Measuring the Ecological and Economic Diversity of Fish

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Abstract
A new measure of fish biodiversity that captures not only the species' number and abundance, but also its economic value is introduced. The measure is formulated by weighting the Simpson's index with price. Its application to the traditional fisheries of Lake Malawi reveals a decline in fish catch biodiversity. The decline is associated with a shift in fish catch from high valued to low valued species. Thus, this biodiversity measure can show the trend in fish biodiversity by using data on fish catch and price per species only. The availability of catch and price data for most fisheries makes this measure to be applicable as a monitoring indicator for the sustainable management of fisheries.

Key words: Fisheries; biodiversity; market prices.

Introduction

Measuring biodiversity of a community has been one of the central issues in ecology and conservation biology both because of its academic necessity and because of its importance in devising conservation strategies (Ganeshaiah *et al.,* 1997). It has been observed that in measuring biodiversity, the breadth of ways in which differences can be expressed is potentially infinite. Species can be differentiated in terms of their biochemistry, biogeography, ecology, genetics, morphology, or physiology. As a result, there is no single all-embracing measure of biodiversity. This means that it is impossible to state categorically what biodiversity of a group of organisms is. Instead, only measures of certain components can be obtained, and even then, such measures are only appropriate for restricted purposes (Gaston and Spicer, 1998). In this paper an economic biodiversity measure which captures not only the species number and abundance but also their economic values is developed.

Ecological diversity measures

The literature on ecology provides a variety of indices that can be used to measure fish biodiversity. One of the simplest methods suggested is to count the number of species in a community. Such an approach is mostly criticised for being too simplistic as it does not account for the extent of representation of each of these species in the community. This method may also not be suitable in most tropical lakes because of the enormous number of fish species inhabiting the lakes, most of which have not yet been identified and scientifically named. Other indices measure biodiversity based on both number and abundance of species. These heterogeneous indices differ mostly in the amount of weight that they give to the two elements of number and dominance. Examples of indices in this category include Shannon index and Simpson's index (Magurran, 1988).

One major problem cited in the literature associated with these indices is that they assume that all species in a community contribute equally to its biodiversity, and ignore biological and ecological differences between species (Geneshaiah *et al.*, 1997; Harper and Hawksworth, 1994). To address this weakness, taxonomic, morphological and functional diversity indices have been developed (Warwick and Clarke, 1995; Clarke and Warwick, 1998; Ganeshaiah *et al.*, 1997; Pauly *et al.*, 1998). However, these indices demand a lot of biological information, thereby, making them less applicable.

Economic biodiversity measure

The indices discussed above are ecological in nature and as such, they focus on ecological differences among species. Heywood (1995) reports about the growing perception among both ecologists and economists that the importance of biodiversity lies first and foremost in its role in the production of goods and services that are useful to human welfare – its socio-economic importance. Ecological and socio-economic importance are not necessarily the same because it does not always follow that if biodiversity is important to the functioning of some ecological system, then it will automatically be valuable to society. The concept of socio-economic value is very important because it determines the conservation and utilisation of biodiversity. In particular, the rationale for socio-economic valuation of biodiversity lies in the fact that the signals generated by the market in form of prices lead to excessive rates of exploitation and loss of biodiversity (Heywood, 1995).

Thus, in order to reflect the socio-economic value of diversity, the ecological diversity measure must be modified (Barbier *et al.*, 1995).

Methodology

In most cases, studies that claim to measure the economic value of biodiversity in reality measure the economic value of biological resources rather than their diversity (Pearce and Moran, 1994). An ideal measure of economic diversity would have to take into account all the values of biological resources. Unfortunately, methodologies for determining economic values of species require reasonably detailed information about the resources. Most studies continue to use the value of biological resources as a proxy for the value of biodiversity because it is easier to estimate (Tacconi, 2000; Pearce and Moran 1994). In fisheries since most of the species caught are marketed, an economic value of species can be approximated by using market prices. In using market prices, the major interest is not in the market prices per se, but rather in the pattern of selection and types of preferences that they imply (Hanemann, 1988).

The use of market prices in valuing biodiversity should be understood in relation to their weaknesses. In particular, since the markets are typically incomplete, market prices fail to fully reflect the contribution of individual species to a range of ecological services.

To capture the economic value of species, the Simpson's biodiversity index is modified such that it uses market values of species catch biomass rather than the actual species catch biomass. Original formulation of Simpson's diversity index is given by:

$$D_t = \sum_{i=1}^{s} (\frac{y_{it}}{Y_t})^2$$

where D_t is the Simpson's index for year t, s is the total number of species, y_{it} is the catch of i^{th} species harvested in year t, and Y_t is the number of species harvested in year t.

Diversity decreases with increasing value of D_t which ranges from almost zero to one. Simpson's economic biodiversity index can therefore be presented as:

$$B_t = \sum_{i=1}^{s} (\frac{P_{it} Y_t}{TR_t})^2$$

where B_t is the economic biodiversity index for period t, P_{it} is the price of the i^{th} species in year t and TR_t is the total revenue for year t.

A comparative analysis of weighted and unweighted biodiversity measures was carried out using data on catch per species and price per species for the traditional fisheries of Lake Malawi. Data were obtained from the Malawi Fisheries Department. A total of 12 species groups was considered for the period between 1989 to 1997 (Table 1). Both annual and average prices were used to weight the indices (Table 2). The indices were weighted by annual prices in order to capture fluctuations in value which result from fluctuations in resource availability. This can also capture the shift in value of fish resulting from the exploitation of high valued species. Using data from the traditional fisheries of Lake Malawi, three different biodiversity measures were calculated based on the Simpson's index namely, unweighted index, annual-price-weighted index, and average-price-weighted index.

Results and Discussion

A comparison between the weighted and unweighted biodiversity indices is presented in Figure 1. The figure shows that on average, the value of the weighted indices are lower than that of the unweighted index.

The differences between the two diversity measures can be explained by the differences in the catch values of the species groups. When the catch is valued, species dominance declines (biodiversity increases). Thus, the lower values of weighted indices when compared to the unweighted index suggest that, on average, the catches are dominated by less valuable species. If the catches were dominated by valuable species, price weighting would have increased dominance even further and the weighted indices would have had higher values than the unweighted indices. Thus, price weighting can have two different effects on the value of B depending on the relative abundances of the valued and less valued species. These effects can be summed up in the following proposition: *the economic biodiversity index of a community dominated by species of high (low) market value will be greater (less) than an ecological biodiversity index of the same community.* Thus

$$\frac{\partial B}{\partial P} > (<)\ 0 \Rightarrow B > (<)\ D$$

where D is an ecological (unweighted) Simpson biodiversity index and B is the weighted index.

Since the value of the weighted biodiversity index reflects the product of the economic scarcity and the abundance of species, an ecologically dominant species will become more (less) dominant in the weighted index if it is more (less) valuable.

The overall trend depicted by Figure 1 suggests that there is a general decline in biodiversity (increase in dominance) which is associated with a

Table 1. Annual fish catch by species for the traditional fisheries of Lake Malawi: 1989 -1997

Species group	Annual catch (tonnes)								
	1989	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**
Chambo	6132.00	5142.35	5029.57	4445.23	4554.08	3123.15	1931.75	1208.94	471.63
Other tilapia	3339.50	518.15	922.38	359.97	315.10	266.78	324.61	282.05	95.79
Kambuzi	7815.77	11969.37	7351.23	9410.58	8443.92	6281.03	6124.96	1367.74	478.37
Utaka	8385.09	11318.11	9531.41	8865.36	13069.91	14286.55	10829.34	8419.20	6659.52
Chisawasawa	54.38	200.95	193.96	357.10	164.91	353.74	154.81	246.30	277.42
Kampango	1796.03	2047.55	3182.99	1444.91	1915.90	1710.04	2581.46	1282.06	667.09
Mlamba	1589.60	1551.79	2591.01	1220.15	1453.95	1324.56	1648.35	879.22	441.20
Usipa	11693.80	2025.86	4614.73	12566.51	10224.81	7544.88	14522.16	11141.73	8213.76
Nchila	233.21	74.50	416.38	214.05	148.79	217.05	106.14	24.25	6.73
Mpasa	181.04	145.05	79.41	143.15	163.95	200.43	175.19	147.82	42.08
Sanjika	139.25	99.59	267.11	238.76	355.58	135.86	264.25	167.64	85.52
Others	2331.29	3082.43	3398.57	4344.41	4037.78	4424.54	4770.02	2288.52	1879.58

Source: Malawi Fisheries Department

Table 2. Annual and average fish prices by species: 1989 - 1997.

Species Group	Annual Price (Kwacha per kilogram)									
	1989	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**Average Price**
Chambo	0.64	1.18	1.63	2.33	3.16	6.47	8.00	9.57	9.66	4.73
Other tilapia	0.62	0.94	0.79	1.20	2.35	4.44	6.27	8.00	9.20	3.76
Kambuzi	0.45	0.75	0.77	0.92	1.32	1.56	2.21	3.50	3.28	1.64
Utaka	0.35	0.85	1.11	1.50	1.75	2.05	4.31	5.30	5.50	2.52
Chisawasawa	0.45	1.22	0.74	0.84	1.61	1.85	2.20	3.00	3.60	1.72
Kampango	0.57	0.95	1.14	1.43	2.14	2.86	2.42	3.00	3.50	2.00
Mlamba	0.56	0.87	1.09	1.24	1.75	3.13	3.30	4.82	5.00	2.41
Usipa	0.36	0.78	0.62	0.93	1.04	2.70	1.91	2.15	3.23	1.52
Nchila	0.88	0.96	1.12	0.72	1.95	2.15	3.00	3.15	4.20	2.01
Mpasa	0.95	1.74	1.54	1.25	2.83	5.60	7.96	8.56	9.78	4.47
Sanjika	0.63	1.63	0.87	0.66	2.87	6.58	8.00	8.15	10.50	4.43
Others	0.53	0.38	1.10	0.97	1.37	2.58	6.06	8.50	10.50	3.55

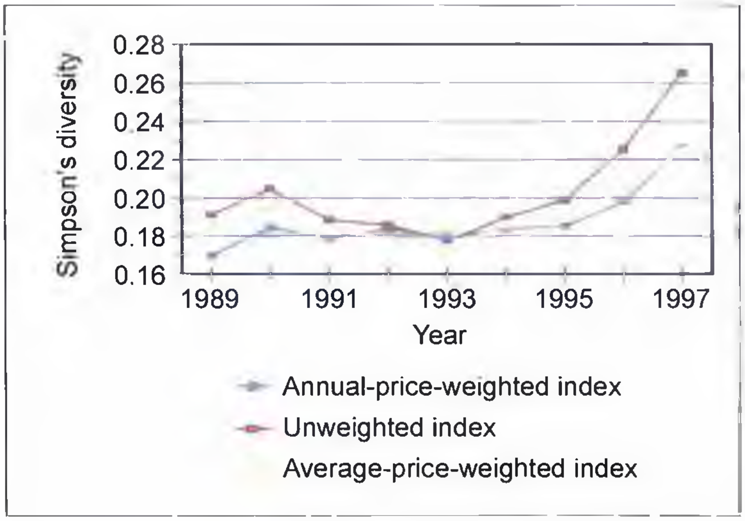

Figure 1. A comparison between the weighted and unweighted biodiversity indices

shift in fish catch from high valued to low valued species. This outcome is in agreement with the observation by FAO(1993) that most of the high valued and popular food fish such as Chambo are in decline in Lake Malawi.

The use of average market prices removes fluctuations in fish value leading to greater stability in the weighted index. However, a comparison between annual-price-weighted and average-price-weighted indices shows that there are no marked differences in the trend resulting from averaging, implying that not much is lost by using average prices. This result is typical of the traditional fisheries of Lake Malawi but could be different for other fisheries.

These results show that the economic biodiversity measure may be an appropriate indicator for monitoring sustainability in fisheries, since it captures both the ecological and economic values of fish species. The measure is also appropriate because it uses data that are readily available for most fisheries. The measure is, therefore, recommended for use in fisheries management.

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