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Effects of flow regulation along longitudinal gradient on size-related metrics of fish populations from a Mediterranean basin

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The size structure of fish population can provide insights in species-specific knowledge and a relevant indicator of ecosystem health, which can be used in fish management (Emmrich *et al.*, 2014). The main goal of the present study was to assess the influence of flow regulation on the size structure of fish populations along a longitudinal river gradient. We focused on four fish species widely distributed in the Southern Iberian Peninsula, *Gobio lozanoi* Doadrio & Madeira, 2004, *Alburnus alburnus* (Linnaeus, 1758), *Lepomis gibbosus* (Linnaeus, 1758) and *Luciobarbus sclateri* Günther, 1868, this later being the only native to the area. Some studies reflect changes in mean fork length, size range and size diversity related to of anthropogenic perturbation and land use (Murphy *et al.*, 2013; Benejam *et al.*, 2015). Benejam *et al.* (2016) also showed that fish had smaller sizes in populations downstream of weirs due to the effect of water diversion. In spite of these precedents, there are still few studies relating flow regulation effects on fish size metrics. We hypothesized that flow regulation and the existence of artificial habitat (i.e. artificial fish refuge derived from anthropogenic structures), assist the establishment of the non-native species.

Fish populations were sampled at 29 localities distributed in 8 hydrological sectors with different flow regulation along the longitudinal gradient in the highly regulated Segura River

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basin. Sample sites include three types of stretches in terms of the existence of artificial fish habitat: sectors without flow-related artificial habitats (18 localities), sectors with by-pass refuges related to weirs points (5 localities) and sectors with lentic artificial habitats next to the tail of reservoirs or just downstream of the dams (6 localities). A total of 4825 specimens (1560 *L. sclateri*, 1280 *G. lozanoi*, 1636 *A. alburnus* and 349 *L. gibbosus*) were caught during autumn 2009 and were measured in situ for fork length (FL) and total weight (TW). Size frequency distributions, somatic condition (calculated by residual index Kr, from the regression of log-transformed TW-TL) and population size metrics (number of size classes, size diversity, mean, maximum and minimum sizes, and size range, variance and coefficient of variation) were examined.

The longitudinal river habitat gradient was defined by the first component of a principal component analysis (PCA), which accounted for 85% of the variability of 6 environmental variables (elevation, distance from source, ecological status, riparian quality index, river habitat index and conductivity). Hydrological sectors were also established by means of a PCA applied to water temperature and hydrological metrics (period 1994-2010) (Marsh, 2004). Hydrological metrics included mean daily base flow, flow variability (Q_{10}-Q_{90}), mean of high spell peaks, flow contingency and flow predictability. We analyzed the variability of population size metrics due to hydrological alteration using analyses of covariance (ANCOVAs). Log-transformed size structure metrics of the different species were used as dependent variables in the ANCOVAs, where the longitudinal gradient was the covariate and hydrological sectors (7 levels) and artificial-habitats (3 levels) were the factors.

Sectors representing natural flow condition had an elevated seasonal and annual flow variation, with high flow short-time peaks in the spring and autumn and severe droughts in summer. The PCA showed that some sectors (a group that we named IMPACT 1) showed high contingency (similar inter-years flow patterns) and flow peaks keep along the time. They also showed a reverse flow regime (non-natural), with high flow in summer and low flow in autumn. This impact is directly related with the agricultural water demands and the management of large reservoirs within the basin. Another group of sectors (IMPACT 2) had high flow peaks and temperatures, as well as constant and high flows throughout the year. These fluvial sectors included by-pass stretches where there are daily water diversions to agricultural use.

Flow regulation and the presence of flow-related artificial habitats affected the variability in several size metrics of fish populations (Table 1). *Lepomis gibbosus* and *G. lozanoi* populations showed higher size diversity and larger sizes in sectors influenced by IMPACT 2. *Lepomis gibbosus* attained its maximum sizes in stretches with bypass refuges, where there are flow dispersion and artificial structures to guard against peaks of flow. Size metrics of *A. alburnus* were not affected by the studied factors, although higher somatic condition was observed in populations affected in IMPACT 1 sectors, in which this species with preference for large lakes and fast-flowing rivers (Kottelat & Freyhof, 2007) could be benefitted. The opposite effect was observed on the condition in the individuals of *G. lozanoi*. *Luciobarbus sclateri* had lower mean size and less size classes (due to the absence of large sizes) in the most natural sectors, in agreement with previous studies (Castejón *et al*., 2011).

The regulation of flows by dams affects the structure and functionality of fish assemblages, making easier the establishment of non-native species (Alexandre *et al*., 2013). Our results suggest that flow regulation might be contributing the establishment of the invasive alien fish species. The knowledge about expected size structures of native fish populations under natural flow regime could be used to detect flow disturbances and to improve the design of management programs. For example, an increase of mean length together with a decrease in size classes could be caused by a loss of small sizes, which could be in turn driven by drag effect in areas where high peaks of flow are released. Consequently, the effect of flow regulation on fish

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population structure should be studied further, since it can be a useful tool in the fish population management.

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TABLE 1. Significance of the factors and their interaction included in the ANCOVAs to examine their influence on size structure metrics for the populations of the four studied fish species. Significance levels: *** P< 0.001; ** P< 0.01; * P< 0.05; ms (for marginally significant) P< 0.1

		G. lozanoi	*L. sclateri*	*L. gibbosus*	*A. alburnus*
Mean length	Hydrological sectors	**	**		
	Artificial habitats	*	ms		
	Interaction	*			
Maximun length	Hydrological sectors			***	
	Artificial habitats	*		***	
	Interaction			**	
Minimum length	Hydrological sectors		**		
	Artificial habitats		**	ms	
	Interaction		**		
Size range	Hydrological sectors			***	
	Artificial habitats	ms		**	
	Interaction	ms	ms	**	
Size variance	Hydrological sectors				
	Artificial habitats			*	
	Interaction	ms		ms	
Size CV	Hydrological sectors				
	Artificial habitats			ms	
	Interaction	ms			
Number of size classes	Hydrological sectors	*	*	*	
	Artificial habitats			*	
	Interaction	**	**	*	
Size diversity	Hydrological sectors		ms	*	
	Artificial habitats			*	
	Interaction			*	
Somatic condition	Hydrological sectors	**	*		ms
	Artificial habitats	**			
	Interaction	ms			ms

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