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Efficacy of population size structure as a bioassessment tool in freshwaters

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ABSTRACT

Bioassessments are used to measure system health and assess disturbance. While fish-based freshwater bioassessments are cost-effective and perform well in speciose systems, such bioassessments remain difficult to implement in species-poor Mediterranean regions. Population size structure metrics may provide meaningful biological information where depauperate communities preclude the richness and composition measures generally used. We focus our assessments of population size structure responses to anthropogenic perturbation on one of the most widespread native stream fish (*Squalius laietanus*). We explore a number of population size statistics as metrics for a Mediterranean region, where current bioassessments perform poorly. Our sampling encompassed 311 sites across Catalonia (NE Spain) where we characterized anthropogenic perturbation using a summary of impacts, including local data on stream condition and landscape indicators of degradation, via a principal component analysis. Anthropogenic perturbation in streams was collinear with altitudinal gradients and highlights the importance of appropriate statistical techniques. Of the population size structure metrics explored, average length was the most sensitive to anthropogenic perturbation and generally increased along the disturbance gradient. Although we expected to find consistent changes in variance, kurtosis, and skewness, the observed relationships were weak. River basin mediated responses suggest the importance of environmental landscape factors. The unexpected increases of mean *S. laietanus* body size with anthropogenic perturbation, strong effects of river basin, collinearity with spatial gradients and the species-specific nature of responses preclude the direct application of size structure in freshwater bioassessments. Although its application in fish-based freshwater bioassessments appears difficult, population size structure can provide insights in species-specific applications and management.

1. Introduction

Bioassessments provide useful tools to measure aquatic system health and to communicate necessary environmental management to society (Karr and Chu, 1999; Simon, 1999). While fish-based bioassessments have historically performed well in speciose regions, such bioassessments are difficult to implement in species-poor ecosystems (Moyle and Randall, 1998). A shift from community-based measures to population or individual-based measures might improve fish-based bioassessments where there exists insufficient species diversity for the community-based measures. Even while supporting high levels of endemism, fish species-poor Mediterranean regions such as the Iberian Peninsula have had difficulty in implementation of currently used bioassessment indices to assess aquatic health (Benejam et al., 2008). Interestingly, population size metrics were already considered in the initial development of freshwater bioassessments (Karr et al., 1986a,b), but have since been neglected. Population size metrics may provide meaningful biological information where depauperate communities preclude the application of richness and species composition metrics, which are the most frequent in fish-based bioassesments.

Body size is a fundamental characteristic of organisms and arguably the most important trait affecting the ecological performance of individuals (Persson and de Roos, 2007). The implications of body size on growth, mortality and trophic interactions

Abbreviations: AP, anthropogenic perturbation; VP, variation partitioning.

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highlight the importance of size structure for populations (Werner and Gilliam, 1984; de Roos et al., 2003; Savage et al., 2004; Brown et al., 2007). A variety of methods have been proposed relating population attributes such as rates of growth, mortality, and competition strength to population size structure using characteristics such as average size, skewness, hierarchy/inequality, modality, variance and kurtosis (Weiner, 1985; Benjamin and Hardwick, 1986; Hara, 1988; Knox et al., 1989; Walters and Post, 2008). Population size structure has commonly been applied to assessments of vegetation (Deal et al., 2010) and marine communities (Rochet et al., 2010), with very few examples of size-based bioassessments to quantify anthropogenic impacts in freshwater systems (for a few exceptions see Bonar, 2002 and Basset et al., 2012). The disuse of size structure is especially interesting as size structure was mentioned as a health metric in early freshwater bioassessment literature (see Table 2 in Karr et al., 1986a,b), but has not been incorporated. Given the recognized importance of size structure in freshwater populations and assuming that it may be easily affected by disturbances, it seems surprising that modern freshwater bioassessments have completely overlooked size structure in favor of indicators such as species richness, species composition and abundance (see reviews in Karr and Chu, 1999 and Simon, 1999). Richness and composition metrics rely on fish communities as a whole, and may include tolerance estimates for individual species. The community dependence of these commonly used metrics explains their lack of applicability in systems where communities may be limited to small numbers of species and where differences are often due to endemism. While the potential benefits of size structure may be offset in some cases by the costs of measuring individuals, incorporating size metrics could foster bioassessment development in regions with relatively depauperate freshwater faunas such as Mediterranean-climate ecosystems, where the application of current rapid bioassessment indices has proven problematic and difficult to implement (Benejam et al., 2008).

Anthropogenic perturbations impact populations through well documented changes in mortality rates, growth, and behavior resulting from direct and indirect effects, including habitat alteration or loss, physiological stress and changes in resource availability (Richmond, 1993; Gill et al., 2001). These changes can be expected to alter size structure. However, the types of anthropogenic perturbation and their potential effects on size structure are diverse. In addition, different statistics may inform of different aspects of the size structure of a population. Skewness reflects changes in asymmetry (Guttal and Jayaprakash, 2008), variance reflects the spread of the body sizes around the mean, whereas kurtosis is more difficult to interpret because it varies with peakedness, tailedness and bimodality (DeCarlo, 1997). Skewness and variance, although quite different statistics, are often highly positively correlated (Bendel et al., 1989). Maximum size is based on a single individual, so it should be a less robust statistic but might change under mass mortality or conditions that ultimately alter the growth or survival of large fish.

Mean sizes are reflective of all of the individuals in a population, and should exhibit noticeable changes as losses occur, be they in small numbers of extreme sizes or large numbers of common sizes. For example, if populations are strongly affected by a mass fish kill, we could expect mean size to decrease as recruits dominate the population (Haedrich and Barnes, 1997), and increase as the perturbation ceases and the size structure recovers. However, if a disturbance chronically precludes recruitment over time (e.g., siltation of fish spawning habitat), mean length should increase as a few older individuals prevail (Tarr, 2000). Indeed many population size structure patterns might result from anthropogenic perturbation in theory. In practice, we are examining whether any of those patterns are consistent with documented anthropogenic perturbation. A predictable size structure relationship with anthropogenic perturbation would suggest a practical alternative for estimating disturbance impacts.

Here we report an increase in mean length, generally an unexpected pattern in a stream fish species, which might explain the disuse mentioned above. We analyzed the relationship of population size structure as a response to anthropogenic perturbation in the four most abundant fish in NE Spain in order to compare size-structure metrics and inform their possible inclusion in future bioassessments. Our objectives were: (i) to quantify changes in size structure associated with anthropogenic perturbation and (ii) to evaluate the relative utility of each size structure metric. We hypothesized that as a result of anthropogenic perturbation we should expect changes in length frequency distributions reflected in a variety of size metrics such as maximum length, average length, skewness, kurtosis, and variance. We predicted that average length would be the more robust statistic and that the response to anthropogenic perturbation would be species-specific.

2. Materials and methods

2.1. Sampling and study area

We sampled fishes in Catalonia (NE Spain) over two years, from June through October 2007, and from March through September 2008, at 364 sites across the region (Fig. 1), including every official stream water body recognized by the Catalan Water Agency (Agència Catalana de l'Aigua). Each site was sampled once. Of these sites, 311 were successfully fished, 45 were dry and 8 were not fishable at the time of sampling due to flooding. The variation in sampling date did not affect our analyses below (see Appendix A in Supporting Information). The Catalonia region comprises the northeast corner of the Iberian Peninsula over an area of 32,114 km^2. Bordered to the north by the Pyrenees mountain range, the landscape is comprised of larger basins such as the Ebro and Llobregat rivers, corresponding to streams of inland and mountain origin, and smaller littoral basins. Most of the population, around 5.5 of the approximately

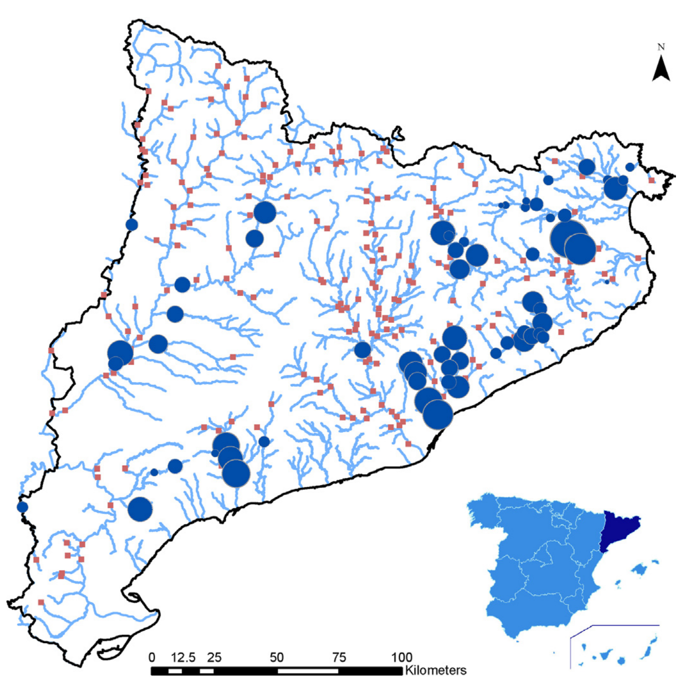

Fig. 1. Location of the study area (Catalonia, NE Spain) and sampling sites (red squares), including sites with *Squalius laietanus* (blue circles, scaled to mean fork length).