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Stability vs. organization: Potential of a trophic model for the management of shallow tropical streams

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ABSTRACT

Streams in the Hondo River basin (Mexico–Belize) face ecological disturbances caused by use of fertilizers and pesticides, as well as invasion by exotic species. These threats can affect ecosystem functioning, with loss of biotic integrity. Mass-balance trophic models were developed to quantify the energy flow and assess the maturity and health states for three locations in the basin, in two seasons. Quantitative sampling was carried out for plankton, fish, macrobenthos, insects, benthic autotrophs, detritus, and exported organic matter. Field sampling was supplemented with a literature review to define functional groups and their diets. Results showed that more than 50% of the energy flow originated from detritus, which suggests that the systems are bottom-up controlled. Low values of energy transfer efficiency, connectivity, omnivory, recycling, mean path length, and ascendency suggest that the freshwater bodies in this basin are oligotrophic, but they are not in a good health and thus have low stability and are susceptible to disturbance, despite the fact that they also have a high number of specialized functional groups, indicative of a well-organized food web, supposed to be representative of healthy ecosystems. The potential of these models to manage shallow tropical streams is discussed.

1. Introduction

Pollution, exotic species, habitat modification, and other stressors are ecological disturbances that modify matter and energy flow[1] (Arias-González et al., 2004). Structure and function of food webs determine the biotic integrity of the ecosystem and indicate health status (Costanza and Mageau, 1999).

In freshwater environments of the Hondo River basin anthropogenic activities, such as sugar production and urban settlements, result in fertilizer and pesticide run-off that causes environmental deterioration (Díaz-López et al., 2006). Energy flow and cycling of matter dynamics are important and can be estimated by ecological models.

Mass-balance trophic models provide a static description of trophic flows in the ecosystem, and its information can be used to compare time series, as well as in a management context; the software Ecopath with Ecosim (EwE) is designed to build such models, to estimate their parameters and to perform several analyses based thereupon (Christensen and Pauly, 1993). The program incorporates indices useful for quantifying attributes associated with the degree of development and health of ecosystems (Christensen, 1995; Costanza and Mageau, 1999).

Although trophic models have been built for coastal lagoons and coral reefs In the Yucatan Peninsula (Arreguín-Sánchez et al., 1993; Vega–Cendejas, 2003; Arias-González et al., 2004; Castelblanco-Martínez et al., 2012), this paper proposes proposed the first freshwater model for the region.

Recent relevant research that has addressed similar issues and questions includes the work by Medina et al. (2007), who investigated the sustainability of coastal fisheries in Chile, as ascertained by food-web parameters, and found low values of FCI and P/R > 1, which was interpreted as indicative of low maturity; on the other hand, Álvarez-Hernández (2003), disregarded a low FCI, considering P/R < 1 as a more important indicator to conclude that a Caribbean coral reef food web was relatively mature. Lima et al. (2014) considered the Madeira River, Amazon basin, to be both mature and resilient, with a high FCI and a P/R much lower than 1. Food chains apparently grow longer in desert streams invaded by many exotic species (Walsworth et al., 2013), while organization (specialization) in these ecosystems may be related to such abiotic factors as pH (Layer et al., 2013). Coll and Libralato (2012) reviewed similar studies in the Mediterranean.

The aims of this study are to describe flows of energy and cycling of matter in three ecological strata (shallow lotic environments) in the Hondo River basin, and to evaluate the state of maturity and health of the ecosystem, based on several indices derived from the model. Food

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[1] Abbreviations for food-web parameters: biomass (B), production/biomass (P/B), consumption/biomass (Q/B), ecotrophic efficiency (EE), total primary production/total respiration ratio (P/R), connectivity index (CI), system omnivory index (SOI), Finn's cycling index (FCI), mean path length (MPL), ascendency (Asc).

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webs were analyzed by using a trophic model elaborated using EwE vers. 6.1 (Christensen et al., 2005).

2. Material and methods

2.1. Study area

The Hondo River basin is located in southeastern Mexico, northern Belize, and northeastern Guatemala. The basin covers an area of approximately 3598 km^2. The Hondo River main stem spans more than 160 km from its sources in the Guatemalan Petén; it flows into the Bay of Chetumal and forms the border between Belize and Mexico (Magnon-Basnier, 1996).

Sampling points were chosen to represent three ecological strata: Cristóbal Colón stream, upper basin; Aguadulce stream at Sabidos, lower basin; and a shallow part of the main channel of the Hondo River at Juan Sarabia (Fig. 1). Each site was visited in March and June 2010 to obtain representative data of the dry (February–May) and rainy (June–October) seasons. Although the region has three climatic seasons, the cold sason, characterized by low temperatures due to northerly winds (November–January), was not considered, as depth and current are much more important drivers of ecosystem dynamics than temperature in these streams (Schmitter-Soto and Gamboa-Pérez, 1996).

2.2. Model and data

The Ecopath model, first proposed by Polovina (1984), has been developed by Christensen and Pauly (1992) and Walters et al. (1997). The program analyzes the energy flow in the ecosystem in a given time. The model assumes mass balance, i.e. the production of any given functional group is equal to the biomass of that group consumed by predators plus the biomass caught, plus any exports from the system; it is based on the definition of functional groups and food consumption relationships (Fetahi and Mengistou, 2007). Its basic mass-balance equation (Pauly et al., 2000) is:

$$B_i \cdot (P/B)_i \cdot \mathrm{EE}_i = C_i + \sum_{j=1}^{k} B_j \cdot (Q/B)_j \cdot \mathrm{DC}_{ij}$$

where: i is a functional group in the ecosystem at a given time; B_i is the biomass of i during that time; $(P/B)_i$ is the production/biomass rate of i, which equals the mortality rate if equilibrium is assumed; EE_i is ecotrophic efficiency, the fraction of total production of group i used in the ecosystem; $\boldsymbol{C_i}$ is mortality due to fishing (equal to zero in the present work); B_j is predator biomass (j); $(Q/B)_j$ is the food consumption by biomass unit of j; and DC_{ij} is the contribution of i to the diet of j. The equation is balanced so that net production of functional group i is equal to total mortality. Here, for each functional group B, P/B, Q/B, and EE were calculated to generate the balance (Walters et al., 1997; Christensen and Pauly, 1998; Christensen and Walters, 2004). EE was estimated by EwE, given the other parameters. Diet composition of all consumers must be incorporated into the analysis (Christensen and Pauly, 1992).

Informative ecosystem indices included CI, SOI, FCI, MPL, and Asc. CI is the number of realized links divided by the number of possible links in the system (Christensen, 1995); SOI is the variance of the trophic level for the prey groups of a consumer (Christensen and Pauly, 1993); low values of CI and SOI suggest simplicity of the food webs and abundance

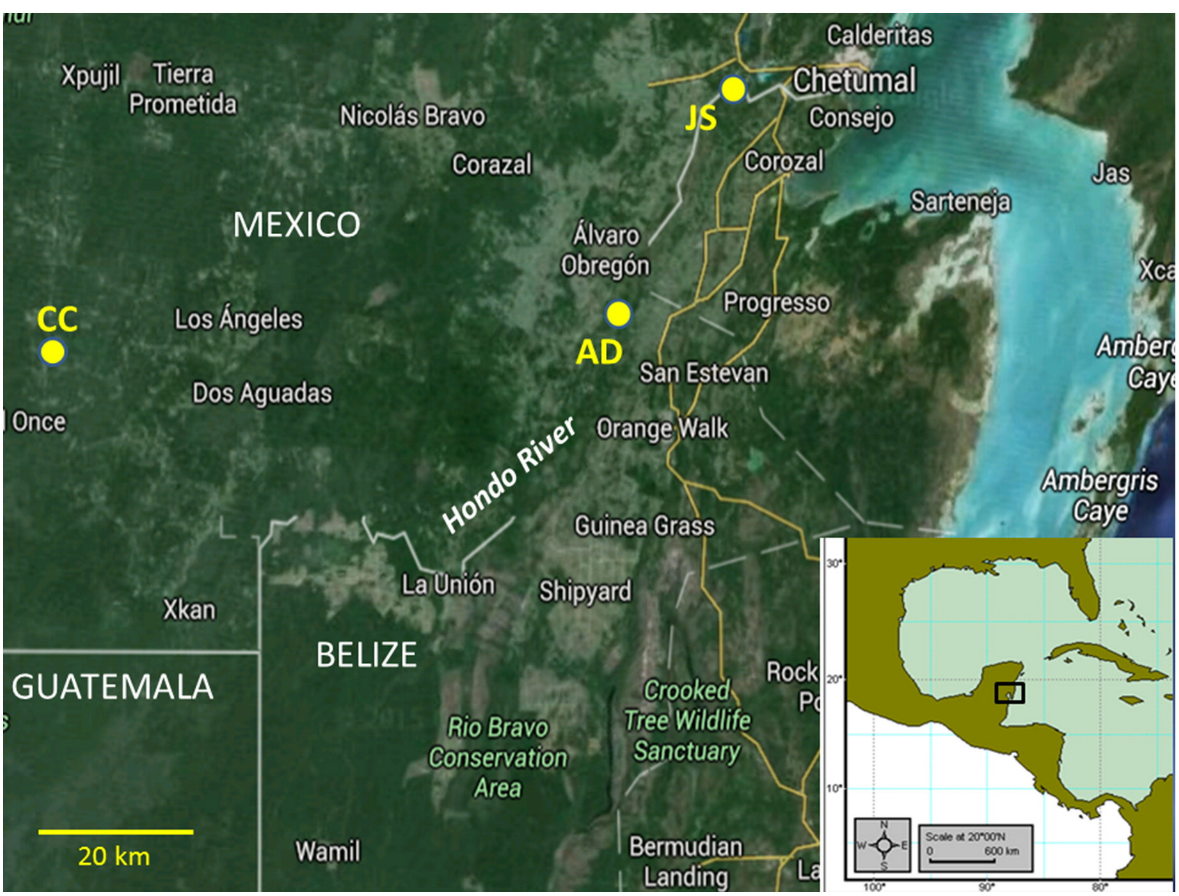

Fig. 1. Sampling sites in Hondo River basin. Only Mexican side illustrated. CC: Cristóbal Colón stream, upper basin; AD: Aguadulce stream, lower basin; JS: main stem of the Hondo River at Juan Sarabia.