Multinational Footprint

Contents

The footprint of fisheries on the oceans

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Footprint analysis consists of expressing all human activities in terms of the land area required for generating products that are consumed by humans, or for absorbing the waste generated in the course of supplying these products (Wackernagel and Rees 1996). However, extending the footprint concept to the oceans, or parts thereof (ocean basins, EEZ, LME, etc.), requires that account be taken of the fact that the productivity of a given area of ocean is determined by the local primary production, which can vary tremendously over small distances, depending on local mixing processes (Longhurst 2007). Thus, it is not appropriate to consider the surface area of ocean areas as the 'footprint' reference, but rather their average primary production. This leads to the need for the concept of Primary Production Required, or PPR (Pauly and Christensen 1995).

Basically, estimating the PPR of a given area of ocean involves three steps:

1. Estimating the primary production (PP) of a given ocean area;
2. Estimating the PP *required* (i.e., as embodied in the catch) by all the fisheries operating in the area in question; and
3. Expressing PPR as a percentage of the PP in that area, after re-expressing the estimates in (1) and (2) in the same units.

These three items are elaborated upon in the following paragraphs.

Estimating primary production

Primary production estimates were derived using the model described by Platt and Sathyendranath (1998), which computes depth-integrated primary production from chlorophyll

pigment concentration based on satellite data (SeaWiFS, www.seawifs.gsfc.nasa.gov), and photosynthetically active radiation as calculated in Bouvet *et al.* (2002). The primary production estimates presented here pertain to the average monthly values for the period 1998-2007 inclusive, which, for the purpose of footprint analysis, was assumed to be representative of the entire 1950-2010 period (see also Kleisner and Hoornaert 2015).

Note that PP is usually expressed in milligrams of carbon per day and meter squared ($mgC \cdot day^{-1} \cdot m^{-2}$), which here needs converting into the units for catches used by the *Sea Around Us* (t wet $weight \cdot year^{-1} \cdot km^{-2}$).

Estimating the Primary Production Required by the fisheries of an area

The data used here as input, covering 1950 to the most recent year, were the catches reconstructed by the *Sea Around Us*, spatially allocated to ½ degree latitude/longitude cells as described in Lam *et al.* (2015).

The absolute Primary Production Required is then computed from:

$$PPR = \sum_{i=1}^{n} \frac{C_i}{CR} \times \left(\frac{1}{TE}\right)^{(TL_i - 1)} \quad \ldots 1)$$

where C_i is the catch of species i, CR is the conversion rate of wet weight to carbon, TE is the transfer efficiency between trophic levels, TL_i is the trophic level of species i, and n is the number of species caught in a given area. We applied a 9:1 ratio for CR and 10% for TE, which is a reasonable average for the oceans as a whole (Pauly and Christensen 1995). Species-specific trophic levels, usually derived from diet composition data, were taken from FishBase (www.fishbase.org) for fishes and SeaLifeBase (www.sealifebase.org) for invertebrates.

Expressing PPR as a percentage of the PP in that area

Re-expressing PPR as a percent of the local PP value (by ½ degree cell, which can then be regrouped to EEZs, or LMEs) is a matter of computing, for each cell, PPR·100/PP, with PPR and PP expressed in the dimension and units, i.e. t wet weight.

The resulting % PPR can then be plotted as global maps (Swartz *et al.* 2010; Watson *et al.* 2014), or assigned to LMEs (Pauly *et al.* 1998; Dulvy *et al.* 2009), or to the different countries exploiting a given EEZ, which can be done by applying Equation (1) to each country separately.

Evaluation of the results

Although Coll *et al.* (2008) suggested an approach for computing PPR thresholds, the most prudent interpretation may be to evaluate PPR in relative terms, and especially with reference to the terrestrial primary production required by the human enterprise, which was about 40-50% in the early 1980s (Vitousek *et al.* 1986). Thus, Swartz *et al.* (2010) used 30% of PPR as a 'high value', based on the estimated PPR of 25-35% on continental shelves reported by Pauly and Christensen (1995).

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