



Exploring cross correlation among diversity indices[☆]

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ABSTRACT

This paper analysed cross correlations among multispecies and single species bio-economic diversity measures related to a local dynamic fisheries ecosystem along the period {1986:1–2014:12}. We focused on bio-economic Simpson, Shannon and multispecies Berger Parker indexes (our proposal of multispecies pure leadership indicator) and the percentage share of income of anchovy and mackerel. These two species were chosen because they showed the highest correlation with the multispecies diversity indices, and led, respectively the “*anti-diversity*” and “*prodiversity*” groups of species within the ecosystem. Time series were subjected to a double treatment to avoid the potential for spurious and biased correlations. First, the long run and seasonal cycles were removed by means of a cyclical ARFIMA modelling approach. Second, the time series were pre-whitened using conventional ARMA modelling. Correlations between the multispecies indices were remarkably high and hardly changed with the pre-whitening procedure. Conversely, the correlations of the multispecies indicators with the income shares of the two leading species decreased to almost the half after pre-whitening, but still remained significant. The concentration in our particular ecosystem is high (i.e. diversity low) and it is significantly correlated with the income shares of the leading species. Accordingly, the risk of collapse for the local fishing sector is high.

1. Introduction

Diversity embodies the variety and heterogeneity of ecosystems. High diversity contributes to their stability. An ecosystem is said to have a high species diversity if many equally or nearly equally abundant species are present. On the contrary, if an ecosystem is composed of few species or if only a few species are abundant, species diversity is low. Quantifying diversity remains problematic because there is no single index that adequately summarises this concept (Hurlbert, 1971; Purvis and Hector, 2000), and the existing diversity indices combine, in non-standard way, the two key and independent attributes of ecosystems, the species richness and relative abundance (or evenness) (Ricotta, 2003). Many articles and several specific books discuss diversity measures (Pielou, 1975; Grassele et al., 1979; Patrick, 1983; Magurran, 1988, 2004), however there is no clear consensus about which indices are more appropriate and informative.

Some of the most widely used diversity measures are species richness (n) and Simpson (SIM), Shannon (SHA) and Berger Parker (BP) indices (Buzas and Hayek, 1996; Gorelick, 2006). Each of these indices

have strengths and weaknesses. For example, species richness does not take into account the abundance of each species, while Berger Parker index focuses on the relative abundance, but just on the related to the most common species, ignoring the rest. Simpson and Shannon indices take into account both the number of species, as well as the abundance of each species. The former is weighted toward the abundance of the most common species (Sanders, 1968; Risser and Rise, 1971; Whittaker, 1972), while the later weighs all species by their frequency, without favouring either common or rare species (Tsallis, 2001; Keylock, 2005). This balance of both diversity attributes is often understood as an advantage of Shannon index, occasionally categorised as the fairest index (Jost, 2007; Melo, 2008). However, it is also reasonable that the index choice could be more influenced by the specific objectives pursued, rather than by its inherent mathematical properties. Thus, if we were especially concerned with the dominant species, Simpson or even Berger Parker index would be the logical choice, and conversely, in some conservation biology applications (when for example, the rarest elements are as important as the commonest), even n would be a reasonable choice. Additionally, some authors (Lande, 1996; Magurran,

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2004) recommend Simpson over Shannon index on the grounds that the former converges more rapidly to its final value and is an unbiased estimator, while Jost (2007) emphasizes that because the exponential of the Shannon entropy is the only diversity measure that can be consistently decomposed into meaningful independent α and β components it should be the standard diversity measure.

In the empirical settings, the parallel use of some diversity indices is a general praxis, although strong correlations between diversity measures should not be surprising, as they represent aspects of the same phenomenon and, in fact, most of the measures can be derived from the same basic generalized Hill's entropy formula (1973). In this sense, Ricklefs (1990) stated that the results of most studies are relatively insensitive to which index of diversity is applied. However, investigation of diversity indices are sporadic and only a few authors pay attention to the correlation among diversity indices. For example, Bryja and Kula (2000) analysed Spearman's rank correlations of numerous diversity indices on bug collections, Magurran (2004) summarised data on diversity indices correlation and Izsák (2007) analysed the correlation of the Shannon diversity index with members of Hill's and Hurlbert's parametric index family. However, to our knowledge, neither the time dimension of the correlation among diversity indices nor their degree of dependence toward each of the species in a specific dynamic ecosystem have been addressed.

In the framework of applied time series analysis and fisheries related diversity, our paper aims to make an attempt to a more systematic and formalized treatment of this topic. In order to do so, we will consider 72 *bio-economic* diversity indices: the *bio-economic* Simpson (SIM_t) and Shannon (SHA_t) indices (Kasulo and Perrings, 2006; del Valle et al., 2016), our new proposal of a new multispecies pure leadership indicator, henceforth multispecies Berger Parker (MBP_{1t}) and the percentage share of income of each and every 69 fish species (IS_{it} , $i=1, \dots, 69$) in our particular ecosystem, which is defined as the macro-fishery comprised by the entire commercial fish species monthly landed in a specific local geographical area during the time horizon (1986:1–2014:12). When commercial fish species are involved, multispecies *bio-economic* indices (instead of the conventional quantity or biomass based ones) are useful tools to analyse the risk of survival of the fishing activity itself (del Valle et al., 2016). The underling idea is that, the same as in a portfolio, the lowest the species diversification in the fishing activity, the higher the concentration, dominance and dependency of the fishing industry to the evolution of the dominant species and, accordingly, the greater the risk of a potential fall down in the local fisheries sector. However, species dominance is not straightforward when the focus is on dynamic ecosystems, because frequently it is guided by trends and/or highly seasonal patterns. Instead of relying on the usual but misleading species rankings based on income share averages (yearly or monthly), the own correlation of any of the multispecies bio-diversity indices $\{SIM_t, SHA_t, MBP_{1t}\}$ and every $\{IS_{it}, i=1:69\}$ is in fact a synthetic measure of dominance that provides an alternative ranking of the species in a dynamic ecosystem.

Since we are working in a dynamic framework, the stationarity of the series is required so as to avoid the risk of spurious correlations. If the series share common trends or similar seasonal effects, these components may in fact dominate the serial cross correlations (ρ_{xy}) and related cross correlograms (CCR), leading to an incorrect guess about the real size of the linear dependence between the concerned indices. Accordingly, it is strongly advisable to remove the trend and/or seasonal effects from the series before investigating cross correlations. Additionally, the pattern of the cross correlation (CCR) may be also affected by the underlying autoregressive–moving-average (ARMA) structures of the time series. One strategy of dealing with this additional difficulty is pre-whitening. Taking advantage of Arteche (2007) and Garcia et al. (2013), we are following a cyclical ARFIMA framework (Arteche and Robinson, 2000; Arteche, 2007) to deduce a series specific filter so as to remove potential stochastic cycles. Afterwards, potential remaining deterministic cycles will be also checked and removed using

conventional seasonal dummy variables (SD) in sin-cosine form. Once the stochastic and deterministic cycles have been removed; following Shumway and Stoffer (2017) we focus on pre-whitening the series in a pairwise basins, by fitting conventional ARMA models and exploring the serial cross correlations (ρ_{xy}) and related cross correlograms (CCR) among the residuals of the fitted model for a series x and the filtered values for series y , $y \neq x$.

The remainder of this paper is organised as follows. After this introduction, Section 2 describes the materials and methods of the paper, paying attention on the data, the formulation of the bio-economic diversity indices and the double treatment of the series x so as to focus on cross correlations in a dynamic framework (i.e. our specific method to remove potential stochastic and/or deterministic cycles and the pre-whitening approach used). Section 3 summarises the major empirical findings made in the paper and Section 4 concludes adding some discussion points.

2. Materials and methods

2.1. Data

Our operative data set is made up by the deflated monthly incomes (I_{it}) (2012€) $\{t = 1986:1, \dots, 2014:12\}$ of each of the commercial fish species ($i = 1, \dots, 69$) auctioned at first sale in the inshore fish market of the Basque fishing and landing port of Ondarrao (Fig. 1) (for now on, ecosystem Ω_t). The original data come from the landing records of Santa Clara Fishers' Guild. Ondarrao has come to be a key landing and commercialization port for fresh fish in the Northeast of Spain, significantly overtaking the real dimension of its own fishing fleet. As a reference, only around 0.5% of the Basque inshore vessels were registered in the fishing port of Ondarrao in 2014; however, around 35% of the fish caught by the Basque inshore fleet was landed there. Accordingly, Ondarrao is considered to be a suitable representative of other fishing landing ports in the area such as Getaria, Hondarribia, Pasaia or Bermeo, respectively bringing together 27%, 15%, 10% and 7% of the total landings of the Basque inshore fishing fleet (del Valle et al., 2016).



Fig. 1. Ecosystem Ω_t (Ondarrao fishing port).

Ondarrao located in the Northeast Spain is a key port for fresh fish. In 2014 around 35% of the fish caught by the Basque inshore fleet was landed in Ondarrao. Basque inshore vessels mainly operate in ICES VIIIc, VIIIb and VIIIc, ICES fishing areas.

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