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Adaptive Sampling Strategy for Assessment of Avian Diversity

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Abstract

Measurement of biodiversity is an important issue in ecological studies and planning wildlife conservation. The conventional method of measurement involves sampling in various forms such as line transects or quadrats. Many field studies appear to be rather ad hoc in their design, especially with respect to amount of effort put in. A crucial question in this context is how much sampling effort should be considered enough. Earlier studies (Gore and Paranjpe 1997) indicate that for estimation of diversity indices, a sample of 1000 individuals should suffice. On the other hand, effort needed to estimate species richness is one order of magnitude higher. In this paper we focus attention on estimation of avian species richness. The main issue is distribution of efforts over time and space. 'Time' involves two aspects, time of the day and season in the year. 'Space' involves various habitat types available in a study site. Different sampling strategies are compared using simulation. Finally, these are applied to species abundance data collected at some sites in The Western Ghats. An adaptive cyclical sampling strategy appears to be useful.

Keywords and Phrases: Biodiversity, Species richness, Survey strategy, Adaptive sampling, Simulation.

AMS Classification: Primary 62P12; Secondary 65C05.

1 Introduction

Biodiversity, the great variety of life forms in the plant and animal kingdom, is regarded as one of the most extra ordinary features of nature. It is also a challenge to our ability and ingenuity in quantification/measurement. Biodiversity measurement can be helpful in many ways. It facilitates comparison between localities. We can also use it to estimate changes at the same locality over time. Monitoring temporal changes in biodiversity is one of the commitments of the 1992 Rio summit. This raises the whole issue of developing a strategy to be adopted for data collection and analysis to arrive at estimates of diversity. For a general discussion of statistical issues in measurement of diversity see Gore and Paranjpe (2001). Two quantitative aspects of diversity are widely regarded as central to its measurement. They are: species richness (number of species of a taxon in a given geographical area) and species evenness (differences in relative abundance). The two can be combined in various ways to form diversity indices (see e.g. Patil and Taillie (1982)) In this paper we shall address the question of measuring species richness only. If considerable data on abundances of species is already accumulated, it is possible to fit a suitable model to species abundance distribution such as negative binomial (Fisher et al 1943) or lognormal (Preston 1962) etc. and then estimate the number of unseen species. However our focus is not on analysis but planning diversity studies with the aim of observing economically, most of the species in a taxon of interest in a given area. Gore and Paranjpe (1997) carried out a simulation study of this problem. Their finding was that observing about 1000 individuals randomly in a natural community (say of trees or birds or mussels) is adequate to estimate a diversity index such as Simpson index or Shannon-Wiener index. On the other hand, estimating species richness turned out to be a tougher problem. Here the effort required was of the order of 10,000 observations (for a bird community with 504 species). For comparison consider the area in Peninsular India namely Western Ghats. This biodiversity hotspot (area 200,000 sq.km) is home to some 480 bird species. So the above study suggests observing about 10,000 birds to estimate species richness of the Western Ghats. But it leaves open the issue of distributing the total effort over time and space. Our immediate interest is planning a field study on a much smaller scale. The motivation for this is as follows: a recent biodiversity act passed by the Parliament of India requires local government bodies, such as Municipalities, to prepare species inventories for the area under their control. The area may be of the order of couple of 100 sq.km. Number of species may be somewhere around 100. Hence we plan to work on a scenario that the target number of species is substantially smaller than the species richness in Western Ghats as a whole.

2 Simulation Approach

We shall try to answer the above questions through simulation studies. One reason for adopting such an approach is that analytical methods attempted seem to become mathematically intractable and require unmanageable computations. (see Christen and Nakamura(2003))

The general method to be adopted is as follows.

a. Consider an area with known species richness. Take data from an extensive field study in this area, done by experts. Use this data set as a reference or the universe. Since we address avian diversity, a typical sampling unit is a transect. Therefore the data set will be a list of transects, time of observation and species abundances recorded on each transect.

b. Adopt a particular sampling strategy to select a subset of transects available. Birds recorded on these transects (in the reference set) are treated as 'observed' in the simulation exercise. These observations are then used to obtain species richness estimates. The simplest is the total number of species recorded in the selected transects.

c. Repetition of such exercise enables calculation of bias and standard error of estimates.

The number of species seen in a sample is in fact a lower bound on the number of species present. Hence such an estimate will always have a negative bias in it. Reducing this bias becomes progressively more difficult as species accumulation continues. Law of diminishing marginal returns becomes operative. Reason for this is intuitively obvious. Initially it is easy to spot unseen species. Soon all easily observable species get recorded. The remaining species pose extra difficulty because they are rare or cryptic or nocturnal or very similar to some common species etc. Hence enormous effort is needed to locate these. It is therefore prudent to stay away from the ambition of seeing every species present. Aiming at a fairly large fraction of the total may be more practical. We will work on a target value of 80%.

3 Reference Data Set

One of the authors (P Pramod) recorded species along with their abundance over a period of two years in three habitats of Silent Valley National Park, Kerala. They are Evergreen (EV), Semi evergreen (SE) and Teak Plantation (P). Every month he visited every habitat twice. In every visit one transect was covered over a period of two hours. This could be either in the morning or in the evening Thus the total number of transects sampled is (2years X 12 months X 3 habitats X 2 visits) = 144. Total numbers of birds seen is 4898 and in all 180 distinct species were seen. Earlier checklists show that there are 185 species in that area. This constitutes the baseline data for simulation. In the simulation study we shall propose different strategies and compare their performance on the basis of estimate of species richness. We try to answer the question *"Can we arrive at a good estimate of species richness (denoted by S*) with less effort than that put in the reference data?"*

4 Reference Data Set

We begin with the basic sampling design. All 144 transects in the reference set are given equal chance of being selected. We will sample 'with replacement'. This means the transect selected is 'returned' to the reference set and can get selected again. In effect it makes the reference set infinite in size. There is only one parameter to be decided. It is 'n', the number of transects in our sample (in other words, sampling effort). We have a matrix of 180 rows corresponding to species seen and 144 columns corresponding to transects traversed. Entries in the matrix are number of individuals of the species recorded on the transect. Our algorithm is as follows: Suppose n=24. This means our aim is to see what happens if we select 24 transects from available 144. (Repeats are allowed). Select a random number (from integers 1 to 144). It identifies a transect. Note the species on it and their abundances. Record running total of number of distinct species seen and total number of individuals seen for each species. Draw the next random number. Repeat this 24 times. We have completed one run of the simulation with n=24. Take 1000 such runs. The exercise can be done for various values of n, the effort level. Results are summarized in the table 1 below.

Table 1: Species Richness Estimates Based On Simple Random Sampling (With Replacement)

# Transects	24	48	72	96	120	144
Mean	110	137	151	159	165	169
Minimum	84	119	132	138	148	154
Maximum	127	154	166	171	177	179
stdev	6.33	5.81	5.16	4.78	4.38	4.00
MSE	4936.04	1866.67	883.156	460.282	254.51	146.17

We note the following features of the table:

a. Minimum number of species seen increases from 84 (46.67% of 180) with 24 transects to 154 (85.55% of 180) with 144 transects;

b. The maximum number of species seen increases from 127 (70%) at 24, to 179 (99.5%) at 144 transect.

c. SD decreases from 6.3 at 24 transects to 4.0 at 144. d. Table confirms that there is underestimation of species richness. Extent of bias decreases considerably as effort increases.

e. Our target of 80% is reached easily with 72 transects. This is only half of actual effort put in.

Next point concerns variability in the estimate of species richness. Following graph shows empirical species accumulation curve. In this graph, the centerline represents average species richness at different levels of effort over 1000 simulations. Other two curves are empirical upper and lower confidence limits. The graph shows that width of confidence limits for the estimate remains more or less constant beyond 72 transects. Hence extra effort does not seem to improve precision.

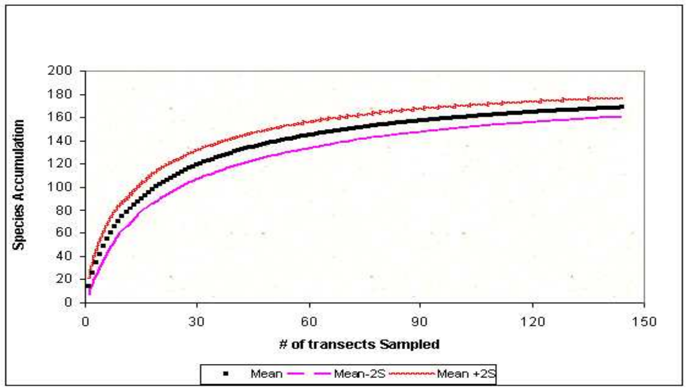


Figure 1: Species Accumulation Curve

It seems fair to say that with simple random sampling and effort level of 72 transects, we are able to get an estimate with about 16% ((180-151)/180) downward bias. The question that remains is whether it is possible to reduce this bias further without increasing effort level. Two possibilities suggest themselves.

1. Continue to use simple random sampling. But adopt a different estimation method.

2. Continue to use the empirical richness as estimate but modify the sampling strategy.

Let us recall here that our method of estimation used thus far is a nave one. We have taken observed species richness as the estimate of unknown 'true' species richness. As noted earlier this estimate is easy to understand but is negatively biased. It is possible to use mathematical modeling to estimate species richness from data on species accumulation. Typically any function that increases with effort level but at a decreasing rate can describe species accumulation quite well. The asymptote (saturation level) of the fitted curve provides a natural estimate. The resultant estimate of species richness at effort level 72 transects is 162, which reduces the bias from 16% to 10%. Unfortunately standard error of estimate increases from 5 to 19. Thus neither estimate is better than the other. If we use bias and standard deviation as two separate indicators of quality of estimator, we sometimes get conflicting results as seen above. In such a case a combined criterion, viz. Mean Square Error (MSE) is used for comparison. It is given by MSE = Bias2 + variance. MSE of the nave estimate is found to be 883 whereas that of model based estimate is 690. In this sense, we may say that the latter shows a slightly better performance. All this discussion is based on an effort level of 72 transects. One point needs to be noted regarding this estimate. The reference data set from Silent Valley represent work by an expert. When one has to plan a study at many localities it is not reasonable to assume availability of experts every where. Hence efficiency is likely to be lower and some escalation is needed. In the absence of any objective criterion we shall work provisionally with a figure of 100 transects. Now let us consider the second option listed above, which is, changing the sampling strategy.

5 Stratified Sampling

In simple random sampling we implicitly assumed that chance of observing a bird is constant regardless of location, time or season. This may not be true. Migratory birds can be seen only in migratory season. Some species are more likely to be seen in an evergreen forest than a teak plantation. Hence distributing the effort accordingly is likely to improve the estimate of richness. We shall take into account three factors, viz. time of the day, season of the year and habitat within the study area.

5.1 Time of the day

Conventionally bird transects are traversed either in the morning or in the evening. Following table gives results of comparison among different proportions, in which effort was divided between morning and evening :

Table 2: Effect of intra-day division of effort on species count

Morning : Evening	Mean richness	S.D.
100:0	133	3.8
67:33	152	4.9
50:50	151	5.2
33:67	147	5.1
0:100	148	4.4

Barring the first row, all other estimates are fairly close to each other. Common practice among ornithologists is to distribute equal efforts between morning and evening, In view of the above results it seems reasonable to stick to the convention.

5.2 Season of the year

Here it is common to concentrate efforts in migratory season obviously because migratory species are not observable in the other season. If all effort (72 transects) is put in migratory season, we get to see on an average 143 species (S.D.=4.4). We further tried adding a small unit of effort (24 transects) in non-migratory season. This improved the estimate to 158 (S.D. = 4.4). Thus an improvement of 10% was possible. Hence our recommendation is that most effort indeed should be put in the migratory season.

5.3 Habitat

The issue is how to divide total effort among available habitats. Since the aim is species accumulation, it seems intuitively obvious that allotment of effort should be related to the number of species that use a particular habitat. We happen to have an overall picture of Western Ghats as a whole.

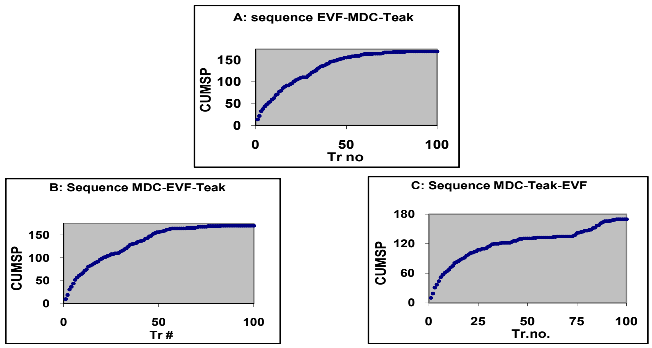
Following table gives number of species in each of 9 major habitats of Western Ghats. This table is based on all India bird data (1177) species.

Table 3: Species Richness by habitat type

Habitat	Spcount
EVF (Evergreen Forest)	145
MDC (Semi Evergreen)	183
Bamboo	90
High Altitude	118
Arid	212
Manmade	215
Riverine	188
SEA	14
BCH (Beaches)	66
Total	477

Of the 1177 species found in India, 477 occur in Western Ghats. Out of 477 species, 145 occur in Evergreen forests. These species may also occur in other habitats. The classes are not mutually exclusive. This table is based on information regarding major habitats in which a species is found as given in Salim Ali and Ripley. (1968-74). In the study area of reference data set, namely Silent Valley, three habitats were examined. They are evergreen (EVF), semi evergreen (MDC) and teak plantation (Man made). In the above table numbers of species in these three habitats are in the proportion 27:34:39 (145:183:215). So effort can also be divided in the same proportion.

Now the question is what sequence of habitats to follow in this study. In fact it is not clear whether a choice of sequence makes a difference. We first compare performance of different sequences of habitats. This comparison is based on species accumulation. A sequence is preferred if the corresponding species accumulation curve rises faster and becomes flat quickly. In this case no new species are seen in the last few transects in the habitat observed last. By this criterion, the sequence EVF-MDC-Manmade seems the best (see Fig. 2 below). Here in fact new species are hardly seen after 82 transects. For the sequence MDC-EVF-Manmade the accumulation curve flattens at 92 transects while in the sequence MDC-Manmade-EVF species continue to be added till the very end. EVF is a species rich habitat. Some species may be essentially restricted to EVF. On the other hand man made habitat (in this case teak plantation) may have many opportunistic species from other habitats. It appears that sequence in which habitats are studied does make a difference.



Number of transects needed to reach saturation level (visual estimate)
Graph A: 82 transects, Graph B: 92 transects, Graph C: 100 transects.

Figure 2: Species Accumulation by Habitat Sequence

One problem is how to decide the right sequence for an unexplored locality. In fact a sampling strategy has to be adaptive and the sequence as well as stopping times should emerge as the study progresses.

6 Cycle Sampling

In view of the above considerations we propose the following sampling strategy. List the habitats to be studied. Traverse one transect in each habitat.. This completes one cycle of field work. Now take up corresponding analysis. This consists of generating species accumulation curves for different sequences of habitats. Our interest is to see if any particular habitat is redundant. To check redundancy of a habitat say teak plantation, we need an accumulation curve with teak plantation as the last habitat in the sequence. A habitat will be regarded as redundant if it fails to add any species in this accumulation curve.(as observed in graph A above). Now take next cycle of one transect per habitat replacing a redundant habitat by any other habitat left out earlier. Cycle sampling continues till the total number of transects traversed reaches the predetermined limit or accumulation curve reaches a plateau or all habitats are dropped as redundant, whichever happens earlier.

In this proposal there are several features that are ad hoc. Why traverse only one transect in a habitat at a time? A larger dose of effort may be more convenient as it saves the time and energy spent in going from one habitat to next. As an illustration we use 4 transects in a habitat at a time from the reference data set. Results are given in the table below.

The table 4 given below shows progress in accumulation. At the end of first cycle (12 transects), teak plantation yielded 6 new species (1.5/transect). Hence there was no redundancy and the entire sequence was repeated. At the end of second cycle (24 transects), it turned out that teak plantation yielded 3 new species in 4 transects. This was below the threshold of 1 new species / transect. Hence unrewarding habitat, namely, teak plantation was dropped. Now each cycle consisted of 8 transects only. At the end of cycle 6, yield from habitat MDC fell below threshold. Hence it was dropped. In the next cycle EVF also failed to remain above threshold. Thus with 60 transects we terminate the sampling exercise. We have observed 158 (88% of 180) species at this effort level, which is 42% of 144 transects traversed in the reference data set.

Table 4: Cycle sampling in Silent Valley

Cycle number	# Transects visited	Habitat	New species seen	New SP/ Transect	Cumulative # seen
	4	EVF	38	9.5	38
	8	MDC	23	5.75	61
1	12	Teak	6	1.5	67
	16	EVF	12	3	79
	20	MDC	12	3	91
2	24	Teak	3	0.75	94
	28	EVF	12	3	106
	32	MDC	8	2	114
3	36	EVF	15	3.75	129
	40	MDC	8	2	137
	44	EVF	4	1	141
4	48	MDC	5	1.25	146
	52	EVF	7	1.75	153
	56	MDC	3	0.75	156
5	60	EVF	2	0.5	158

Will the above results be applicable to any site or are they specific to Silent Valley? This is a reasonable doubt. Perhaps the only way to answer it is to try cyclic sampling strategy at another locality. Now we take the data set from Keerampara panchyat in Kerala (Shaju Thomas et al., 2003).

We begin with a profile of the reference data set. There were 6 habitats/ localities. Effort (number of transects) allotted to each habitat is given in the table below.

Table 5: Effort Allocation in Keerampara

HABITAT/Locality	# Tr.
MDC	14
SCRUB	11
Plantation	41
Paddy	4
CHARUPARA	1
UNKNOWN	1
Total	72

Clearly the first three habitats are of interest to the investigator. Further the effort invested in last three habitats is small. We will restrict attention to the first three habitats for cycle sampling. Following graph gives species accumulation as number of transects increases. It shows that saturation occurs quite early. Total effort invested by the investigator was 72 transects but accumulation seems to have stopped after 24 transects.

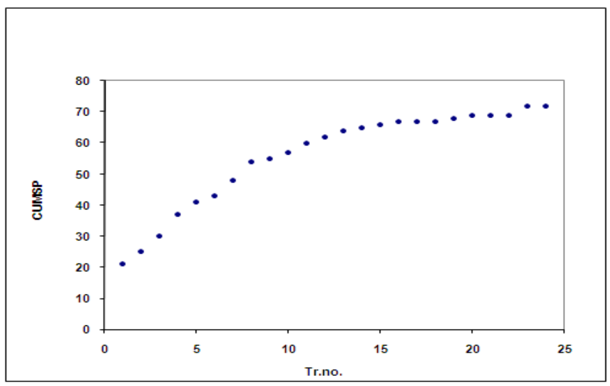


Figure 3: Species Accumulation in Keerampara Sequence: MDC-Plant-Scrub

Now let us look at detailed species accumulation on the basis of cycle sampling. Results are shown in the table below.

Table 6: Cycle sampling in Muvattupuzha (Keeranpara)

Cycle number	# Transects visited	Habitat	New species seen	NewSP /Transect	Cumulative # seen
1	4	Plant	44	11	44
	8	MDC	10	2.5	54
	12	Scrub	8	2	62
2	16	Plant	3	0.75	65
	20	MDC	4	1	69
	24	Scrub	3	0.75	72
3	28	Plant	4	1	76
	32	MDC	6	1.5	82
4	36	Plant	6	1.5	88
	38	MDC	0	0	88
5	42	Plant	3	0.75	91

The above table shows progress in accumulation. At the end of first cycle (12 transects), Scrub yielded 8 new species (2/transect). Hence there was no redundancy and the entire sequence was repeated. At the end of second cycle (24 transects), it turned out that Scrub yielded 3 new species in 4 transects. Hence third cycle did not include scrub. After 8 transects of the third cycle (total 32 transects) accumulation was in all 72 species. Here each habitat yielded at least one new species per transect. So neither habitat could be dropped. In the fourth cycle, however, MDC failed to yield any new species in two remaining transects that were visited. Hence it got eliminated. Cycle 5 consisted of plantation only. In this round plantation also yielded below threshold. Hence the cycle sampling was terminated. Thus in 42 transects (58% of 72) all species but for one were observed. So, the results observed in case of Silent Valley are not unique to that site and are likely to be applicable more generally.

In both the examples above, there were only three habitats in the study and 4 transects were taken from each habitat in each cycle. This need not be so, especially when there are many habitats in a study site. We can take only one transect from each habitat in each cycle. This modification can be incorporated quite easily. We illustrate it with data from Uttar Kannada in Karnataka. It was collected by RJR Daniels.

We begin with a profile of the reference data set. There were 10 habitats. Effort (number of transects) allotted to each habitat is given in the table below.

Table 7: Effort Allocation in Uttar Kannada (R. Daniel's data)

Habitat	# Tr.
EVF (Evergreen forest)	28
UHB (Urban habitation)	4
OCH *(Orchards)	2
PLT *(Plantation)	20
EST (Estuary)	11
MSH,L/R *(Marshes/lakes/rivers)	18
MSC (Moist scrub)	5
WCL,DCL (Wet/Dry cultivation)	3
BCH (Beaches)	7
MDC (Moist Deciduous)	9
Total	107

Some of these habitats were clubbed together for the purpose of this exercise. UHB, OCH and PLT were together called 'Manmade' and EST and MSH were together called 'Mangrove'. We are thus left with 7 habitats. We selected one transect from each habitat in each cycle. Accumulation results are given in table 8 below.

In this simulation exercise, at the end of cycle 1 (7 transects), 130 species were seen. No habitat was redundant. At the end of cycle 2 (14 transects), 177 species were seen. Again no habitat was redundant. Cycle three increased the species number to 196. In this cycle, two habitats became redundant. They are MDC and MSC. Fourth cycle had only 4 habitats. In addition to 2 redundant ones, one more habitat (WCL/DCL) had to be left out because we ran out of transects in that habitat. In this round, accumulated number of species went up to 197. BCH yielded no new species and hence was dropped. At this stage we recorded 73% (197/ 271) of species present in the reference data set. The effort required in only 23% (25/107) of that put in by the expert. This exercise could be continued for some more rounds. But perhaps the main point is already conveyed.

Table 8: Cycle sampling in Uttar Kannada

Cycle number	# Transects visited	Habitat	New species seen	Cumulative # seen
	1	MDC	42	42
	2	EVF	21	63
	3	WCL,DCL	31	94
1	4	EST	18	112
	5	MSC	8	120
	6	UHB	5	125
	7	BCH	5	130
	8	MDC	9	139
	9	EVF	5	144
	10	WCL,DCL	12	156
2	11	EST	11	167
	12	MSC	7	174
	13	UHB	1	175
	14	BCH	2	177
	15	MDC	0	177
	16	EVF	1	178
	17	WCL,DCL	9	187
3	18	EST	2	189
	19	MSC	0	189
	20	UHB	1	190
	21	BCH	4	194
	22	EVF	1	195
4	23	EST	1	196
	24	UHB	1	197
	25	BCH	0	197

7 Discussion

The problem of estimating effort required for assessing diversity in general and avian diversity in particular, seems to have received little attention in literature. Current practice of equal effort in morning and evening seems reasonable. Also it is adequate to concentrate most effort in migratory season with some supplementary work in non-migratory season. One intuitive rule for dividing total effort among various habitats in a given study site is to devote effort proportional to the number of species supposed to be present in such habitat. Situation may vary in terms of spatial configuration and extent of habitats. Unit of effort spent in a habitat in a cycle should be adjusted accordingly. As an instance, if time spent in switching habitats is considerable, it may be better to cover multiple transects in a habitat in a cycle. The strategy outlined here prescribes a sampling methodology for an area of a few square kilometers such as Panchayats and municipalities. So the time spent in moving from one habitat is negligible. The proportions can be estimated using some standard such as Salim Ali and Ripley. We have suggested an adaptive sampling strategy that is dynamic and adjusts decisions at a point of time according to the accumulated information available at that point. This strategy called cycle sampling seems capable of saving effort to a substantial extent.

8 Conclusion

It is interesting to note that cycle sampling strategy described here reduces the effort level considerably (about 50%). This strategy will be very useful where resources are limited. However we need to keep in mind that the results presented here are based on peninsular Indian bird studies. The strategy may vary for a different ecological setting such as north east. Also it is not yet clear how cycle sampling will suit other taxa such as plants, fishes or insects. The cycle sampling strategy outlined here clearly shows that coupling analysis with the field studies can considerably reduce effort and save resources. The work presented here is based on simulation. Theoretical and analytical formulation of the approach remains an open question.

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