Estimating Arribada Size Using a Modified Instantaneous Count Procedure

Charles E. GATES, Roldán A. VALVERDE, Claudette L. MO,
Ana C. CHAVES, Jorge BALLESTEROS, and Jocelyn PESKIN

Estimates of the number of nesting female turtles are illustrated, using an instantaneous count (IC) procedure modified by sampling in space as well as time. Variations of the modified IC procedure are shown to be equivalent to four methods, including the strip transect (in time), the line intersect (in time), and quadrat sampling (in time), depending on the specific sampling variant utilized. Estimators for all procedures, as well as for similar ones, are derived, as are the variances of the estimates. The modified IC procedure is illustrated with estimated "arribada" (or arrival) sizes at Playa Nancite, Costa Rica. ARRIBADA, a computer program for analyzing either actual or simulated strip transect data from arribadas, is described briefly.

Key Words: Arribada; Costa Rica; Instantaneous counts; Olive ridley turtle; Line intersect in time; Quadrat in time; Strip transect in time; Variance of abundance.

1. INTRODUCTION AND LITERATURE REVIEW

Many tropical and subtropical beaches around the world serve as nesting grounds for the different species of marine turtles. Because most of the life cycle of sea turtles occurs in the ocean where animals are not easily accessible, most of the knowledge of sea turtle biology originates from studies based on their ephemeral terrestrial phase. Adult populations of sea turtles generally are assessed a priori by counting the number of females that lay their eggs at a particular beach (Magnuson et al. 1990). This can be done either by counting the number of nesting individuals directly or by counting the number of tracks that these animals leave behind during their nesting excursions; however, both methods are often not feasible. Because this methodology does not allow for the assessment of some aspects intrinsic to the biology of sea turtles, several complications arise, making it difficult to accurately evaluate the status of a given population. For instance, female turtles do not necessarily lay eggs every time they crawl up on the beach. Direct observation of the animals could be suggested, but this may not be logistically and economically

feasible, particularly in remote beaches. In addition, males normally are not present in beach surveys, further limiting the assessment of the status of a population.

Another difficulty that arises at some beaches is that the number of nesting animals is too large to allow a direct, accurate account of the nesting effort of a population. This situation is best exemplified by the olive ridley sea turtle (*Lepidochelys olivacea*). This turtle is known to nest on many beaches in relatively low numbers, as with other sea turtle species. However, at a few locations, this species seems to prefer to nest in large numbers. This phenomenon has been termed "arribada" (or arrival) (Richard and Hughes 1972). The arribada phenomenon is characterized by a mass of female turtles that crawl up the beach to nest in a synchronous fashion over a period of a few nights. The arribada event usually takes place unpredictably, several times during a nesting season, with some females participating in more than one event (Hughes and Richard 1974).

During an arribada it is common to observe female turtles in different nesting stages that include animals crawling up and down the beach, animals digging or covering nest cavities, and animals actively depositing a clutch of eggs in the nest receptacles. These aspects make it difficult to accurately estimate the number of nesting animals. On average, the whole nesting process may last for about an hour per turtle (Cornelius and Robinson 1985), time which sea turtle biologists utilize to gather information. A main trait of arribada events is that turtles aggregate in a very small nesting area, which increases the degree of difficulty of accurately estimating the actual number of animals that take part of one of these events. As illustrated by Cornelius, Alavarado-Ulloa, Castro, Mata del Valle, and Robinson (1991), proposing and implementing a practical, scientifically sound method for estimating the number of animals that nest during an arribada is critical to research, management, and conservation of olive ridley sea turtle populations.

There are many sampling methods available to the biological researcher for estimating population numbers, each with its own relative advantages, disadvantages, and degree of practicality. For example, there are the capture–recapture, line and strip transect, quadrat sampling, change-in-ratio, and aerial survey methods. The biological sampling procedure termed "instantaneous count" (IC) is a simple, inexpensive method requiring a minimum of assumptions for valid estimation, yet is easy to understand, implement, and analyze. Another important advantage of the IC method is that valid estimates of the variances of population sizes are available and readily computable. The IC method does not appear in a recent, distance-based biological sampling text (Buckland, Anderson, Burnham, and Laake 1993), as distances to individual animals are not directly utilized in the IC method. For another application of the IC method, the reader is referred to section 6 of Ramsey, Gates, Patil, and Taillie (1988).

We are aware of only a few quantitatively based attempts to estimate the size of arribadas. Hughes and Richard (1974) used a single strip transect (ST) to estimate arribada sizes at Playa Nancite. Estimates for the September, October, and November 1971 arribadas were given as 115,000, 103,000, and 70,000, respectively. However, total turtle visits were counted and the expansion method used was not given. Meylan (1982) discussed in a general way the estimation of population size in sea turtles and mentioned aerial transects as well as counting tracks, both from the air and on the ground. She noted that in various species, one- to two-thirds of turtle trips to the beach do not result in egg clutches. Márquez , Peñaflores, Villanueva, and Díaz (1982) mentioned catch

effort, tagging, and "direct censuses" as methods for estimating numbers of laying turtles. Márquez and Dissel (1982) presented an estimation procedure based on empirically modeling the distribution of nesting olive ridleys on the beach over time. Cornelius and Robinson (1982) gave a detailed formula with many constants required for estimating arribada sizes, based ultimately on the quadrat sampling method in time. In no instance was there any evidence for unbiased estimation or any attempt made to estimate the variance of the estimate.

The intent of this article is to modify the basic IC method to estimate the number of egg-laying females that participate in major arribada events. Formulas and a computer program have been developed to provide unbiased estimates of the number of laying animals, along with the variability of those estimates. The procedures and formulas will be illustrated with sample data from Playa Nancite, one of the two main Costa Rican arribada beaches. A later paper will provide a more detailed biological assessment of the estimates from many arribadas.

2. DESCRIPTION OF THE INSTANTANEOUS COUNT PROCEDURE

First, we give a description of a "classic" use of the IC procedure as a simplified example and then describe the method as it would have to be modified to estimate the numbers of laying female turtles in an arribada.

In the classic IC use, where a researcher might be interested in the use of a popular but unregulated rafting river, snapshots could be taken by a camera mounted at a fixed location in the target area, such as a short section of the river, perhaps at a canyon exit. The photographs must be taken at random times with respect to the use of the river by rafters. Clearly, a photograph could be taken at timed intervals, say, every hour, perhaps automatically during daylight hours, assuming all rafters do not begin simultaneously—a highly dubious premise. Even one such snapshot would give an unbiased estimate of the usage by rafts or, alternatively, by the number of individuals, given that an independent estimate of the average time to transit the field of view of the fixed-position camera were available. We would highly recommend against taking only one snapshot, as the variance of estimate would not be computable. Obviously, all days of the week would have to be sampled if, for example, there were any chance that weekend usage would be higher than a weekday. Similar comments hold with respect to usage throughout the rafting season.

To simplify the presentation here, we will assume that it is of interest to estimate the usage of the hypothetical river only during the week encompassing the Fourth of July. Assume that a camera is mounted to take photos every two hours, seven times daily, during the 14-hour days for seven days, yielding a total of 49 photos over the 98-hour period. Further, suppose 13 rafts, carrying a total of 69 individuals, have been observed in the 49 photos. Assume that an independent study has determined the average time for a raft to cross the camera's field of view is five minutes; then the estimated number of rafts using the river during the specified week is readily computable. We can formalize the mathematics by defining $\widehat{M}, n_{\cdot}, H, \bar{h}$, and t as the estimated number of rafts using the river, the total number of sightings determined from the photos, the total number of

hours of raft usage during the week, the average time for a raft to cross the camera's field of view, and the number of sampling times, respectively; then

$$\widehat{M} = \frac{n.}{C_t} = \frac{n.H}{\bar{h}t} = \frac{13(98)}{.0833(49)} = 312, \tag{2.1}$$

where $C_t = \bar{h}t/H$ is the proportion of time that is sampled. With an average of $69/13 = 5.31$ individuals per raft, the estimated number of individuals using the river during the Fourth of July week is $5.31(312) = 1,656$.

3. GENERAL MODIFICATION OF THE IC PROCEDURE FOR ARRIBADAS

Olive ridley turtles will visit the beach without laying a clutch of eggs and will spend much additional time, even when on a viable egg-laying visit, in travel to and from the ocean, digging, covering the nest, and other activities.

As previously discussed, these aspects would complicate the computation of estimates of the number of egg-laying females, mostly due to the difficulty of quantifying each of them. Therefore, it is essential that the only turtles counted are those exhibiting unambiguous egg-laying activity (UELA). We recommend that eggs must be seen to satisfy the UELA requirement.

Sampling an arribada would be directly comparable to the rafting example only if we were able to count an entire beach at once. One possible way to photograph an entire beach might be to fire a magnesium flare and take a photo from overhead; however, this is patently absurd on many grounds.

Excepting very small arribadas, it is totally impractical to survey the entire beach at once, magnesium flares or not. Therefore, we must resort to subsampling *area*, as well as *time*. The procedure is as follows. Set up any number of lines roughly at right angles to the curve of the beach. These lines should extend from the high tide line to the furthermost point used by the turtles. The lines should not be so close to each other as to overlap, either in time or space, although that is unlikely under field conditions. The entire arribada beach should be sampled, as well as all hours of the arribada. Turtles cannot be cognizant of our arbitrary time and distance units; thus, both time and line intervals may be systematically determined. An observer then walks these lines as quickly as possible at predetermined times during an arribada, counting UELA turtles that are within a specified distance of each predetermined line. For now, we shall term this sampling a "transect in time." There are numerous ways of defining the specified distance from the line, four variations of which will be described in detail in the next section. In this most general development, let the *effective transect width* be $\bar{w}$; this quantity will be treated as a variable (although it is a constant in two variants). Thus, the total sampled area is $a = \bar{w}\Sigma l_i = \bar{w}L$, where a and l_i represent the sample area and the length of the ith line, respectively. From this we calculate the area and time expansion factors:

$$C_a = \frac{a}{A}, C_t = \frac{\bar{h}t}{H}, \tag{3.1}$$

where $A, \bar{h}, H$, and t are the total available nesting area of the arribada beach, the average time spent in UELA (hours), the length of arribada (hours), and the number of sampling periods, respectively.

The estimate of the number of laying female turtles for the modified IC method when subsampling both the time and space dimensions is therefore

$$\widehat{M} = \frac{n_{..}}{C_a C_t} = \frac{AH}{tL} \cdot \frac{n_{..}}{\bar{w}\bar{h}}, \tag{3.2}$$

where $n_{..} = \Sigma\Sigma n_{ij}$ are the total UELA turtles seen, and L is the total transect length. n_{ij} is the number of UELA turtles seen in the ith period and the jth transect.

4. DERIVATION OF $v(\widehat{M})$

Clearly, estimates of numbers of turtles are inadequate without corresponding variances and confidence intervals. We shall derive $v(\widehat{M})$ in its most general form, simplifying later. It immediately follows from Equation (3.2) that

$$v(\widehat{M}) = \left[\frac{AH}{Lt}\right]^2 v\left[\frac{n_{..}}{\bar{w}\bar{h}}\right]. \tag{4.1}$$

Clearly the quantities in the first set of brackets are known, fixed constants for a given arribada, while those in the second pair represent the ratio of one variable divided by the product of two variables. Let $\tau = \bar{h}\bar{w}$; then, if the numerator is statistically independent of the denominator in the $v[..]$ expression, which is almost surely true for marine turtles, Fieller's result for the ratio of two random variables (Finney 1964, pp. 27–29), gives us

$$\hat{v}\left(\frac{n_{..}}{\tau}\right) \cong \left[\frac{v(n_{..})}{n_{..}^2} + \frac{v(\tau)}{\tau^2}\right]\left[\frac{n_{..}^2}{\tau^2}\right]. \tag{4.2}$$

To evaluate the variance of τ, we invoke the exact variance of the product of two variables (Goodman 1960, p. 710):

$$\hat{v}(\tau) = \hat{v}(\bar{w}\bar{h}) = [\bar{w}^2 v(\bar{h}) + \bar{h}^2 v(\bar{w}) - v(\bar{w})v(\bar{h})]. \tag{4.3}$$

Equation (4.3) assumes that effective transect width and average laying time are statistically independent—it would appear they almost surely are. Thus, putting all of the pieces together, the most general form of the variance of the estimated number of laying turtles is

$$\hat{v}(\widehat{M}) \cong \widehat{M}^2 \left[\frac{\hat{v}(n_{..})}{n_{..}^2} + \frac{\hat{v}(\bar{w})}{\bar{w}^2} + \frac{\hat{v}(\bar{h})}{\bar{h}^2} - \frac{\hat{v}(\bar{w})\hat{v}(\bar{h})}{\bar{w}^2\bar{h}^2}\right]. \tag{4.4}$$

$\hat{v}(\bar{w}), \hat{v}(\bar{h})$ may be estimated from independent data samples with m_w, m_h observations. There are at least three ways of evaluating $\hat{v}(n_{..})$; all methods involve calculating an average $\hat{v}(n_{ij})$ and then expanding that value to the variance of a total. One could calculate (1) the average variances of counts, ignoring both time and line variability, (2) the average of variances of sampling period counts within lines, or (3) the average of

variances of line counts within sampling time. We have chosen the last method on the basis of extensive computer simulation, as well as common sense. Thus,

$$\widehat{v}(n_{..}) = \frac{m\Sigma\Sigma n_{ij}^2 - \Sigma_i n_{i.}^2}{m - 1}, \qquad (4.5)$$

where m is the number of individual transects. Equation (4.5) makes the implicit assumption that the l_j are of approximately equal length. If such lengths are unequal, a necessarily more complex expression is

$$\widehat{v}_a(n_{..}) = \frac{m^2\Sigma_i[L\Sigma_j l_j n_{ij}^2 - (\Sigma_j l_j n_{ij})^2]}{L^2(m - 1)}, \qquad (4.6)$$

where the ranges of summation are $j = 1, m$ and $i = 1, t$, and t is the number of sampling times of the arribada, including daylight hours. Equation (4.6) weights the variance estimates directly proportional to the lengths of the individual components of the transect with $\Sigma l_i = l_. = L$. Using Equations (4.5) or (4.6) as is appropriate, it follows immediately that the 95% confidence intervals for $\widehat{M}$ will be approximated by

$$\widehat{M} \pm 1.96\widehat{M}\sqrt{CV^2(n_{..}) + CV^2(\bar{w}) + CV^2(\bar{h}) + CV^2(\bar{w})CV^2(\bar{h})}, \qquad (4.7)$$

where the square of the CV (coefficient of variation) is defined as $CV^2(*) = \widehat{v}(*)/(\bar{*})^2$. Equation (4.4) and, of course, Equation (4.7) clearly specify that for fixed sample size and so forth, the standard error of estimated population size is proportionate to that estimate. Although this concept is somewhat counterintuitive (i.e., the larger the arribada, the larger the standard error), it is not at all unusual in the estimation of abundance. The simple explanation is that the sampling unit is the transect length, l_j, at any one time period, not the individual turtle.

5. SPECIAL CASES OF THE PRECEDING DERIVATION: THE ST IN TIME, THE LINE INTERSECT (LI) IN TIME, THE EXTENDED LI IN TIME, AND QUADRAT SAMPLING IN TIME

We discuss four specific sampling plans, special cases of the preceding general description of "transect" sampling. These are (1) the strip transect in time, (2) the line intersect in time, (3) the extended line intersect in time, and (4) quadrat sampling in time.

The simplest of these is clearly the strip transect in time. Here, the researcher at any one sampling period counts any UELA turtle whose carapace center (and hence turtle center) is within the two prespecified boundaries (as was done at Playa Ostional). In traditional strip transect methodology, the width of the strip is $2w$, where w here is the half-width of the strip. Thus, the sample area at a given sampling time is $a = 2wl_. = 2wL$. Because the width of the transect used is a constant, $\sigma_w^2 = 0$. This simplification enables us to present the results for the ST in time method in traditional notation as

$$\widehat{M} = \frac{AH}{2wtl_.} \cdot \frac{n_{..}}{\bar{h}}, \qquad (5.1)$$

with

$$\widehat{v}(\widehat{M}) \cong \widehat{M}^2 \left[\frac{\widehat{v}(n_{..})}{n_{..}^2} + \frac{\widehat{v}(\bar{h})}{\bar{h}^2} \right]. \tag{5.2}$$

If the CV of $\bar{h}$ is small relative to the CV of $n_{..}$, then the approximate variance of estimated turtles and the approximate 95% confidence intervals would be given by

$$\widehat{v}(\widehat{M}) \cong \widehat{M}^2 \left[\frac{\widehat{v}(n_{..})}{n_{..}^2} \right] \tag{5.3}$$

and

$$\widehat{M} \pm 2\widehat{M} \sqrt{\frac{\widehat{v}(n_{..})}{n_{..}^2}}. \tag{5.4}$$

We use 2.00 versus 1.96 here to compensate for the omitted sources of variation.

The second of the four special cases of transect sampling in time is the line intersect in time sampling method. Here, sampling at a given time period is analogous to the traditional line intersect sampling method. An UELA turtle is said to be on the line if any part of the turtle's carapace touches the line. The effective width of the line intersect is the average of average turtle carapace lengths and widths. (We note that an alternative measurement would be to use the criterion that if any part of the UELA turtle should touch the line, it would be counted. The advantage of this approach is that more turtles would be eligible for counting; the disadvantage is that the variation in average total turtle length and width would be considerably more variable than that of the carapace alone.)

Under the entirely realistic assumption that the UELA turtles are in random orientation relative to the lines and therefore the beach, the line intersect in time method is equivalent to a strip transect in time method with effective width being the average carapace length and width. Equations (3.2) and (4.4) may be used to give unbiased estimates of arribada size and for confidence intervals about the estimated arribada size. Simplification of $\widehat{v}(\widehat{M})$ will be considered in the discussion.

An alternative analysis to the LI in time data would be to use the traditional de Vries (1979) approach. There are two variations we consider here, both requiring measurement of each UELA turtle during the arribada. Because the olive ridley turtle carapaces are near-ellipses (ratio of minor/major axis $\cong .91$), we could consider the turtle carapaces to be circles as an approximation—a more precise formulation does not make that assumption. We strongly recommend against either procedure for arribadas due to the complete impracticality of measuring these distances under field conditions; determining if a turtle shows UELA is difficult enough. However, for the interested reader, the necessary time extension to the traditional line intersect method is developed in the following paragraph. In LI sampling for population densities at the ith time period, the traditional de Vries formula for circular objects is

$$\widehat{D}_i = \frac{\Sigma_{j=1}^{n_i}(1/d_{ij})}{L}, \tag{5.5}$$

where d_{ij} is the diameter, interpreted here as the average of width and height (carapace or total turtle, depending on the criterion chosen) of the jth UELA turtle in the ith sampling period. Because estimating total UELA turtles is of greater interest than density, we convert density to total estimated count by multiplying Equation (5.5) by the total nesting area, A. To expand Equation (5.5) to the total count over time, including the daylight hours, we sum over all time periods and divide by the previous time expansion factor, C_t:

$$\widehat{M_c} = \frac{\Sigma_{i=1}^t \widehat{N}_i}{C_t} = \frac{AH\Sigma_{i=1}^t \Sigma_{j=1}^{n_i}(1/d_{ij})}{L\bar{h}t}. \tag{5.6}$$

If d_{ij} is considered a constant, say $\bar{w}$, then Equation (5.6) reduces to Equation (3.2). For circular objects, de Vries gave as the estimated variance (equivalent to one sampling period in our notation)

$$\widehat{v}(\widehat{N}_i) = \left(\frac{A}{L}\right)^2 \Sigma_{j=1}^n (1/d_{ij})^2. \tag{5.7}$$

Thus, the variance of $\widehat{M_c}$ in our notation, using Equations (5.6) and (5.7) as well as the variance of the ratio of two variables, yields

$$\widehat{v}(\widehat{M_c}) = \widehat{M_c^2}\left[\frac{\widehat{v}(\Sigma\widehat{N})}{(\Sigma\widehat{N}_i)^2} + \frac{\widehat{v}(\bar{h})}{\bar{h}^2}\right] = \widehat{M^2}[CV^2(\Sigma\widehat{N}_i) + CV^2(\bar{h})], \tag{5.8}$$

assuming statistical independence of estimates at different sampling times. The variance of turtle dimension does not appear here explicitly, but it is involved in $\widehat{v}(\widehat{N}_i)$. An easier and more precise adaptation of the de Vries LI in time sampling method would be to measure the maximum length (either total or, preferably, carapace length), say d'_{ij}. In this case,

$$\widehat{N}_i = \frac{\pi A}{2L}\Sigma(1/d'_{ij}); \widehat{v}(\widehat{N}_i) = \left(\frac{\pi A}{2L}\right)^2 \Sigma(1/d'_{ij})^2; \widehat{M_{dv}} = \frac{H\pi A}{2\bar{h}tL}\Sigma\Sigma(1/d'_{ij}). \tag{5.9}$$

The form of the variance estimate for $\widehat{M_{dv}}$ is exactly of the same form as Equation (5.8), merely substitute the new definitions for $\widehat{v}(\widehat{N}_i)$ and $\widehat{M_{dv}}$ given by Equation (5.9).

The third variation of transect sampling in time we have arbitrarily called an "extended line intersect in time." This variation was developed and used at Playa Nancite, August–November 1994. Here, at a given sampling period, one of us (J. P.) counted all UELA turtles whose carapaces were totally enclosed by or touched the ends of a strip of 150.5 cm, centered on the line. This sampling method may also be thought of as a strip transect (in time) with a variable outer edge. Thus, the effective strip width, in cm., is $w = 150.5+$ average carapace size, as defined in the LI in time method. The variation of w here is clearly that of average carapace size. Equations (3.2) and (4.4) may be used to estimate arribada size and to place 95% confidence limits thereon. Simplification of the most general expression for $\widehat{v}(\widehat{M})$ will be considered in the discussion.

The fourth variation of IC in space sampling we have termed "quadrat sampling in time." A quadrat is traditionally a square area, although occasionally rectangular or

Table 1. Number of Nesting Turtles Participating in Four Arribadas During the 1994 Nesting Season at Playa Nancite, Costa Rica, as Estimated by a Modified Instantaneous Count Method

Month	Number of UELA turtles	Estimate $\hat{M}$	Standard error	Lower confidence limit	Upper confidence limit	Coefficient of variation (%)
August	50	11,148	2,275	6,598	15,698	20.4
September	71	23,320	3,418	16,485	30,155	14.7
October	168	36,336	3,176	29,982	42,690	8.7
November	84	10,684	1,430	7,725	13,444	13.5

NOTE: $\alpha = .05$, $\bar{h} = .228$ hour, H= 54 hours, $a/A = .0344$, $m = 20$, $\bar{w} = 2.206$ m., and L= .377 km.

circular. There is no conceptual statistical difference between a quadrat and a ST, except perhaps that the latter are traditionally longer and narrower. In an idealized arribada application, multiple quadrats are placed at random on the available nesting area of the beach, generally aligned at right angles to the curvature of the beach. Systematic placement of the quadrats in nesting turtle estimation is permissible, but extreme care must be taken that all potential nesting areas on the beach are sampled proportionately. This proportionate sampling could be achieved by dividing the potential nesting area into minihabitats (adjacent to the vegetation line, adjacent to the high tide line, etc.) and locating quadrats, even systematically, within each minihabitat.

Because conceptually, quadrats are identical to ST's, the analysis has already been described. All formulas appropriate for the ST have already been provided [see Equations (5.1)–(5.4)], provided the quadrats are at least rectangular. The effective width of the transect will be the width of the quadrat, the constant fixed length of the individual transect—the length (depth) of the quadrat. So clearly, $\hat{v}(n_{..})$ will be estimated by the simplified form, Equation (4.5).

6. DATA ANALYSIS

Arribada sizes in Table 1 were estimated by counting the number of UELA turtles on 20 transects during the 1994 nesting season at Playa Nancite, Costa Rica. All transects were surveyed approximately every two hours during a session. An arribada session is defined as the period in which female olive ridleys continuously emerge to nest; thus, a session for the olive ridley typically includes the time interval between dusk and dawn. Total length of the transects was varied from 345.4 to 377.0 m, depending on the different beach configuration each month, and mean UELA time used was 13.67 min. (.228 hrs.) The average carapace size used was 70.12 cm; thus the effective strip width was 220.62 cm. Data were analyzed using the computer program ARRIBADA.

7. COMPUTER PROGRAM, ARRIBADA

Although inexpensive compared to other methods, determining numbers of nesting turtles via the modified IC method still takes substantial resources. Although the computations for analyzing arribada data are not onerous, a computer simulation program would

appear to be most useful for biologists in exploring the effects of various variables on the final estimates and their variances, such as total length of the transects surveyed. ARRIBADA is such a PC computer program that either (a) analyzes actual data from an arribada or (b) simulates the random allocation (in both time and space) and subsequent counting of laying turtles in an arribada by ST sampling in time. In the former case, complete generality is ensured by requiring the user to enter the effective width of the transect. Copies of the computer program and its requirements, sample data sets, both actual and simulation, and the documentation are available on request; merely send a formatted 5 1/4" or a 3 1/2" floppy diskette (with over 500k capacity) to the senior author.

8. DISCUSSION

Four variations of IC sampling in space have been defined in this article and used at some time at either Ostional or Nancite; there are undoubtedly other variations that could be described. Some criteria for choosing from among these variations and others could be as follows. First, the ST in time and the quadrat (in time) sampling methods have the clear statistical advantage that $\sigma_{\overline{W}}^2 = 0$, by definition, and $\widehat{v(M)}$ will be simpler, without requiring that the CV of effective strip width be relatively small. One practical means of ensuring fixed width would be to set up posts in pairs of lines, marking the strip boundaries. The disadvantage of this approach is that of more field work. From a statistical viewpoint, the wider the effective strip width (within limits), the better, as a greater proportion of the total beach area will be sampled. We would not recommend an effective strip width of much more than about 2 m, that being about the maximum width the observer can handle under the very trying field conditions. The disadvantage of using a line intersect in time sampling procedure is that the effective strip width would be small and not many turtles will be counted. Thus, more individual lines would be required to obtain reasonable sample size.

Permanent quadrats were set up in a systematic manner by Cornelius (see Cornelius and Robinson 1982) at both Playa Ostional and Playa Nancite, using 10 × 10 m plots. Apparently, these quadrats failed to sample all potential nesting areas proportionately. Their method of estimation, however, was completely different from that described here.

The third method was introduced by one of us (J. P.) in the August–November 1994 arribadas at Playa Nancite. The fixed width of 150.5 cm was determined by her arm span. All transect surveying for the specified months was done by her and is thus consistent for these months. We cannot recommend this procedure unless the same person will be taking all data for a given arribada.

The arribada estimates, shown in Table 1, appear to be quite reasonable. Observe that the estimated number of laying turtles, the standard error, the confidence intervals, and the CV's all appear to be correlated with the number of UELA turtles. The October arribada estimate is unusually high. The observer (J. P.) reported that at the peak it was literally not possible to walk on the beach without stepping on turtles.

The simulation program, ARRIBADA, was "exercised" to see how well the Nancite standard errors of the estimate for September agree with an extensive, idealized simulation.

Table 2.   Data From Simulating the September, 1994 Arribada

Distribution of time to egg-laying:	Average $\widehat{M}$	Empirical standard error	Average estimated standard error	Empirical CV (%)	$1 - \widehat{\alpha}$ (from estimated variances)
Normal	23,158	2,507	2,434	10.8	.936
Uniform	23,330	2,470	2,439	10.6	.951
Poisson	23,431	2,440	2,444	10.4	.958

NOTE: M = 23,320, 1,000 replications of each distribution, $\bar{h}$ = .228 hour, H = 60 hours, a/A = .0345, m = 20, $\bar{w}$ = 2.206 m., and L = .377 km.

We used (a) 1,000 replications, (b) a selection of the numbers of population strip transects (580) and sample strip transects (20), such that the ratio of sampling area/total arribada beach area was similar to that observed, .0344, (c) the same average nesting time (13.67 minutes= .228 hr.) as Nancite, (d) the true population size of 23,320, and (e) the distribution of times of egg-laying from populations with normal, Poisson, and uniform variability, respectively. The results are shown in Table 2.

In the simulation mode, ARRIBADA generates two kinds of variances, the empirical variances derived from all 1,000 replicate estimates, and the average of 1,000 estimated variances from Equation (5.3). Estimated variances for the Nancite September data appear to be most reasonable. The proportion of time the confidence intervals, using the computed variances $1 - \alpha$, included the true population size was determined by enumeration. It appears that the simulated confidence limits are very close to being correct. Close agreement with the desired .95 confidence level is clearly indicative of the reasonableness of the two successive approximations used in determining the variance of estimate. Slightly superior confidence intervals might be achieved here by using $\log(\widehat{M})$ and subsequent log-based confidence intervals (see Buckland et al. 1993). The observed variance of estimate for the September arribada is also consistent with the two variances reported here.

Based on computer simulation, it would appear that the more complex forms of the variance of estimate [e.g., Equation (4.4)] can be safely ignored. Independent samples ($n = 120$) were taken of UELA time over the four 1994 arribadas, leading to the previously cited average of 13.67 min., with a variance of the mean UELA time of .2564. This implies a CV of .037 (3.7%), comparing favorably with the CV's reported in Table 1 and 2, where estimated variances assume $CV(\bar{h}) = 0$. Average carapace width and length were determined by one of us (R. A. V.) during the August 1994 arribada, independent of the turtles counted on the transects. The average carapace size ($n = 35$) was 70.12 cm with a variance of average of lengths and widths as 8.09, implying a CV of .0406 (4.1%). On the basis of these relatively small CV's, it would appear that the simplest form of $\widehat{v}(\widehat{M})$, Equation (5.4), is a useful approximation.

One item for further research is our implicit assumption that average UELA time and average carapace size are constant over time at a given arribada beach. It is our opinion that, although there may be minor variation in these variables in arribadas between and within years, the variation would not greatly influence the various estimators due to the relative constancy of the species. The size of UELA turtles appears to be remarkably

similar, compared to almost any species, from time to time and between the two arribada beaches in Costa Rica.

One practical problem that arose at Ostional with the use of the relatively narrow strip transects was that turtles were constantly knocking down the temporary tubes used as boundary markers. For ST's, we suggest long pieces of garden hose connected to wood or metal stakes about 2 m tall. The stakes would be buried deeply in the sand, whereas the hose would be well above the turtles, creating a minimum of interference.

To keep track of the location of the individual line intercepts, as at Nancite, we suggest the use of white painted guide posts. These posts can be placed at the end of the intercepts, well within the vegetation area. A compass can be used at the beginning of every intersect on the high tide line to establish a heading perpendicular to the length of the beach; then the observer can follow this heading toward the vegetation. The posts cannot violate the assumptions of the method employed because turtles will nest at random with respect to the location of the posts.

The most general form of the variance of estimates, Equation (4.1), shows clearly that decreasing the following factors will decrease the variance of estimated population size: A , the area of the arribada beach, H, the total length of the arribada in hours, and the variance of n (all of which are beyond control of the researcher). Decreasing the controllable factors, the variance of $\bar{h}$ and $\bar{w}$, will also decrease the variance of estimated population. Increasing the total length of the transect, L, the number of sampling times, t, and the number of samples for determining $\bar{h}$ and $\bar{w}$ will decrease the variance of estimated population size. An increase in two critical and (conceptually) easily adjusted factors, the total length of the transect and the number of sampling periods during the arribada, provide a way to decrease the variance of an estimate. Doubling of either alone will quarter the variance and halve the standard error [this is most easily observed in Equation (4.1)].

The only assumptions required by the various modifications of the IC method when sampling arribadas in time are (a) the turtles are sampled in time and space at random with respect to the ebb and flow of the arribada, (b) the average UELA time, $\bar{h}$, is estimated unbiasedly, and (c) $\bar{w}$ is measured unbiasedly also, but only for the modified IC equivalent to the LI in time and the extended LI in time methods. That is, if it were known that the arribada was to peak near midnight, it would be entirely incorrect to sample only at midnight. Sampling at regular intervals throughout the arribada, including midnight, would be satisfactory.

In summary, we present here for marine turtle biologists four variations of the modified IC method, which we term the LI in time, the ST in time, the extended ST in time, and the quadrat in time methods for use in the arribada phenomenon. Methods of procedure and practical, easy-to-use formulas are provided for estimating female turtle population size and associated standard errors.

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