Numeracy for Everyone

3. Just for Ecologists

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Most techniques in statistics are used in many disciplines besides ecology and have a wide range of applications from anthropology to zoology. They are used in industry, agriculture, social sciences and business. That is why we have called this series 'Numeracy for Everyone'. In the forthcoming parts, we will discuss applications of statistics in some of these fields. But some techniques are developed specially for ecological problems. Let us briefly look at a selection of those techniques.

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Abundance Estimates or Wildlife Censuses

Let us suppose there are complaints that spotted deer in the wildlife reserve come out, destroy crops and cause damages. One possibility is that there are too many deer and culling is necessary. Then it is essential to estimate the size of the animal population.

Foresters claim that Project Tiger has been successful and tiger numbers have risen steadily. To confirm this, an estimation exercise, often called 'census' is essential.

There are various approaches to 'census'. We will describe some briefly.

Along with the method we also discuss limitations of these methods. Subject to these limitations they give estimates which are better in general than individual guess values.

(a) ***Water Hole Census:*** In summer, the number of waterholes in a protected wildlife area reduces to just a handful. Animals have to visit them to drink water. So observers are positioned to watch each waterhole continuously for 24 hours, all waterholes

Part 1. Why Quantification?, *Resonance*, Vol.4, No.5, 19-30, 1999.
Part 2. Dice of Life, *Resonance*, Vol.4, No.9,14-23, 1999.

being covered simultaneously. Number of individual animals seen at each waterhole is added up. This is how lions at Gir were estimated to be around 240 in number (Hornbill, No. 4, 24-28, 1985). Two things have to be remembered here. Some animals like bison come to drink water twice a day. Secondly some animals could visit multiple waterholes the same day or some (e.g. blackbuck) could postpone drinking water till the observers disappear.

(b) ***Capture-Recapture:*** In this method some individuals are captured, tagged and released. After a suitable interval, capturing is done again. If the population is large, there is a low rate of recapture (i.e. catching an animal that is already tagged). If the population is small, many previously captured animals reappear in the second capturing exercise. Relevant formulae have to be used to estimate population sizes using capture and recapture figures. Suppose 100 marked fish are released in a pond. Next time, 200 fish are caught, out of which 20 turn out to be already marked. So we guess that in the pond 10% fish are marked. In other words total fish population must be 10 times the number marked. Thus our estimate of fish number is 1000.

While simple as a concept, implementation of capture-recapture method can be quite tricky. How are animals marked? In case of fish, the fin may be pierced and a wire ring may be attached. In case of birds, a thin metal or plastic strip is tied around a leg. Insects are marked using paint. Marks must not be lost or else estimates get inflated. Capturing must not hurt the animals. Some animals are captured with baited traps, using a suitable food item as bait. Some animals become trap attracted and others become shy. This introduces bias. How does one capture tigers and lions? Lions in Gir forest of Gujarat are not secretive and can be photographed in daylight. It turns out that their whisker patterns are unique and so capture as well as recapture is done notionally by photographs.

(c) ***Line Transect Sampling:*** In this method an observer walks along a chosen path and records animal sightings and approximate perpendicular distances of animals seen from the path being traversed. If animal density is high, sightings are many. If visibility is high, animals are seen even at great distances. Calculation of animal densities from such data is a rather complicated matter.

Even while using this method, one must never forget the ecological ground realities. In one study in a small national park, the number of female chitals was found to be very high in the wet season whereas the count of males was high in the dry season. Clearly sex ratios cannot fluctuate wildly within such a short span of time. The explanation of the anomaly lies in changing male behaviour. In rutting season males become bolder and can be observed at a shorter distance from a transect which pushes up the estimated number.

(d) ***Nearest Individual Distances:*** This method is used mainly for static objects like trees, nests, anthills, etc. Points are selected in a forest area and distance from each point to the nearest individual (say a neem tree, if we are measuring density of neem trees) is measured. If density is high, nearest distance is short. If measured distances are long, it suggests low density.

(e) ***Indirect Census Through Dung Piles:*** Here an attempt is made to estimate the number of dung piles (of say elephants or chital) per unit area. From direct observations one can estimate how many dung piles are produced by one individual per day. Also it is possible to estimate the number of days for which a dung pile lasts on the forest floor (after which it merges with the soil). Dividing the number of dung piles per unit area by the life of the dung pile and also by per day per individual output, we get an estimate of animal density. This approach has been used to estimate elephant density in Mudumalai forests of Tamil Nadu.

(f) ***Tiger Census Using Pugmarks:*** Some foresters believe that pug mark of a tiger in the soil is essentially a signature of an individual animal. So pugmarks are located, traced on paper and compared. Similar tracings indicate the same animal. Distinct tracings provide an estimate of the number of tigers.

Many ecologists treat the above method with great scepticism. A recent innovation by Ullas Karanth is identification of individual tigers from stripes using photographs taken automatically as a free roaming tiger triggers the camera. This approach has yet to be put into practice on a large scale. In general, estimation of abundance of animals has proved to be a rather difficult task.

Measurement of Biodiversity

A remarkable feature of our biosphere is diversity. Animals and plants come in such a great variety as to amaze even the most casual observer. Introductory biology courses often devote a great deal of time and effort to teach taxonomy or the system of classification. In animals we have vertebrates and invertebrates. In plants there are flowering and nonflowering plants. Vertebrates are further divided into fishes, amphibians, reptiles, birds and mammals. The splitting goes on till we reach species (which may be further divided into races, varieties, etc.). For the purpose of our discussion, let us stay with species. The number of species of mammals or birds is known to a reasonable level of accuracy. Discovery of a new mammal species is scientific news. On the other hand the number of species of insects present on earth is not known even approximately. It is now widely recognised that biodiversity is a resource. Plant and animal species provide us food, medicine, fodder, clothing and many other things. Secondly diversity is a nonrenewable resource. If a mango tree is killed, another can be grown from a seed. If a species is wiped out, we have no way of recreating it. From algae to angiosperms and from bacteria to baboons, the whole range of organisms is of potential use for mankind. In 1992, leaders of many nations in the world gathered together at Rio de Janeiro in Brazil and signed a convention in that Earth Summit. The convention asks each country to prepare an inventory of its biodiversity and monitor any changes in it. So we must know how to measure biodiversity.

Thinking about biodiversity and its measurement can be difficult for some traditional biologists. Typically they concentrate attention on one taxon or sometimes even a single species. Contemplating the whole biosphere quantitatively may seem rather bewildering. But one can start with simple steps. Some countries have greater biodiversity than others. India is a mega biodiversity country. So are Indonesia and Brazil. In contrast temperate countries have low biodiversity. Some specific geographic areas have very high levels of biodiversity and are called hot spots. Western Ghats and North Eastern Himalayas are two hotspots in India. On the other hand deserts and mountaintops have very low diversity. From such broad generalities we can come down to smaller localities, a district or a tehsil or even a watershed. Also we can narrow down the discussion to a taxon of interest e.g. trees. Measurement of biodiversity has two features – species richness of an ecosystem and evenness. Greater the number of species, richer the ecosystem.

If our target is a small area, say a sacred grove, we can prepare a list of tree species. Birdwatchers often have such checklists for areas of interest to them. If the area is large, a complete and thorough check is not possible. So the method of sample checking has to be adopted.

Species Individual Curve: Suppose we select trees randomly and identify the species (for which good experience is necessary). Then as the number of individuals checked goes on increasing, the number of species encountered also goes on increasing. Initially, it is easy to find a new species. But gradually, as the accumulation progresses, it becomes harder and harder to come up with a new species. A graph of the number of individuals seen versus the number of species recorded is called a species individual curve. This curve gives us a reasonable idea of the total number of species.

Other things remaining constant, greater the number of species, greater the biodiversity. The remarkable degree of variation in species richness can be illustrated by a study of all plants in 50 hectares of forestland in Malaysia, India and Panama. The

Table 1. Tree count in 50 ha. plots in 3 countries.

	Malaysia	India	Panama
No. of species	816	71	303
No. of plants (living stems above 1cm diameter)	3,35,000	27,000	2,44,000

number of individual plants and number of species are given in *Table* 1.

(If we observe 10 times as many trees in India by going over greater area if necessary, will we come across as many species as in Malaysia? The answer appears to be in the negative.)

Now two places with the same number of plant (or animal) species are equally species rich. But should they be regarded as equally diverse? Suppose forest patch A has 99 ber (*Zizyphus* sp.) tree and 1 babul (*Acacia* sp.) tree. Patch B has 50 ber trees and 50 babul trees. Species richness is the same. But patch A seems vulnerable. Loss of 1 babul tree will make it a monoculture of ber. Its diversity is less. If number of species is the same, greater the evenness of numbers of individuals, greater the diversity. Hence comes the issue of relative abundances. In a typical community, there are few abundant species and many other species occurring at low level of abundance. When we talk of a bamboo forest or sal forest we mean that the concerned species is very abundant.

Table 2 gives the summary of data presented by Parthasarathy and Karthikeyan (1997). The number of woody tree species is given by abundance. Thus out of 482 trees recorded, about 1/6th are of single species, 50% are covered by 4 species and 23 species are represented by just one individual each.

If our study area has a small number of species, we can list the species and mention abundance level of each. If the number of species is large, this becomes impractical. Instead, it is custom-

Abundance	Number of Species	Abundance	Number of Species
79	1	10	1
72	1	8	1
57	1	7	4
40	1	6	3
32	1	5	2
14	1	4	3
13	1	3	3
12	1	2	6
11	3	1	23

Table 2.

ary to use certain indices, which summarise this information. We will mention two common indices.

Simpson's index: If there are k species with relative abundances $p_1, p_2 \dots p_k$, Simpson's index of diversity is given by

$$1-\sum_{1}^{k} p_i^2$$

It represents the chance that two individuals selected randomly will belong to different species. For the above data, the value is 0.9277.

Shannon–Wiener index: Its formula is

$$H = -\sum p_i \ln(p_i)$$

where ln is the natural logarithm. For the above data, the index has a value of 3.3523.

These indices have higher values if different species have similar abundances. If one or a few species dominate the scene, the indices come down. These indices are said to measure species diversity or α diversity. By β diversity we mean dissimilarity between two sites. Similarity can be measured by the number of species common to the two sites (suitably normed by total number of species). A popular index of similarity (complement of β diversity) is,

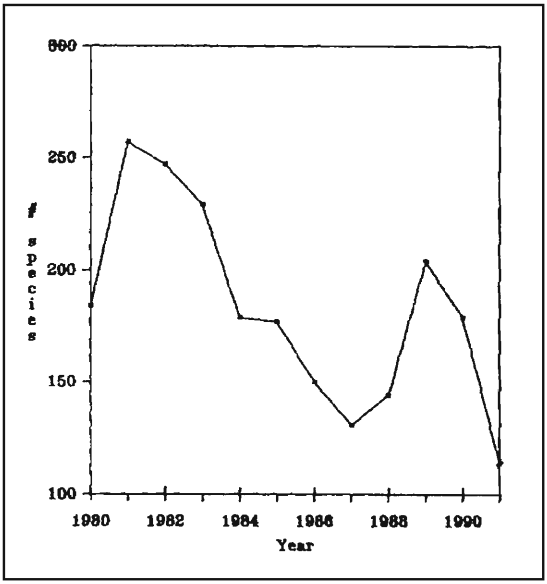
$$\text{Jaccard Index} = \frac{n_c}{n_1 + n_2 - n_c} \times 100$$

where n_1, n_2 are number of species in two sites, n_c is the number of species common in two sites. If no species is common in two sites, similarity is zero i.e β diversity is 100%. On the other hand if all the species are present in both the sites, similarity is 100% or in other words β diversity is zero.

Diversity indices are useful mainly for comparison between ecosystems over space and/or time. See *Figure* 1 which gives a plot of species richness (one possible diversity index) for all birds ringed by BNHS bird ringing team [2]. The graph has a peak at 1981 and a decline upto 1987 and again a rise afterwards. The cause of this pattern is to be explored.

We talk about diversity in a particular group of organisms (birds, trees, bacteria etc). We could also talk about diversity of intestinal parasites or worms. Watve and Sukumar (1995) studied diversity of intestinal worms of wild animals. They measured egg density in dung. They proposed various possibilities regarding patterns in this diversity. Elephant gut should have higher diversity than hare or porcupine. Gregarious animals (e.g. chital) should harbour a greater variety of parasites than solitary animals (e.g. tiger). Animals with multiple stomachs should have greater diversity than animals with single stomach. Carnivores should show in their faeces greater variety of worms than herbivores. As you can see, this is an excellent way of relating host with parasite. Their results show that the only relationship confirmed by empirical evidence is between predation pressure and parasite load. As the predation pressure increases, prey animals with higher parasite loads, being weaker, get eliminated.

Figure 1. Yearly species richness in BNHS bird ringing data.



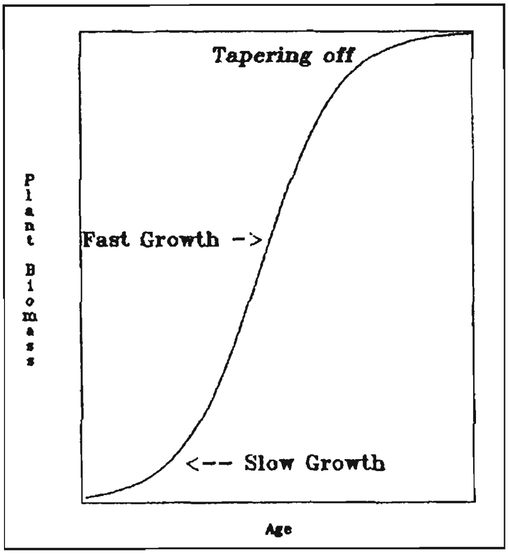
Sustainable Harvesting

This is a crucial concept for utilisation of any renewable biological resource such as pasture, timber, fisheries and so on. We do need to extract biomass for food, fuel, fodder, fertiliser, fiber, etc. But we must do it in such a manner that the resource is not exhausted and we can get more when we need it.

Consider a tree that provides leaves for animals. We can lop all its branches and get lots of fodder at one time. But then the growth of fresh leaves will be very slow. Instead it is better to lop it less heavily. This simple principle of moderation has to be applied to get a sustainable yield.

Consider grass. This is an important source of fodder. In traditional arrangements, each village has a grazing area. As the monsoon rains begin, new growth of grass makes the grazing land emerald green. In summer cattle are often starved of greens. So there is a great temptation to let the cattle graze there right away. This is an unwise practice. Growth of grass tends to be sigmoidal as shown in *Figure* 2. Very roughly speaking growth is very slow initially in June. It picks up in July and tapers off in August. Flowering is in September. Maximum benefit is gained if we harvest grass just after the period of fast growth i.e. roughly say end of July. This may be called the optimal harvesting policy. Given a sigmoidal growth, how to identify the best time for harvest is a technical matter, which we shall skip.

Figure 2. Sigmoidal growth curve.



In case of fisheries it has been found that managing the resource sustainably is very difficult. One traditional practice that helps greatly the conservation of fish resource is that of having a refugium, i.e. an area where there is no harvesting. This forms a place for breeding, restocking, etc. Sacred groves act as the plant refugia in forest areas.

It is very important for nature lovers to know conservationally important traditional practices, to evaluate their efficacy and to promote them if found useful.

Animal Behaviour Models

While it is pure joy to observe animal behaviour, understanding it is a tough scientific task that has been taken up with gusto in recent decades. The evolutionary approach to study of animal behaviour assumes that animals optimise. They extract the highest benefits out of any activity. If not, a mutant that works better will replace them.

(a) *Clutch Size:* Usually clutch size or number of eggs laid by a bird in a breeding season is fixed. This is optimum in the sense if more eggs are laid, due to food shortage or other reasons, mortality rate in chicks goes up and in the end fewer offspring survive.

(b) *Prey Choice:* Fish eaters know that some fish are full of small bones that have to be separated with effort, patience and skill before a morsel of tasty meat becomes available. Other fish are easy to handle and clean. Predators generally encounter some prey types that are tedious to handle, clean, open, etc. (bad) and other types that are easy (good). Predators are very smart and choose the prey so that they get high reward with least effort. If both good and bad types are available aplenty, they choose only the good ones. If good ones become scarce, they take whatever comes their way. All these ideas can be made very precise. They lead to quantitative expectations verifiable through careful experiments.

(c) *Central Place Foraging:* A foraging bird has to search food and bring it back to the nest to feed the chicks. It is necessary to work such that feeding rate of chicks which is high commensurates with their phenomenal growth rates. To optimise food gathering effort, birds adjust the time spent on a patch searching food to the distance of the patch from the nest. If the patch is near the nest, birds make short, quick trips bringing small amounts each time. If the patch is far, they spend much more

Suggested Reading

[1] A J F M Dekker, S Dawson and A Desai, An indirect method for counting Asian elephants in forests, In Censusing Elephants in Forests, Proceedings of an international workshop, Asian Elephant Conservation Centre of IUCN/SSC Asian Elephant Specialist Group, *Technical Report* No. 2, 1991.

[2] A P Gore and S A Paranjpe, *Tabulation and Analysis of Bird Ringing Data from BNHS*, Tech. Report, Department of Statistics, University of Pune, 1995.

[3] K U Karanth, Estimating Tiger, *Panthera tigris*, Populations from Camera Trap Data Using Capture Recapture Models, *Biological Conservation*, Vol. 71, 333-338, 1995.

[4] N Parthasarathy and R Karthikeyan, Biodiversity and Population Density of Woody Species in a Tropical Evergreen Forest, in Courtallam Reserve Forest, Western Ghats, India, *Tropical Ecology*, Vol. 38 (2), 297-306, 1997.

[5] M Watve and R Sukumar, Parasite abundance and diversity in mammals: Correlates with host ecology, *Proc. Nat. Acad. Sci.* USA, Vol. 92, 8945-8949, 1995.

time gathering food so that the extra travel time is not wasted. Is it not similar to what we do? We don't mind a trip to the corner store even for a single matchbox. If we go to a far away place for shopping we make elaborate preparations, shopping list, etc. That makes the long journey worth while.

Exercises

1. Make your cat or dog walk on wet and dry soil. Try to trace outlines of pugmarks by keeping a piece of glass on top and using a marker pen. Try to quantify the shape of the pugmark. Assess visually if there are differences between front and hind pugmarks or between left and right pugmarks. Check if replicate pugmarks of the same foot (say rear left) are equal or just similar.

2. Fill a bottle with a known number of beads of a colour (say white). The aim is to estimate this number using capture-recapture technique. Add a small number (known) of beads of different colour. These are our 'marked' beads. Now shake the bottle well and take out a sample of the mixture. Find the proportion of marked beads. Hence, by rule of three, estimate the number of white beads. Repeat this a few times to see the extent of variability in statistical estimates.

3. Take a pack of playing cards. Suppose the four suits Spade (S), Heart (H), Diamond (D) and Club (C) represent four species. We know that each species is in the same proportion (13/52 = 1/4). Calculate Simpson's index. Now shuffle the cards and take a sample of say 12 cards. Count the number of cards of each suit and hence calculate the relative 'abundance' of each 'species'. Now calculate Simpson's index for this sample. Repeat a few times and see how close these estimates are to the 'true' value. Can you write a BASIC program to simulate this procedure?

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There are three kinds of lies – lies, damned lies and statistics.

– Mark Twain