

Feature article**Tools for Environmental Impact Assessment (EIA) Using Diversity Indices**

S Ajmal Khan*

Centre of Advanced Study in Marine Biology

Annamalai University

Parangipettai-608 502, Tamil Nadu, India

Introduction

Sri Lanka is a fast developing economy. Here the industrial sector comprises of four main categories namely Mining and Quarrying; Manufacturing; Electricity, gas and water; and construction. Tourism is also an important sector here. To develop the nation, government is keen on industrialization. The growth of the industrial sector is fast (29.2 %). The country is also blessed with a rich terrestrial and aquatic biodiversity. The species diversity of Sri Lanka shows that it has 4000 species of flowering plants, 107 species of freshwater fish, 59 species of amphibians, 174 species of reptiles, 435 species of birds, 140 species of mammals and several thousand invertebrates. Within the Asian region Sri Lanka has the highest species density for flowering plants, amphibians, reptiles and mammals. Sri Lanka's waters are home to an astounding array of marine plant and animal life. While coastal ecosystems are typically associated with coral reefs, shipwrecks, which have been unintentionally scattered in the sea, also transform into unique habitats for many species of ocean flora and fauna that find refuge in the various nooks and crevices. Many of the habitats here are considered as hot spots (areas that carry an unusually high number of endemic species are referred to as biodiversity hotspots).

It is quite essential that development going hand in hand with protection of biodiversity and conservation of natural resources. To achieve this environmental impact assessment (EIA) should be the key ingredient in all the development agenda. This article gives information regarding the various biodiversity indices which could be used successfully as the tools for undertaking environmental impact assessment.

Biodiversity indices

Given the large number of indices, it is often difficult to decide which the best method of measuring diversity is. One good way to get a feel for diversity measures is to test their performance with one's own data. A rather more scientific method of selecting a diversity index is on the basis of whether it fulfils certain functions criteria-ability to discriminate between sites, dependence on sample size, what component of diversity is being measured, and whether the index is widely used and understood. The various diversity measures are given below.

Species richness indices**Simpson's index**

Simpson gave the probability of any two individuals drawn at random from an infinitely large community belonging to different species.

*Correspondence: seyedajmal@gmail.com

The Simpson index is therefore expressed as $1-D$ or $1/D$. Simpson's index is heavily weighed towards the most abundant species in the sample while being less sensitive to species richness. It has been shown that once the number of species exceeds 10 the underlying species abundance distribution is important in determining whether the index has a high or low value. The D value which is standing for the dominance index is used in pollution monitoring studies. As D increases, diversity decreases. That way it is effectively used in Environmental Impact Assessment to identify perturbation. The Simpson's dominance index can be effectively used in Palk Bay to study disturbance.

Margalef index

It is having a very good discriminating ability. However it is sensitive to sample size. It is a measure of the number of species present for a given number of individuals.

However it is weighed towards species richness. The advantage of this index over the Simpson index is that the values can come more than 1 unlike in the other index where the values will be varying from 0 to 1. This way comparing the species richness between different samples collected from various habitats is easy.

Berger-Parker index

This simple intrinsic index expresses the proportional importance of the most abundant species. As with the Simpson index, the reciprocal form of the Berger-Parker index is usually adopted so that an increase in the value of the index accompanies an increase in diversity and a reduction in dominance.

Rarefaction index

Even though it is used for standardizing the sample size, it is also used as an index (Hsieh

and Li, 1998). This index relates sample size (number of organisms) with numbers of species. This is very much helpful in comparing the diversity of organisms living in healthy and degraded environments. This index can be used to compare diversity before the commencement of the project and after that so also areas close to the canal and away from it.

Species diversity indices

Shannon-Wiener index

Shannon and Wiener independently derived the function which has become known as Shannon index of diversity. This indeed assumes that individuals are randomly sampled from an independently large population. The index also assumes that all the species are represented in the sample. \log_2 is often used for calculating this diversity index but any log base may be used. It is of course essential to be consistent in the choice of log base when comparing diversity between samples or estimating evenness. The value of Shannon diversity is usually found to fall between 1.5 and 3.5 and only rarely it surpasses 4.5. It has been reported that under log normal distribution, 10^5 species will be needed to produce a value of Shannon diversity more than 5. Expected Shannon diversity is also used ($Exp H'$) as an alternative to H' . $Exp H'$ is equivalent to the number of equally common species required to produce the value of H' given by the sample. The observed diversity (H') is always compared with maximum Shannon diversity (H'_{max}) which could possibly occur in a situation where all species were equally abundant.

Shannon diversity is the very widely used index for comparing diversity between various habitats (Clarke and Warwick, 2001) so also in environmental impact studies.

Brillouin index

The Brillouin index is used instead of the Shannon index when diversity of non-random samples or collections is being estimated. For instance, fishes collected using the light produce biased samples since not all the fishes are attracted by the light. The Brillouin index is used here to calculate the diversity of fishes collected by gears which use light for fishing.

Log series index

This popular method is very widely used because of its good discriminant ability and the fact that, it is not unduly influenced by sample size. It is reported to be a satisfactory measure of diversity, even when the underlying species abundances do not follow a log series distribution and it is less affected by the abundances of the commonest species. If the animal populations in Palk Bay follow log series distribution, this index can be effectively used for studying the impact.

Log normal diversity

It is reported to be independent of the sample size and that way very efficient for comparing the biodiversity of one habitat from another. However it can not be accurately estimated when the sample size is small. Therefore it can be used when the sample size is large. It is also used as a measure of evenness. If the animal populations in Palk Bay follow log normal distribution, this index can be effectively used for studying the impact.

McIntosh's measure of diversity

McIntosh proposed that a community could be envisaged as a point in an S dimensional hyper volume and that the Euclidian distance of the assemblage from the origin could be used as a measure of diversity.

Jackknife index

It is a technique which allows the estimate of virtually any statistic to be improved. The beauty of this method is that it makes no assumption about the underlying distribution. Instead a series of Jack-knife estimates and pseudo values are produced. The pseudo values are normally distributed and their mean forms the best estimate of the statistic. Confidence limits can also be attached to the estimate.

Q statistic

An interesting approach to the measurements of diversity which takes into account the distribution of species abundances but does not actually entail fitting a model is the Q statistic. This index is the measure of the inter-quartile slope of the cumulative species abundance curve and provides an indication of the diversity of the community with no weighting either towards very abundant or very rare species. This statistic can also be effectively used for studying the impact in the Palk Bay.

Species evenness indices

Evenness index is also an important component of the diversity indices. This expresses how evenly the individuals are distributed among the different species. Pielou's evenness index is commonly used. Heip evenness index is also there but comparatively less used. Under perturbation, the evenness changes and therefore the changes in evenness can also be used to study the impact.

Hill numbers

Hill (1973) proposed a unification of several diversity measures in a single statistic. While N_1 is the equivalent of Shannon diversity, N_2 the reciprocal of Simpson's λ and N_∞ is the evenness index. The advantage is that instead of

calculating various indices for diversity, richness and evenness, it can be used to calculate all these measures. That is its advantage. Hill numbers calculated prior to the commencement of the project and after, so also near the canal and away from the canal will provide valuable information regarding the impact.

Caswell neutral model /‘V’ statistics

This is helpful in comparing the observed diversity with the diversity provided by the neutral model (Caswell, 1976). This model constructs an ecologically neutral community with the same number of species and individuals as the observed community assuming certain community assembly rules (random birth/deaths and random immigration/emigrations and no interactions between species). The deviation statistics ‘V’ is then determined which compares the observed diversity (H') with that predicted from the neutral model [$E(H)$]. While the ‘V’ value of zero indicates neutrality, positive values indicate greater diversity than predicted and negative values lower diversity. Values $> +2$ or < -2 indicate significant departure from neutrality. This is helpful in comparing the diversity prior to the commencement of the project and after, so also near the canal and away from the canal.

Newly introduced indices

Taking into consideration the demerits of the routinely used conventional indices, new indices have been recently introduced. Conventional indices are heavily dependent on sample size/effort. Indices with similar effort only can be compared. But with respect to the conventional indices, the effort is not mentioned. Also the old indices do not reflect the phylogenetic diversity. There is also no statistical framework for testing the departure from expectation and the response of species richness to environmental degradation

is not monotonic. Lastly there is no way of distinguishing natural variation to anthropogenic disturbance. The newly introduced diversity measures (Warwick and Clarke, 1995) do not have these demerits.

Taxonomic diversity index

It is defined as the average taxonomic distance between any two individuals (conditional that they must belong to two different species) chosen at random along the taxonomic tree drawn following the Linnaean classification. When the sample has many species, the values are on the higher side reflecting the taxonomic breadth.

Taxonomic distinctness index

It is defined as the average path length between any two individuals (conditional that these must belong to two different species) chosen at random along the taxonomic tree drawn using the Linnaean classification. Here also the higher values reflect the higher diversity of samples. Another advantage of this index is that making use of the average taxonomic distinctness and variation in taxonomic distinctness index, biodiversity between healthy, moderately degraded and heavily degraded habitats could be compared using the 95% histogram, 95% funnel and ellipse plot. Another feature of this index is that in the absence of quantitative data, the above could be accomplished based on qualitative data. This is highly helpful in comparing the diversity of various regions in the Bay.

Phylogenetic diversity index

The total phylogenetic diversity index denotes the taxonomic breadth/ total taxonomic path length and the average phylogenetic index is obtained by dividing the total phylogenetic diversity index by the number of species. In healthy environment due to rich faunal assemblages, (taxonomic

breadth) the total phylogenetic diversity and average phylogenetic diversity are always more.

The following hypothetical data of coral reefs explain the efficiency of the newly used diversity indices which capture the higher level diversity also efficiently (genera and families). In reef 1, there are 12 species of corals, belonging to 12

genera and 12 families. But in reef 2, the same number of species are there but belonging only to 5 genera and 4 families (Tables 1-4). While the conventional indices fail to distinguish the two reefs, the newly introduced indices efficiently make out the differences (Table 5).

| Name of the species | % of cover |
|-------------------------------|------------|
| <i>Psammocora digitata</i> | 10 |
| <i>Seriatopora crassa</i> | 10 |
| <i>Acropora formosa</i> | 10 |
| <i>Pavona varians</i> | 10 |
| <i>Siderastrea savignyana</i> | 10 |
| <i>Cycloseris sinensis</i> | 10 |
| <i>Porites solida</i> | 10 |
| <i>Favia favius</i> | 10 |
| <i>Culicia rubeola</i> | 10 |
| <i>Galaxea clavus</i> | 10 |
| No. of Species 10 | 100 |

| Species | Genus | Family |
|-------------------------------|-------------------------|---------------------------|
| <i>Psammocora digitata</i> | <i>Psammocora</i> | Thamnasteriidae |
| <i>Seriatopora crassa</i> | <i>Seriatopora</i> | Pocilloporidae |
| <i>Acropora formosa</i> | <i>Acropora</i> | Acroporidae |
| <i>Pavona varians</i> | <i>Pavona</i> | Agariciidae |
| <i>Siderastrea savignyana</i> | <i>Siderastrea</i> | Siderastreidae |
| <i>Cycloseris sinensis</i> | <i>Cycloseris</i> | Fungiidae |
| <i>Porites solida</i> | <i>Porites</i> | Protidae |
| <i>Favia favius</i> | <i>Favia</i> | Faviidae |
| <i>Culicia rubeola</i> | <i>Culicia</i> | Rhizangiidae |
| <i>Galaxea clavus</i> | <i>Galaxea</i> | Oculinidae |
| No. of species 10 | No. of genera 10 | No. of families 10 |

| Name of the species | % of cover |
|-------------------------------|-------------------|
| <i>Pocillopora damicornis</i> | 10 |
| <i>Pocillopora verrucosa</i> | 10 |
| <i>Acropora formosa</i> | 10 |
| <i>Montipora tuberculosa</i> | 10 |
| <i>Favia palliada</i> | 10 |
| <i>Favia stelligera</i> | 10 |
| <i>Favia speciosa</i> | 10 |
| <i>Favia fавus</i> | 10 |
| <i>Favia rotumana</i> | 10 |
| <i>Galaxea astreata</i> | 10 |
| Number of species 10 | 100 |

| Species | Genus | Family |
|-------------------------------|------------------------|--------------------------|
| <i>Pocillopora damicornis</i> | <i>Pocillopora</i> | Pocilloporidae |
| <i>Pocillopora verrucosa</i> | <i>Pocillopora</i> | Pocilloporidae |
| <i>Acropora formosa</i> | <i>Acropora</i> | Acroporidae |
| <i>Montipora tuberculosa</i> | <i>Montipora</i> | Acroporidae |
| <i>Favia palliada</i> | <i>Favia</i> | Favidae |
| <i>Favia stelligera</i> | <i>Favia</i> | Favidae |
| <i>Favia speciosa</i> | <i>Favia</i> | Favidae |
| <i>Favia fавus</i> | <i>Favia</i> | Favidae |
| <i>Favia rotumana</i> | <i>Favia</i> | Favidae |
| <i>Galaxea astreata</i> | <i>Galaxea</i> | Oculidae |
| No. of species 10 | No. of genera 5 | No. of families 4 |

Table 5. Biodiversity indices of corals in reef 1 and 2.

| Stations | Reef 1 | Reef 2 |
|-----------------------|--------|--------|
| S | 10 | 10 |
| N | 100 | 100 |
| d | 1.9543 | 1.9543 |
| J' | 1 | 1 |
| H'(log ²) | 3.3219 | 3.3219 |
| 1-Lambda | 0.9091 | 0.9091 |
| Delta | 90.91 | 75.421 |
| Delta* | 100 | 82.963 |
| Delta+ | 100 | 82.963 |
| Lambda+ | 0 | 820.85 |
| Sphi+ | 1000 | 633.33 |

Abundance/biomass comparison (ABC) plots

The advantage of distribution plots such as k-dominance curves is that the distribution of species abundances among individuals and the distribution of species biomasses among individuals can be compared on the same terms. Since the two have different units of measurement, this is not possible with diversity indices. This is the basis of the Abundance/ Biomass Comparison (ABC) method of determining levels of disturbance (pollution-induced or otherwise) on benthic communities. Under stable conditions of infrequent disturbance the competitive dominants in benthic communities are k-selected or conservative species, with the attributes of large body size and long life-span: these are rarely dominant numerically but are dominant in terms of biomass. Also present in these communities are smaller r-selected or opportunistic species with a short life-span, which are usually numerically dominant but do not represent a large proportion of the community

biomass. When pollution perturbs a community, conservative species are less favoured and opportunistic species often become the biomass dominants as well as the numerical dominants. Thus under pollution stress, the distribution of numbers of individuals among species behaves differently from the distribution of biomass among species. The ABC method, involves the plotting of separate k-dominance curves for species abundances and species biomasses on the same graph and making a comparison of the forms of these curves. The species are ranked in order of importance in terms of abundance or biomass on the x-axis (logarithmic scale) with percentage dominance on the y-axis (cumulative scale). In undisturbed communities the biomass is dominated by one or few large species, each represented by rather few individuals, whilst the numerical dominants are small species with a strong stochastic element in the determination of their abundance. The distribution of number of individuals among species is more even than the distribution of biomass, the latter showing

strong dominance. Thus, the k-dominance curve of biomass lies above the curve of abundance for its entire length. Under moderate pollution, the large competitive dominants are eliminated and the inequality in size between the numerical and biomass dominants is reduced so that the biomass and abundance curves are closely coincident and may cross each other one or more times. As pollution becomes more severe, benthic communities become increasingly dominated by one or a few very small species and the abundance curve lies above biomass curve throughout its length. These three conditions (unpolluted, moderately polluted and grossly polluted) can be easily recognized in a community without reference to the control samples. That is the advantage of this ABC plot (Clark and Warwick, 2001)

Dominance plot

Dominance plot is also called as the ranked species abundance plot. This can be computed for abundance, biomass, % cover or other biotic measure representing quantity of each taxon (Clarke and Warwick, 2001). For each sample, or pooled set of samples, species are ranked in decreasing order of abundance. Relative abundance is then defined as their abundance expressed as a percentage of the total abundance in the sample, and this is plotted across the species, against the increasing rank as the x axis, the latter on a log scale. On the y axis either the relative abundance itself or the cumulative relative abundance is plotted, the former therefore always decreasing and the latter always increasing. The cumulative plot is often referred to as a k-dominance plot. The cumulative curve is used for comparing the biodiversity. When k-dominance curve is used for comparing the biodiversity between many

habitats, it is called as multiple k-dominance curves. Here the sample representing the lower line has the higher diversity. In the relative dominance curve, the curves representing samples from polluted sites will be J-shaped, showing high dominance of abundant species, whereas the curves for less polluted habitats will be flatter. In the cumulative dominance plot, the curves for the unpolluted sites will be sigma shaped and the curves for the polluted habitats will be elevated (rises very quickly).

Geometric class plots

These are essentially frequency polygons, plotted for each sample, of the number of species that fall in to a set of geometric (x2) abundance classes. That is, it plots the number of species represented in the sample by a single individual (class 1), 2 or 3 individuals (class 2), 4-7 individuals (class 3), 8-15 individuals (class 4) etc. It has been suggested that impact on assemblages tends to change the form of this distribution, lengthening the right tail (some species become very abundant and many rare species disappear) and giving a jagged curve.

Species area plot

It is a curvilinear curve, plotting the cumulative number of different species observed as each new sample is added (Clarke and Warwick, 2001). The curve which rises further and further with addition of sample is more diverse than the one which has attained the plateau. It is also used for deciding the number of samples to be collected in a particular habitat to get all the species.

Conclusion

The variety of diversity measures, species abundance models and graphical tools available help ably in assessing not only the biodiversity

of all the habitats but also help to find out perturbation. . The advancement in computer technology has made biodiversity studies more easy and interesting. However this development should be made good use of in protecting the very rich biodiversity Sri Lanka is blessed with.

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