Dealing with uncertainty in counts of mountain ungulates

Estimating the numbers of any large mammal is difficult, but particular problems arise in the case of those whose habitat is typically steep and rugged mountains. Accepted sampling procedures such as strip or line transects, or quadrat counts are generally impossible to perform (Seber 1982, Burnham et al. 1980, Caughley 1977). In North America such species as bighorn sheep (*Ovis canadensis*), Dall sheep (*O. dalli*) and mountain goat (*Oreamnos americana*) are often counted from light airplanes or even helicopters, allowing use of some accepted sampling methods, but aircraft are generally unavailable to biologists working in Asia.

In mountainous regions of Asia, Caprid species such as blue sheep (*Pseudois nayaur*), argali (*Ovis ammon*), Himalayan tahr (*Hemitragus jemlahicus*) and ibex (*Capra ibex*) are difficult to census, not only because they inhabit terrain that is inhospitable to ground-based investigators, but because they usually gather together in loose groups that occasionally shift, move, unite, etc. These groups of animals have meaning and are not simply chance assemblages, but they are not fixed, unbreakable units. Successive observations of a band in the same basic area will yield different numbers of animals. This may be a small problem if individuals can be identified on the basis of sex and age class, or physical characteristics. However, there is often residual uncertainty about which animals have, and which have not, been counted toward the total in each band. Most field investigators have had the experience of assuming a band size was certain after numerous observations of a similarly sized group, only to find that the group had suddenly increased on the last day of survey.

Obviously, the more time one spends in a particular area, the more certain one can be of the final estimate of herd size. But constraints of logistics, budget, personnel, etc. often allow only limited field time for surveys of mountain ungulates. Thus, the investigator usually leaves the field uncertain not only about the number of animals in unsampled areas, but even about the number actually observed. This short note suggests an alternative approach to the problem of duplicate vs. unique counts of groups. I do not claim this new approach surmounts the problem of uncertainty, or can produce an unbiased estimate of total numbers when data is insufficient, merely that it depicts data in a straight-forward manner. Furthermore, the approach cannot substitute for standardized survey routes and procedures, and clearly documented observations (including area effectively observed, time and weather conditions) in obtaining reliable results.

THE PROBLEM

Consider a short survey in which a period of 3 days is allowed for intensive observations of a particular mountain, suspected of harboring a band of a Caprid species. A group of 10 ewes with 9 lambs is seen on day 1, as well as a group of 5 adult males. On day 2 the weather turns, snow and rain fall all day, clouds obscure the best habitat, and no animals are seen. On day 3 a group of 5 ewes with 5 lambs is seen 2 km away from the observations of day 1, but the larger nursery group is not seen. If the survey team could stay longer, the question of whether the 5 ewes with lambs seen on day 3 were included within the previously seen nursery band of 19 might be resolved, but with limited field time and multiple herds (or species) to observe, this may be impossible. In either case, the males are known to be a unique group.

Investigators have followed one of two approaches to this sort of problem. In the first, which I would term the "command decision" approach, the biologist simply **decides** whether or not the correct number is 24 or 34 based on reasonable - if undocumented - evidence, and reports that number. The reader of the final report never sees the process by which the raw data, consisting of numerous observations of separate groups, is transformed into a single figure of band size. In the second approach, which I would term the "min-max" approach, the biologist admits the uncertainty and reports only that the number is as few as 24 or as many as 34.

The "command decision" approach masks real uncertainty because definitive data on whether or not the 10 were included within the 19 is lacking. As such, it is less than fully honest and scientific. The "min-max" approach is honest and scientific, but applied strictly may lead to conclusions that are not too useful. Observing numerous groups with many such uncertainties may result in a maximum estimate many times the minimum estimate. Equally importantly, the "min-max" approach does not use information efficiently. Usually, the investigator really **does** have a good reason for thinking that a smaller group probably was or was not counted among a larger group. In addition, neither of the 2 approaches provide an error term analogous to those commonly used in research, such as standard error or confidence interval.

The "Uniqueness Probability" (UP) Approach

I propose a third approach as follows: each small group observed is assigned a probability of being unique, that is of not having been counted among the largest known group. These "uniqueness probabilities" (UP) ranging from zero to one, arise from qualitative but not necessarily subjective evidence, which is then documented in a table to be appended to the final report. This evidence would include factors such as the distance and time-period between the small group observation and other observations, whether or not barriers to movement exist between the various sightings and the level of group fidelity suggested by the entire set of sightings in the area for the type of animal during that season. The best estimate of the total number in the band is simply the sum of the product of all groups after being multiplied by their corresponding UPs. A frequency distribution of possible band size is also generated, thus one can chose to also report a confidence interval for number observed. The confidence interval is determined directly by observing the probability associated with each possible combination of all the groups. An additional example is shown in Table 1 and Figure 1. Note that number observed should not be equated with number present; animals may still be present that were never seen during the survey.

If it can be safely assumed that each band (consisting of 1 or more observed groups) in the entire study area is relatively stationary, then probability distributions of each band are independent and the total number seen in the study area is the product of each band's probability distributions. However, if the species lives in bands which may wander enough to be confused with other bands, or in which bands are temporary, the analysis should be expanded to allow for inter-band uncertainty. That is, the possibility that an entire band was double-counted must be included. In this case, the number to be counted toward the overall total for the duplicate observation of that particular band ought to be zero. In either case, the number of combinations of total herd size may be large, and a computer may be needed to do all the required calculations. A program for use on IBM-compatible computers, written in standard FORTRAN, is available from the author. Figure 2 provides an example of the estimate for an entire study area, produced by multiplying together probability distributions of each separate band.

It can be seen that the "command decision" and "min-max" approaches are both included as logical extensions of this proposed "UP" approach. If all observations are assigned UPs of either 0 or 1, no probability distribution is formed, resulting simply in the point estimate previously decided upon. Conversely, if no auxiliary information is used and all groups are assigned UPs of 0.5, (i.e., tossing a coin), the result is a uniform distribution, logically equivalent to the "min-max" approach.

DISCUSSION

Investigators will differ in assigning probabilities of uniqueness, even given the same evidence. Therefore it might be useful for each project to produce a series of guidelines that best fit the species and investigator's own inclinations. Investigators may establish guidelines for developing UPs solely from quantitative data (e.g., distance of groups from each other), but I suspect that some important criteria will resist quantification (e.g., difficulty of moving between locations, behavioral clues). Consistency in converting qualitative information to quantitative UPs will be valuable. However, if evidence gathered later suggests that the originally assigned UPs were ill-

TABLE 1. Example of using uniqueness probabilities (UPs) to generate a frequency distribution and point estimate of total band size. A. Groups GRP1 and GRP2 were seen simultaneously, so must be included in all calculations. Any other observations might be of animals already counted among the minimum 18. GRP5 is given a lower UP because it was observed only 1.3 km from GRP1, two days apart. GRP3 is given the highest UP because it was observed 3.8 km from GRP1; GRP2 was 2.8 km from GRP1. The point estimate of the band is calculated as follows: (13*1.0)+(5*1.0)+(2*0.95)+(2*0.05)+(8*0.2)=21.6. B. Calculate all the possible combinations for the entire band, and their individual relative probabilities. C. Add combinations resulting in the same total band size.

<u>Observed Group</u>	<u>Size</u>	Uniqueness Probability <u>(UP)</u>	<u>(UP/(1/UP))</u>

	GRP 1	13	1.00	1.000
A.	GRP 2	5	1.00	1.000
	GRP 3	2	0.95	19.000
	GRP 4	2	0.05	0.053
	GRP 5	8	0.20	0.025

	Combination	size	Band probability	Relative Probability	
	GRP1,2 18			1.000	0.038
	GRP1,2,3	20	19.000		0.722
B.	GRP1,2,4	20	0.053		0.002
	GRP1,2,5	26	0.250		0.009
	GRP1,2,3,4	22	1.000		0.038
	GRP1,2,3,5	28	4.750		0.181
	GRP1,2,4,5	28	0.013		0.001
	GRP1,2,3,4,5	30	0.250		0.010
	(SUM)		(26.316)		

	Band Size	Combination	Probability	
	18	GRP1,2	0.038	
	20	GRP1,2,3; 1,2,4	0.724	
C.	22	GRP1,2,3,4		0.038
	24	(none)	0.000	
	26	GRP1,2,5		0.009
	28	GRP1,2,3,5;1,2,4,5		0.181
	30	GRP1,2,3,4,5		0.064

FIGURE 1. Example showing the frequency distribution of numbers generated by the calculations in Table 1. Illustrated are numbers of argali from a small band in Qinghai Province, China, 1991.

advised, it is but a mechanistic process to re-compute the frequency distribution and point estimate of total number observed.

The qualitative nature of information available to investigators in such surveys is a weakness. Clearly, all efforts should be made to document as many aspects as possible with quantitative data. However, we should not harbor illusions that field work can be transformed into a controlled laboratory, or that an investigator sufficiently experienced or capable can triumph over uncertainty when presented with only a few small pieces of a large and complicated puzzle.

The UP approach presents uncertainty honestly, while allowing the investigator to bring to bear all other relevant data, background information, and intuition at his/her disposal. It also forces the investigator to think clearly about considerations as to whether certain animals have been counted more than once, by being explicit with assumptions that are otherwise hidden. It frees the investigator from the difficult task of estimating the total number seen from simultaneous consideration of the entire set of observations, requiring instead only that smaller sets of observations be compared in which duplicate counts are possible. Once UPs for subsets are developed, an estimate for the total number seen is determined mechanically.

FIGURE 2. Example showing the resultant distribution (and cumulative distribution) of numbers of animals seen when numerous independent bands are considered to constitute a single herd. This illustrative example is of blue sheep from an area in Qinghai Province, China in 1991, and shows lower and upper 90% confidence limits, as well as the median.

The UP approach does not deal with the problem of animals that, for whatever reason, are never seen. Ground surveys invariably miss animals and correction factors may be necessary (e.g., Fox et al. 1991). Therefore, I reiterate that no claim is made that this new approach determines the true number of animals. Rather, it transparently displays the true degree of uncertainty, and efficiently uses all the information available to the investigator.

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