TOWARDS A HOLISTIC INDICATOR OF FLOW DISTURBANCE IMPACT: FISH COMMUNITY SIZE SPECTRA

CARLOS ALONSO
JAVIER HERRANZ
JOAQUIN SOLANA
DIEGO GARCIA DE JALON
Dept. of Natural Systems and Resources, Polytechnic University of Madrid, Ciudad Universitaria, S/N 28040 Madrid, Spain

RICHARD NOBLE
Freshwater Fisheries Laboratory, Hull International Fisheries Institute, School of Biological, Biomedical and Environmental Sciences, University of Hull, Hull, HU6 7RX, England

Fish size-spectra provide a simple synthetic metric to assess the effects of pressures on the overall function of river ecosystems. An exploration of the effects of hydrological pressures on this metric is addressed in order to test its sensitiveness as a potential holistic indicator of ecological integrity. A set of 652 sampling sites with individual fish length data were used to compare the size-spectra among unimpaired sites and sites only affected by hydrological pressures. The variation of size-spectra along a gradient of rheophily was also considered. Our results show that size spectra slopes are naturally steeper in rheophilic than in limnephilic reaches. According to this, hydrological alterations produce different responses in the fish community size spectra. Hydrologically impaired rheophilic reaches show an increase in the ecological efficiency (size spectra slope) but a decrease in community capacity (elevation of the size spectra), whereas limnephilic reaches experience a decrease in the ecological efficiency but an increase in the food-web capacity (increased elevation of the size spectra). Slight differences in the type of the hydrological alteration (e.g. water abstraction vs. hydropeaking) might explain these effects.

1 INTRODUCTION

Size spectra (ataxonomic frequency distributions of individual length classes for a multiple species community) provide a simple approach to a generalized description of food-web function, capacity and efficiency [1]. Body size is linked to physiological properties such as production, metabolic rate, reproductive efficiency, and trophic interactions. These links generally produce a roughly log-linearly decrease in the abundance of organisms with increasing body size [2]. Comparison of size spectra among sites can be useful to assess spatial differences in productivity that might be ultimately produced by the impact of environmental changes [3]. The slope of a size spectrum can be viewed as an indicator for food-web efficiency, whereas the elevation of the line can serve as a proxi for food-web capacity [4].

Steeper slopes are expected for impacted than for unimpaired sites [1]. Several recent works have addressed the ability of freshwater fish communities size spectra to asses biotic impacts [3], [4]. An exploratory study of the fish community size spectra as a potential metric for assessing impacts of hydromorphological pressures was conducted within the REFORM Project [5]. Significant differences were found when comparing the size spectra profile of impaired vs. unimpaired fish communities. However, contrarily to what could be expected from the theory on the response of size-spectra to impacts, no significant differences were detected among size-spectra slopes of impacted and unimpaired sites.

It was then hypothesized that this lack of differences among slopes might be due to the result of two counteracting responses to hydromorphological impacts, namely; (1) those driving limnephilic (highly efficient) fish communities in lower reaches (limnephilic) to steeper slopes size-spectra (less efficient) (e.g. hydropeaking); and (2) those rheophilic fish communities towards smoother size-spectra slopes (e.g. water abstraction for irrigation purposes reduce the intensity of both winter peak flows and summer low flows). According to the River Continuum Concept [6] and the Habitat Templet Concept [7],and to Jul-Larsen *et al.* (2003)'s results [8], one may expect to find a theoretically continuous variation of the size spectra slopes towards smoother slopes along the rheophilic-limnephilic gradient.

To test this hypothesis, three subsidiary hypotheses should be tested:

(1) Size spectra of rheophilic fish communities show steeper slopes (lower food-web efficiency) than limnephilic communities.

(2) The effect of hydrological alteration on the fish community size-spectra is different along the rheophilic-limnephilic gradient.

(3) The hydrological pressures differ among upper and lower reaches. Upper reaches are impacted by the dams that are operated by irrigation schemes, which lead to smoother hydrographs (e.g. water abstraction), whereas increased flow variability (e.g. hydropeaking) mainly affects the lower reaches.

2 METHODS

Data from the EFI+ Spanish dataset (EFI+ Consortium, Spanish Team 2009) were used to calculate the size spectra. A total of 1,534 wading electrofishing sampling sites were initially considered. After quality control (removal of partially sampled sites and/or with less than 3 log10(length) classes, selection of sampling occasions in July to October) 652 sites were remaining.

Rheophily was accounted by assigning every site to a Huet (1953) region: lower trout region (metarhithral); grayling region (hyporhithral); and barbel region (epipothamal). Unimpaired sites were selected according to the lack of significant morphological, water quality and hydrological pressures within the river segment (624 sampling sites). Impacted dataset (28 sites) included sites that were only affected only dams upstream, within the river segment. This impacted dataset was rather smaller than the unimpaired set due to the multiple pressure scenarios that generally affect stream reaches. Therefore sites of grayling and barbel regions were merged into a single hyporhithral-epipothamal region.

Total length (mm) of every individual fish was then log10 transformed and classified into 0.1 log10(length) classes. The number of captures at the first electrofishing run (to include sites where only a single pass had been conducted) divided by the sampled area was obtained as a proxi for the density (individuals ha^{-1}) at every site. Fish density of every log10 length class was accounted at every site, and log10(density[individuals ha^{-1}]) transformed. Length classes at the lower and upper end of the range, for which electrofishing surveys are less effective were excluded. Selected length classes ranged $2.1 \leq \log10(\text{length[mm]}) \leq 2.7$.

To test the 1st and 2nd subsidiary hypotheses, the slopes and intercepts of pairs of regression lines fitting the response variable log10(density[individuals ha^{-1}]) were compared by means of analyses of covariance (ANCOVA). The ANCOVA model is a linear model with one continuous predictor (covariate) and one categorical predictor (factor) but focusing on the effects of the factor levels, adjusted for the covariate. To test the 1st hypothesis, the unimpaired subset of sites were fitted to a linear model where log10(length) class is the covariate and the region (trout or grayling+barbel) is the categorical predictor. The 2nd hypothesis was tested similarly but this time fitting separately the subset of sites in every region and remaining the unimpaired or hydrologically altered condition as the categorical predictor. The procedure of these ANCOVA consisted in fitting the most complicated model first (the one that has different slopes and intercepts for each level of the factor), and then simplify it by removing non-significant terms until a minimal adequate model (in which all the parameter are significantly [$p<0.1$] different from zero) is left.

The 3rd subsidiary hypothesis was tested by means of a logistic regression where the probability for an altered site to be located in the trout region is predicted from the type of alteration: hydropeaking or water abstraction. All tests were conducted in R (R Core Team [2015]).

3 RESULTS

There is no indication of any difference in the slope of the relationship between the two regions (this is the region by log10(length) class interaction with t= -0.564, p= 0.573 >> 0.1) in unimpaired conditions. When the non-significant interaction term was deleted from the model, we tested whether or not region had a significant effect on log10(density) once we control for fish region. Removing the region term caused a non-acceptable reduction in the explanatory power of the model, with an F value of 4.04 and a small p value (p= 0.044 *). The effect of region in reducing the intercept (proxi for elevation of the size spectra [community capacity]) is therefore significant and cannot be removed from the model. Consequently, there is not empirical evidence for size spectra slope to significantly vary along the river continuum. However, the community capacity (measured by the intercept of the size spectra for a fixed slope) is slightly (though significantly, $p<0.05$) greater in the trout region than in the grayling+barbel region (Fig. 1[a], [c]).

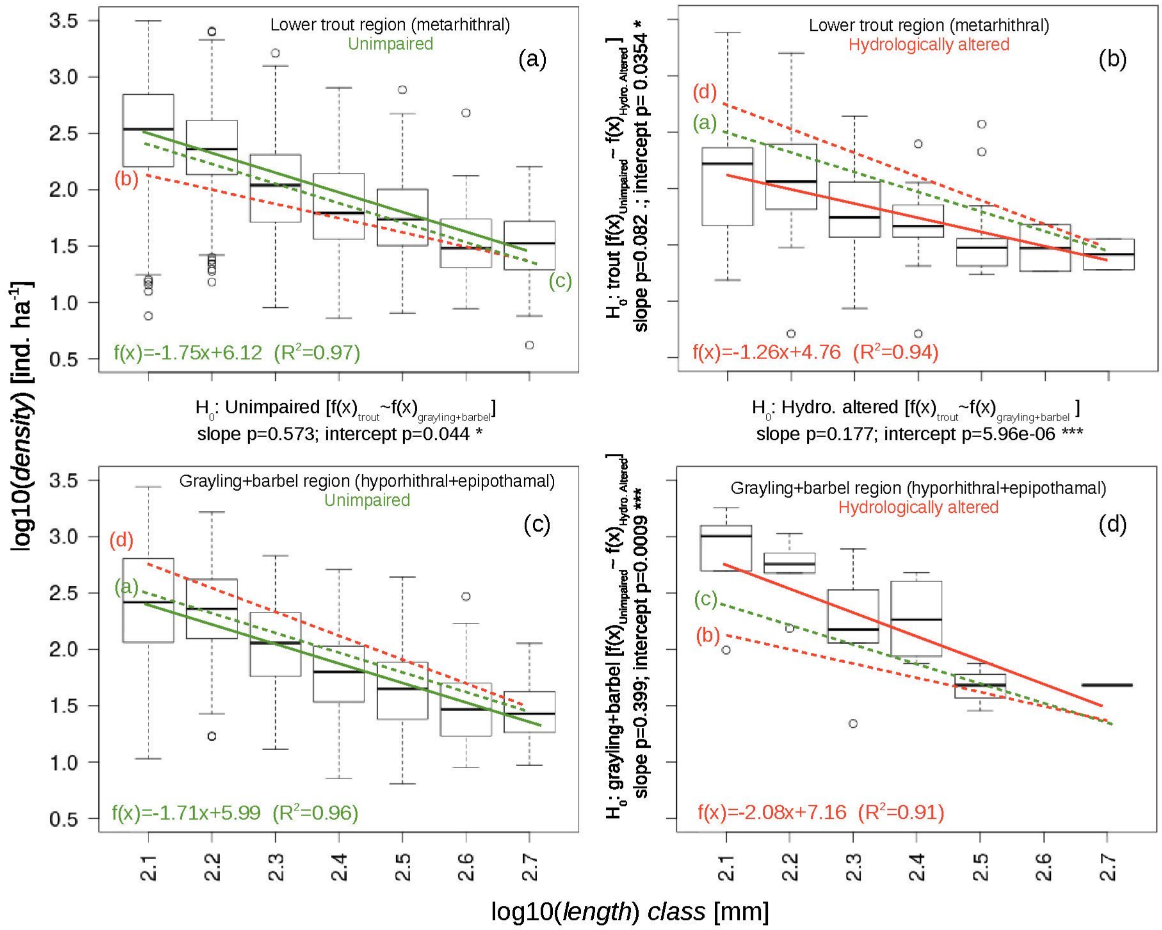

Figure 1. Fish community size spectra at (a) trout region and (b) grayling+barbel region, in unimpaired conditions (green); and in hydrologically altered sites (c) and (d), respectively (red). Dashed lines (size spectra in different conditions) are included to visualize comparisons. Results of the ANCOVA are also included among pairs of compared conditions.

Tests of the 2nd subsidiary hypothesis show that size spectra slopes become significantly smoothened (p= 0.082 .) when comparing linear models between unimpaired (slope= -1.75) and hydrologically altered sites (slope = -1.26) in the trout region. The intercept is also significantly lower (p= <2e-16 ***) in altered conditions, showing that hydrological alteration sensitively reduces the community capacity in the metarhithral region (Fig. 1[a], [b]). This effect is not so clear in the hyporhitral-epipothamal region. There is no significant effect (p= 0.399) of hydrological alteration in the slope, although a steepening is perceived between unimpaired (slope = -1.71) and altered sites (slope= -2.08). However, the effect of hydrological alteration in increasing the intercept (proxi for community capacity) is significant (p= 0.0009 ***) once the effect on the slope is controlled (Fig. 1[c], [d]). Comparison between the two regions in hydrologically conditions show that, although not highly significant (p= 0.177), size spectra slope is steeper in grayling+barbel (slope= -2.08) than in trout region (slope= -1.26). Once controlled the effect of region on the slope, intercept is significantly (p= 5.96e-06 ***) higher in the grayling+barbel region than in the trout region, suggesting an increse in the community capacity along the river continuum in altered conditions.

Test of the 3rd subsidiary hypothesis showed that hydropeaking is associated to grayling+barbel region (estimate= -1.109) whereas water abstraction lays mainly in sites of the trout region (estimate= 0.906), though not significantly (p= 0.248 and p= 0.322, respectively).

4 DISCUSSION

Fish communities size spectra show different response to hydrological alteration along the rheophily-limnephily gradient, although this effect is only significant over 90% level at the trout region (rheophilic). However, there is a significant change of the response of community capacity to hydrological alteration. Under altered flow regimes slopes become smoothened and capacity reduced in rheophilic sites; and slopes steepened and capacity increased in limnephilic sites. This suggest that rheophilic fish communities become artificially more energetically efficient yet less biomass abundant when hydrologicaly altered. Limnephilic communities show the opposite response.

There is no evidence of different size spectra along the rheophily-limnephily gradient in unimpaired but a slight reduction in the capacity (although this lack of differences might be due to the narrow range of this gradient -no upper trout or bream regions- in the studied Iberian rivers). Therefore, the observed different responses can only be due to the slightly different distribution of hydropeaking and water abstraction pressures. Hydropeaking devices artificially increase the intra-annual variability of the hydrographs and are mainly located in the limnephilic region. In the other hand, water abstraction artificially stabilizes the hydrograph, reducing the intra-annual variability. The impacts of these types of hydrological alteration on fish communities seem high enough to change size spectra more intensively than the natural gradient of rheophily-limnephily.

The change of the fish community capacity when comparing unimpaired vs. altered sites is an artificially induced effect on the fish community, and its consequences on the whole biotic community is still to be uncovered. In this context, Murry & Farrell (2014)[4] tested the responses size spectra of a large river fish community to variations in predatory demand and pressures affecting primary production (decreasing total phosphorus and increasing summer water temperature). They found that food-web capacity (i.e. size spectra height) was greatest when total phosphorus was high and the double-crested cormorant population was low, whereas ecological efficiency (i.e. size spectra slope) was not correlated to the measured perturbations.

Although more significant evidences coming from wider range of conditions are needed, size spectra can be considered a promising synthetic and easy-to-measure indicator of the structural and functional integrity of stream biota.

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