight line in a south-facing direction from the platform and

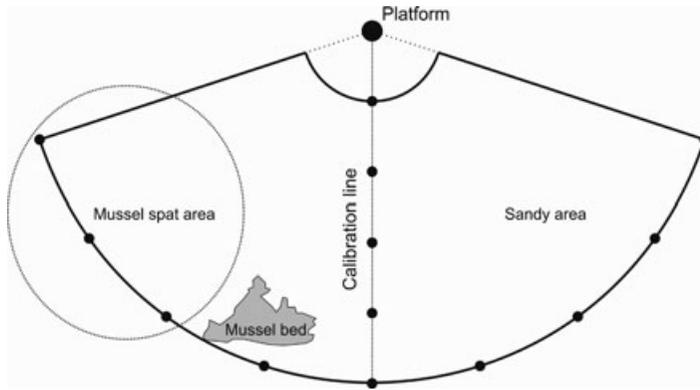


Fig. 3. Study area for the field test. The study area was made up of a 2/5 part of a 500-m-radius circle ( $144^\circ$ ). The area within a 100-m radius of the platform was not included to eliminate birds from the survey that may have been disturbed by the presence of the platform. The study area included a 7-year-old mussel bed, a mussel spat area ( $<1$ -yr old), and a sandy area dominated by lugworms.

eight additional poles along the 500-m radius line (Fig. 3). TMA values were fit to the fixed distances on the calibration line by nonlinear least squares regression using Equation 3. The nine poles along the 500-m radius were used to correct for directional change in the slope of the tidal flat and possible tilt of the tripod by adjusting parameter  $\alpha_0$  according to the direction (i.e., compass heading) using piecewise linear interpolation.

For each observation period, TMA readings were calibrated to the 5-pole calibration line using a fixed  $60\times$  magnification of the scope, and all eight remaining poles along the outer 500-m radius were measured to correct for changes in slope. Next, TMA values and compass headings of all oystercatchers in the study area were determined. Finally, to estimate our maximum prediction error, we measured all nine poles along the outer radius a second

time during the survey. The distance of the oystercatchers to the platform was calculated by entering the measured TMA value ( $x$ ) into the parameterized Equation 3. We determined the spatial position of the birds from the estimated distance, the compass heading, and the GPS coordinates of the observation platform using simple trigonometry.

## TEST RESULTS

**Laboratory.** Laboratory tests revealed a reliable linear relation between TMA values and the viewing angle for all three observers (Table 1).  $R^2$  was 0.996 for all observers. Moreover, differences in calibration lines among observers were small, with a standard error of only 0.025% for the intercept ( $\alpha_0$ ) and 1.5% for the slope ( $b$ ). However, although differences in the calibration lines were minor, they were not

Table 1. Linear regression results from the laboratory test on the relation between the TMA and viewing angle. The data demonstrate reliable fits for all three observers. The variance in parameter settings among different observers seems relatively small, but is not negligible at greater distances. Substitution of the x-value at 500 m based on the mean parameter settings, in Equation 3 parameterized as "mean + SE," results in an error of nearly 10% (49.8 m).

	Observer 1	Observer 2	Observer 3	Mean	SE
Intercept ( $^\circ$ )	91.35	91.43	91.38	91.387	0.023
Slope ( $^\circ$ )	-0.064	-0.067	-0.066	-0.066	0.001
$F$	3701.9	3141.1	3294.1	8362.1	
$P$	$<0.001$	$<0.001$	$<0.001$	$<0.001$	
$R^2$	0.996	0.996	0.996	0.995	

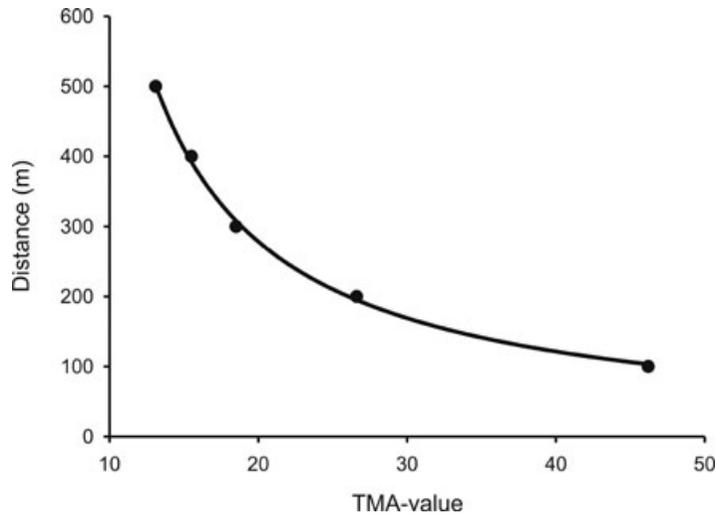


Fig. 4. Typical regression relating TMA-values to the calibration line. Note that the sensitivity of the TMA decreases with distance.

negligible. At a distance of 100 m, substitution of the  $x$ -value based on the mean parameter settings in Equation 3 parameterized as “mean + SE,” resulted in an observer error of only 3.3 m. However, this error increased to 49.8 m at 500 m. This indicates that an averaged calibration line cannot be used at greater distances and that individual calibrations are necessary.

**Field.** Calibration of the TMA resulted in reliable fits to the calibration line for all observation periods (Fig. 4, Table 2). The parameter settings of the intercept ( $\alpha_0$ ) and the slope ( $b$ ), obtained by nonlinear regression using Equation 3, varied slightly between periods depending on both the setup of the device and the observer. The maximum prediction error at 500 m varied among periods from 18.4 to 36.2 m, with a mean of  $26.8 \pm 4.7$  (SE) m. Finally, we found a maximum observation error in the compass

readings of 1 degree. This results in a maximum prediction error of 8.7 m at 500 m.

As an example, Figure 5 shows how the TMA can be used to determine the spatial position of oystercatchers. The figure shows all oystercatchers measured during the four observation periods. During these surveys, each individual bird took about 10 to 20 sec to measure. In total, we obtained 297 individual measurements during these periods. The figure clearly illustrates that the highest densities of oystercatchers were found on the mussel bed and in the spat fall area.

## DISCUSSION

We describe a simple and low-cost method to estimate the spatial position of shorebirds using a Telescope-Mounted Angulator. Measurements

Table 2. Regression results of the TMA values on the calibration line. The calibration yielded reliable fits for all four periods. Obtained parameters varied slightly depending on the exact setup of the device and the observer. The mean maximum error (at 500 m), calculated based on the difference between the first and second measurements of the poles along the 500-m radius, was  $26.8 \pm 4.7$  (SE) m.

	Period 1	Period 2	Period 3	Period 4
Intercept ( $^{\circ}$ )	90.272	90.359	90.069	90.537
Slope ( $^{\circ}$ )	-0.066	-0.070	-0.063	-0.065
$F$	1061.9	787.5	783.4	228.4
$P$	<0.001	0.001	0.001	0.004
$R^2$	0.999	0.999	0.999	0.996
Max. error (m)	33.76	36.22	18.36	18.98

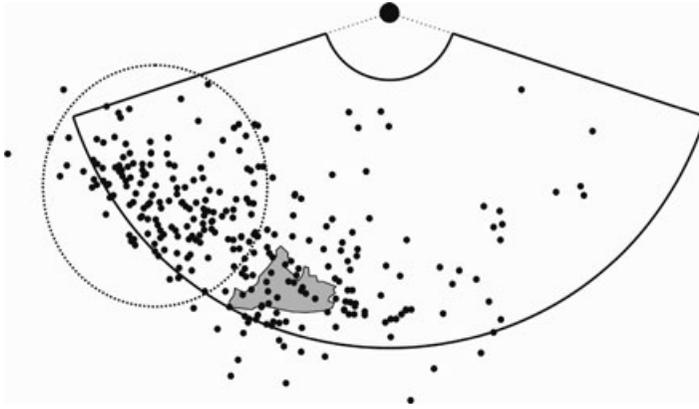


Fig. 5. Spatial position of all oystercatchers measured at low tide during four tidal cycles over a one-month period. Results show highest densities on the mussel bed (shaded area) and in the area with mussel-spat fall (dashed circle).

can be made quickly (10–20 s) and the method is therefore especially well-suited to estimate the positions of larger birds. In addition, the method is also applicable for smaller and faster-moving flocking species. Although it would not be possible to estimate the position of each individual in such cases, the flock's position could easily be determined. In our field tests, we used the TMA on an intertidal mudflat. However, the device could likely be used in other areas with relatively flat landscapes, for example, to estimate the position of animals on calm water surfaces, pastures, prairies, or savannas.

Our laboratory tests showed that the TMA can produce consistent estimates of the viewing angle, but that these differed slightly among observers. Therefore, individual calibrations for each observer improve accuracy, particularly for birds at greater distances. Our results from the field demonstrated that TMA measurements can be reliably used to calculate the distance to focal birds using simple basic trigonometry. However, accuracy of this method is highly dependent on the flatness of the landscape, the mounting height of the telescope, and, as with other optical instruments, weather conditions, particularly strong winds. Therefore, sufficient viewing height, a flat landscape, and relatively calm winds ( $<6 \text{ m sec}^{-1}$  in our tests) are important factors influencing the accuracy of the method. In our field study, with a 4-m viewing height and a relatively flat intertidal mudflat, the TMA provided a reliable method to estimate spatial positions at distances

up to 500 m with an error of approximately 5%.

For bird surveys, counting in premarked plots is a method typically used in situations similar to those where the TMA can be used (Ens and Altung 1996, Zwarts et al. 1996). Compared to plot counting, our method has three advantages: (1) The TMA allows spatial positioning of all individual birds, whereas counting in plots only produces averaged densities for each plot. (2) The TMA is more accurate. Counting in premarked plots is typically used at resolutions between 50 and 400 m, with viewing heights generally varying from 5 to 10 m. In our study, the TMA produced a mean error of 27 m at a viewing height of only 4 m. (3) Using calibration points, we were able to estimate the prediction error of the TMA. With counts in plots, quantification of observer error is not possible. Finally, compared to other, less common methods like angulation by riflescope (Folmer et al. 2010), photography or video (Gordon 2001), or the use of a laser range finder (Ransom and Pinchak 2003), the TMA is typically more accurate at greater distances because it is mounted on a spotting scope. In our study, we used the TMA at distances up to 500 m, but, depending on the viewing height and accuracy needed, the maximum observation distance could probably be increased to 800 m.

In summary, we show that the TMA is a simple, low cost, and useful tool for accurate estimates of the spatial position of shorebirds at a relatively small scale on flat surfaces like an

intertidal mudflat or a calm water surface. The TMA provides more detail and accuracy than counting in premarked plots, and is applicable at greater distances than video monitoring or distance estimation with a laser range finder. Our method can be a valuable addition to large-scale monitoring programs, providing good spatial detail for large numbers of birds at low cost and in relatively little time. Additionally, the TMA may be useful in experimental contexts because the estimates can provide detailed information on, for example, the predation pressure of shorebirds on sessile benthic fauna.

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