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ROBUSTNESS OF MULTISTAGE SAMPLING DESIGNS FOR ESTIMATION OF PROTECTION LEVELS AGAINST LIVESTOCK DISEASE

Harrison S.[1], Cameron A.[2]

Pour étudier la séroprévalence de la fièvre aphteuse en Thailande, un échantillonnage en deux étapes et en probabilité proportionnelle à la taille a été utilisé pour choisir les villages et le bétail. Cet article discute l'application d'un échantillonnage simulé pour estimer les proportions de bovins et de buffles ayant une protection contre la fièvre aphteuse.
La taille des échantillons nécessaires pour fournir des estimations avec un niveau d'erreur non supérieur à 10 p. cent, au moindre coût, ne varie pas beaucoup avec les coûts des échantillons, ou avec le niveau de protection de la population et le niveau de variance des villages.
Le schéma standard de l'OMS de 30 unités d'échantillonnage primaires et de 7 unités secondaires fournit une estimation de la proportion de bétail protégé proche de la cible de 10 p. cent.

INTRODUCTION

Progress towards disease eradication requires a high proportion of protected animals. "Active surveillance" in which blood samples tested for seroprevalence can provide improved monitoring of protection levels. A cost-effective design is two-stage sampling, in which villages are selected with probabilities proportional to size (PPS), with fixed-sized samples of animals drawn from selected villages. This design has been employed for determining protection of cattle and buffalo against foot-and-mouth disease (FMD) in north-west Thailand[3].
Robustness of a sampling design could be examined with respect to: definition of optimal design (e.g. statistical precision, cost-effectiveness, maximizing expected net gain or net present value from sampling); purpose of sampling (single snapshot versus monitoring change); balance between first and second stage sampling costs; discontinuities in cost functions; average livestock populations of villages; between and within village variations in proportion protected; form of distribution for between-village variation; and whether sampling is conducted with and without replacement. This paper uses a simulation approach to determine optimal sampling designs and evaluate their robustness, in the light of experience in Thailand.

SAMPLING DESIGN, EFFICIENCY AND PRECISION

Consider a livestock population divided into M primary sampling units (PSU, villages), each with N_i members (cattle and buffalo), for a total population of N members ($N = \Sigma N_i$). m villages are selected *with replacement* with probability proportional to size, i.e. the probability of selecting each is $p_i = N_{ii}/N$. A constant number (n) of secondary or elementary sampling units (SSU) is drawn selected *without replacement* from each village. The objective is to estimate π, the *proportion* in the population having high blood titre against FMD. The unbiased estimator of the population proportion π is now

$$\hat{\pi} = \sum_{m}\sum_{n} x_{ij}/mn = \sum_{m} \bar{p}_i$$

where x_{ij} =1 for a blood titre indicating protection against FMD and x_{ij} =0 otherwise, for animal j in village i. The variance of the sampling distribution of proportions is estimated as:

$$\hat{V}(P_{pps}) = \sum_{m} (p_i - \hat{\pi})^2/(m(m-1)) \quad \text{(Yamane, p. 288).}$$

and depends on the variation between clusters but not within clusters.
A standard design employed for a variety of World Health Organisation (WHO) surveys of immunisation coverage involves selection of 30 villages and 7 people from within each village (Henderson and Sundaresan, 1982; Lemeshow and Robinson, 1985; Fredrichs, 1989). The logic underlying this design is that a target precision in estimation of a population proportion of plus or minus 10% is sought, i.e. $z_{0.025}\, s_P \leq 0.1$ where z is the standard normal variate and s_P is the standard error. Under simple random sampling, and assuming the worst case in terms of sample size (where $\pi = 0.5$ and hence $s_P = .5/\sqrt{n}$,), the half-width of the 95% confidence interval would be given by $1/\sqrt{n} \leq 0.1$, or $n \geq 100$. Using a *design factor* of 2.0 (i.e. assuming that two-stage sampling is half the efficient as simple random sampling), a sample size of at least about 200 is indicated. The standard design of $m\,n = (30)(7) = 210$ meets this requirement, and hence provides a "ballpark" figure for sample size. Lemeshow and Robinson (1985) observe that the "30 clusters is based more on tradition and intuition than

1 The University of Queensland, Qld. 4072, Australia.
2 Lao-Australian Animal Health Project, PO Box 7042, Vientiane, Lao PDR.
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on statistical theory" and caution against its mechanical application without regard to any specific population. Larger samples are needed to obtain reliable estimates with respect to rare diseases (where $\pi << 0.5$).

OPTIMAL SAMPLE DESIGN AND SIZE

Various approaches can be used to determining optimal sampling designs. A design can be chosen which meets an accuracy target at least cost, or the smallest sampling error for a given sampling budget can be sought. Alternatively, an acceptance sampling approach could be adopted which compares risks of incorrect statistical judgements about overall protection level. Another possibility is to consider explicitly the costs and benefits of alternative sampling designs in terms of the Bayesian expected net gain from sampling or net present value of sampling (Harrison, 1997).

A widely used cost function for two-stage sampling is the following formula (Yamane, 1967, p. 264; Snedecor and Cochran, 1989, p. 449; Levy and Lemeshow, 1991, p. 262):

$C = c_0 + c_1 m + c_2 m n$

where c_0 are overhead costs; c_1 are costs per PSU, and c_2 are costs per SSU. The cost per PSU is assumed constant over all PSU, and the cost per SSU is assumed constant for all SSU within each PSU.

In setting up an active surveillance program, costs would be incurred for: laboratory facilities to test blood specimens; training of technicians in laboratory testing; purchase or hiring of vehicles; acquiring equipment such as chillers, specimen bottles, syringes, ropes and protective clothing; obtaining sampling frames and drawing samples; and reporting of survey results. For each village included in the sample, costs are included for vehicle expenses in travelling to and from villages; wages for staff collecting specimens; accommodation and meals for field team; and payments or gratuities to villagers assisting with the survey. For each animal from which a blood specimen is drawn, there would be costs comprising mostly staff wages and laboratory testing costs (materials and technician time).

Alternative sampling designs have been compared through synthetic sampling from populations with specified parameters, using random number generation procedures on a computer. For any nominated sampling design (equivalent to a treatment in a simulation experiment), a large number of synthetic samples (replicates) can be generated, and the sampling efficiency determined in terms of the estimated variance of the overall sample proportion of protected animals. A computer program in Q-BASIC has been developed to carry out simulated sampling. The base parameter levels, derived from experience in Thailand, are as follows. The protection level in the population is 50%, between-village variance of proportion protected is 0.6, villages have an average of 200 cattle plus buffaloes, and sampling costs are c_0 =100,000 baht, c_1=1800 baht and c_2=70 baht.

The program consists of nested loops in which treatments are specified by varying the number of villages from 10 to 40 in steps of 10 and the number of livestock per selected village from 5 and 30 in steps of 5. The proportion of protected animals by village is assumed to follow a normal distribution. Each treatment is replicated 250 times. When drawing samples for each village, sampling without replacement is achieved by reducing total numbers of protected and unprotected animals according to whether each sample observation is a protected animal ($x_{ij} = 1$) or an unprotected animal ($x_{ij} = 0$). Simulation output is provided as Table I.

Suppose the accuracy requirement for active surveillance is that the error in estimation of the proportion of protected animals in the population be not more than 10%. Case 1 of Table I indicates the sampling errors (1.96 standard errors) for various $\{m,n\}$ pairs. Provided the number of villages is sufficiently large (20 to 30 or more), increasing the number of animals per selected village has little impact on sampling error. Accuracy of estimation improves strongly as the number of villages included in the sample is increased from 10 to 20, but increasing the number of villages beyond 20 to 30 yields only small increases in sampling accuracy. Within the range of sampling designs of interest, the overall survey cost depends primarily on the number of villages included in the sample. The classic {30,7} design would go close to achieving this accuracy target. The simulation model may be used to carry out sensitivity analysis with respect to a number of parameters. Some examples follow.

Increased variance of proportion between villages. High variability between villages with respect to proportion of animals protected would increased the likelihood of obtaining extreme villages in the sample. As indicated under Case 2, for which the between-village variance has been doubled, a larger sample of about 40 villages and 10 animals per village would be required to achieve a 10% accuracy target.

Higher population protection level. If the proportion of protected animals is near zero or one, a smaller sample may be adequate. As indicated under Case 3, at a protection level of 80%, samples of only 20 villages by 15 animals, or 30 villages by 15 beasts, would meet the 10% error target.

Changed relativity in samping costs. For the "Revised" costs column of Table I, c_2 has been halved and c_3 doubled. Designs of {30,15} and {40,10} remain the least-cost ways of obtaining the 10% error requirement for Cases 1 and 2 respectively. In Case 3, {30,5} is now less costly than {20,15}, i.e. relatively lower village sampling costs favour more villages and fewer animals in each.

Non-constant sampling costs per village. If the number of villages is increased, the cost of travel between them could be reduced. If the number of livestock sampled per village is increased, it may not be possible to sample two villages per day. Non-linearities or discountinuities in cost functions - not encountered in the Thai sampling - may lead to clearcut or "natural" optimal designs.

Snapshot versus comparative estimates of protection level. Sometimes the interest will be in monitoring the progress of vaccination in terms of changes in the protection level over time, i.e. the difference between proportions rather than the level of a single proportion. This will require a larger sample for a given precision level, particularly if different villages are used in each sample (Harrison, 1997).

Table I
Sampling errors for various two-stage PPS designs

Sampling design		Cost (1000baht)		Error (1.96 SE)		
m	*n*	Normal	Revised	Case 1	Case 2	Case 3
10	5	122	116	0.1941	0.2189	0.1588
10	10	125	123	0.1774	0.2084	0.1539
10	15	129	130	0.1627	0.2031	0.1453
10	20	132	137	0.1533	0.1908	0.1355
10	25	136	144	0.1465	0.1770	0.1307
20	5	143	132	0.1332	0.1552	0.1207
20	10	150	146	0.1203	0.1417	0.1013
20	15	157	160	0.1115	0.1373	0.0997
20	20	164	174	0.1144	0.1378	0.0968
20	25	171	188	0.1017	0.1276	0.0887
30	5	165	148	0.1085	0.1218	0.0940
30	10	175	169	0.1012	0.1183	0.0851
30	15	186	190	0.0936	0.1123	0.0802
30	20	196	211	0.0968	0.1195	0.0813
30	25	207	232	0.0885	0.1089	0.0769
40	5	186	164	0.1002	0.1132	0.0797
40	10	200	192	0.0805	0.0941	0.0707
40	15	214	220	0.0770	0.0937	0.0662
40	20	228	248	0.0806	0.0990	0.0689
40	25	242	276	0.0785	0.0984	0.0642

In summary, the least-cost sampling design for a target precision level appears quite robust to variations in cost and other assumptions. The classical {30,7} design appears to provide close to the target 10% error under a variety of circumstances.

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