

## Spatial variability in the growth of invasive European barbel *Barbus barbus* in the River Severn basin, revealed using anglers as citizen scientists

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**Abstract** – Life history trait analyses of non-native fishes help identify how novel populations respond to different habitat typologies. Here, using electric fishing and anglers as citizen scientists, scales were collected from the invasive barbel *Barbus barbus* population from four reaches of the River Severn and Teme, western England. Angler samples were biased towards larger fish, with the smallest fish captured being 410 mm, whereas electric fishing sampled fish down to 60 mm. Scale ageing revealed fish present to over 20 years old in both rivers. Juvenile growth rates were similar across all reaches. Lengths at the last annulus and  $L_{\infty}$  of the von Bertalanffy growth model revealed, however, that fish grew to significantly larger body sizes in a relatively deep and highly impounded reach of the River Severn. Anglers thus supplemented the scale collection and although samples remained limited in number, they provided considerable insights into the spatial demographics of this invasive *B. barbus* population.

**Keywords:** recreational fishery / invasion / non-indigenous / somatic growth

**Résumé** – Variabilité spatiale de la croissance du barbeau européen invasif *Barbus barbus* dans le bassin de la rivière Severn, révélé en utilisant des pêcheurs comme des scientifiques citoyens. Les analyses des traits d'histoire de la vie de poissons non indigènes aident à identifier comment les populations nouvelles répondent à différentes typologies d'habitat. Ici, à l'aide de la pêche électrique et des pêcheurs à la ligne en tant que citoyens scientifiques, des écailles ont été recueillies sur des barbeaux, *Barbus barbus*, population envahissante de quatre tronçons des rivières Severn et Teme, dans l'ouest de l'Angleterre. Les échantillons des pêcheurs ont été orientés vers des poissons plus gros, le plus petit capturé étant de 410 mm, tandis que la pêche électrique a échantillonné des poissons jusqu'à 60 mm. La scalimétrie a révélé des poissons présents âgés de plus de 20 ans dans les deux rivières. Les taux de croissance des juvéniles étaient semblables dans tous les secteurs. Les longueurs au dernier annulus et le  $L_{\infty}$  du modèle de croissance de von Bertalanffy ont révélé, cependant, que le poisson atteint des tailles de corps significativement plus grandes dans un secteur relativement profond et fortement endigué de la rivière Severn. Les pêcheurs ont ainsi complété la collecte d'écailles et, bien que les échantillons soient restés limités en nombre, ils ont fourni des indications considérables sur la démographie spatiale de cette population invasive de *B. barbus*.

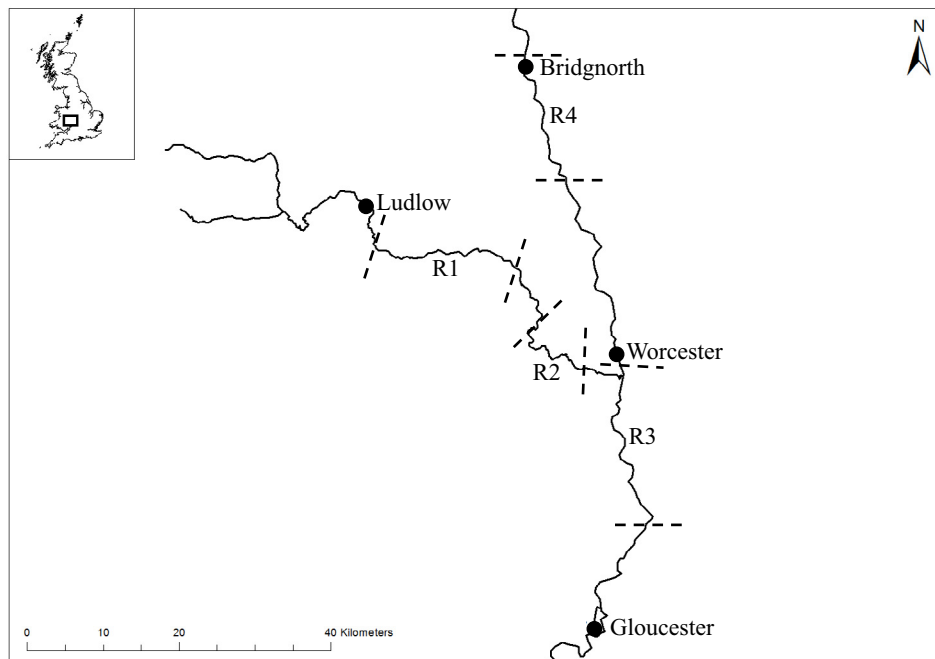
**Mots-clés :** pêche récréative / invasion / non autochtone / croissance somatique

The spatial analyses of life history traits of non-native fishes help predictions of the introduced species that will establish and develop invasive populations in new regions (Davies and Britton, 2015). These analyses also reveal the environmental conditions under which that species can thrive, for example their habitat preferences and thermal tolerances (Rahel and Olden, 2008). Traits such as somatic growth rates can show considerable variation over relatively small spatial

scales, such as within catchments, especially where there has been considerable habitat disturbances caused by anthropogenic activity, such as impoundment (Rypel, 2011).

Invasive fishes are often associated with ecological impacts (Gozlan *et al.*, 2010), although their populations can also support important recreational fisheries (Hickley and Chare, 2004). A strong example is the European barbel *Barbus barbus* where, in Britain, this cyprinid fish is only indigenous to eastern flowing rivers, but has now been introduced for angling into numerous rivers in their non-indigenous range (Wheeler and Jordan, 1990; Antognazza

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**Fig. 1.** *Inset:* Location of the study area within Great Britain. *Main map:* Locations of the upstream and downstream locations of each study reach (R1–R4) on the Rivers Teme and Severn, where the upstream and downstream limits of reaches are marked with dashed lines. A number of important urban areas are also marked (filled circle).

*et al.*, 2016). In the River Severn, western England, 509 adult fish were introduced in 1956 for fishery enhancement (Wheeler and Jordan, 1990). These fish established and dispersed throughout the middle and lower river, with reports in the 1970s of their capture by anglers in the River Teme, a major tributary of the Severn (Hunt and Jones, 1975; Wheeler and Jordan, 1990; Antognazza *et al.*, 2016; Fig. 1). The species has since been an important component of angler catches in both rivers (North, 1980; North and Hickley, 1989; Britton *et al.*, 2013). Whilst there was a series of studies completed on *B. barbus* invasion biology in the River Severn from samples collected in the 1960s (e.g. Hunt and Jones, 1975), there has been limited study of this population since (Britton *et al.*, 2013). This is despite their presence over a wide range of physical habitats, ranging from narrow and shallow sections of the River Teme to impounded, deep and slow flowing sections of the lower Severn.

Citizen science approaches, where volunteers collect and/or process data as part of a scientific enquiry, are being increasingly applied to ecological research (Silvertown, 2009; Bonney *et al.*, 2014), and have been used to supply fisheries data, including catch returns (Post *et al.*, 2002; O'Neill and Faddy, 2003). More recent applications include non-lethal tissue sampling for genetics (Williams *et al.*, 2015; Guindon *et al.*, 2015) and stable isotope analysis (Bašić *et al.*, 2015; Bašić and Britton, 2016). Given the frequent difficulty of obtaining ecological information on *B. barbus* in large rivers using regular sampling methodologies such as electric fishing (Britton *et al.*, 2013), then the use of angling within data collection approaches could provide considerable benefit. Thus, the aim here was to analyse the spatial variability of the age and growth rates of invasive *B. barbus* in the Rivers Severn and Teme utilising scales collected by electric fishing and supplemented by angler catches.

Scales were collected from four reaches of the rivers between 2011 and 2016 (Fig. 1). The spatial separation of the reaches was based on the likelihood of *B. barbus* not moving between them. As adult *B. barbus* are highly vagile (Britton and Pegg, 2011) then each reach was at least 20 km in length (Fig. 1). Reach 1 was the furthest upstream reach in the River Teme, from a small weir at Ashford Carbonell (52°20'07" N; 2°42'14" W) to Stanford Bridge (52°17'24" N; 2°25'14" W) (Fig. 1). Reach 2 was the lower River Teme, from a weir at Knightwick (52°11'57" N; 2°23'22" W) to upstream of a weir of Powick (52°10'11" N; 2°14'49" W). This weir was used as barrier between Reach 2 and 3 as an ongoing tracking study on *B. barbus* suggested it is largely impassable except under high water conditions (C. Gutmann Roberts, unpublished data). Reach 3 started downstream of this weir and continued into the lower River Severn between Diglis Weir (52°10'45" N; 2°13'34" W) and Upper Lode Weir (51°99'41" N; 2°10'13" W), as the tracking study mentioned above revealed *B. barbus* frequently move between both rivers. Reach 4 was in the middle River Severn, between Bridgnorth (52°31'37" N; 2°25'03" W) and Arley (52°24'27" N; 2°20'49" W) (Fig. 1). The physical, flow and chemical parameters of each Reach are provided in Table 1.

Electric fishing was completed in Reach 3 on September 22nd, 2015 from Powick Weir downstream for 500 m, with Reach 1 and 2 electric fished in September 2016. Reach 4 was unable to be electric fished during the study. Following their capture, fish were measured (fork length, nearest mm), and 3–5 scales removed and placed into a paper envelope before the fish were returned to the river. Regarding angling, the Environment Agency has trained a small number of catch-and-release anglers in the River Severn catchment to measure captured fish and collect scale samples in order to assist their fisheries

**Table 1.** Sample sizes by study reach and their altitude (as metres above sea level, MSL), river flow (as  $Q$  values,  $\text{m}^3 \text{s}^{-1}$ ; CEH, 2016), and average score per taxon (ASPT, as a measure of biological water quality), mean concentrations of ammonia ( $\text{mg N L}^{-1}$ ), nitrate ( $\text{mg L}^{-1}$ ) and phosphates ( $\text{mg L}^{-1}$ ) in 2009 (Environment Agency, 2009).

Reach	$n$	MSL (m)	$Q_{10}$	$Q_{50}$	$Q_{95}$	ASPT	$\text{NH}_3$	Nitrates	Phosphates	Mean width	Mean depth (m)
1	37	48	34.9	8.3	1.6	6.1	0.05	20.9	0.05	15	1.0
2	98	21	42.1	10.1	2.0	6.0	0.03	20.1	0.06	15	1.0
3*	88	8	219.0	53.6	15.4	4.9	0.06	22.0	0.24	35	4.0
4	18	17	146.5	36.5	10.7	5.8	0.04	17.4	0.14	25	2.0

\* Data presented for the River Severn section of the reach, rather than the River Teme (Fig. 1).

management activities. Correspondingly, scales were available for angler captured *B. barbus* from each reach. Note these sampling methods did not allow for the sexing of individual fish and so this was unable to be accounted for in subsequent testing of data.

Scales were aged on a projecting microscope, with ageing errors minimised by application of a quality control (QC) procedure (Musk *et al.*, 2006). In the QC, agreement in ages between readers were generally above 80% for fish up to the age of 15 years but were reduced thereafter (48–74%). Thus, in subsequent analyses, only fish to age 15 years were used. Scales were measured for scale radius, distance to last annulus and distance between annulus 1 and 2, with these converted to length at the last annulus and length increment between age 1 and 2 years old by back-calculation (Dahl Lea method; Francis, 1990). Length at the last annulus enabled growth rates over the life time of the fish to be assessed, whilst the increment between age 1 and 2 years enabled assessment of juvenile growth rates (Beardsley and Britton, 2012). Differences in the lengths of the fish sampled by angling and electric fishing were tested using a generalised linear model (GLM), as these data were not normally distributed, with the significance of differences assessed by linearly independent pairwise comparisons with Bonferroni adjustment for multiple comparisons.

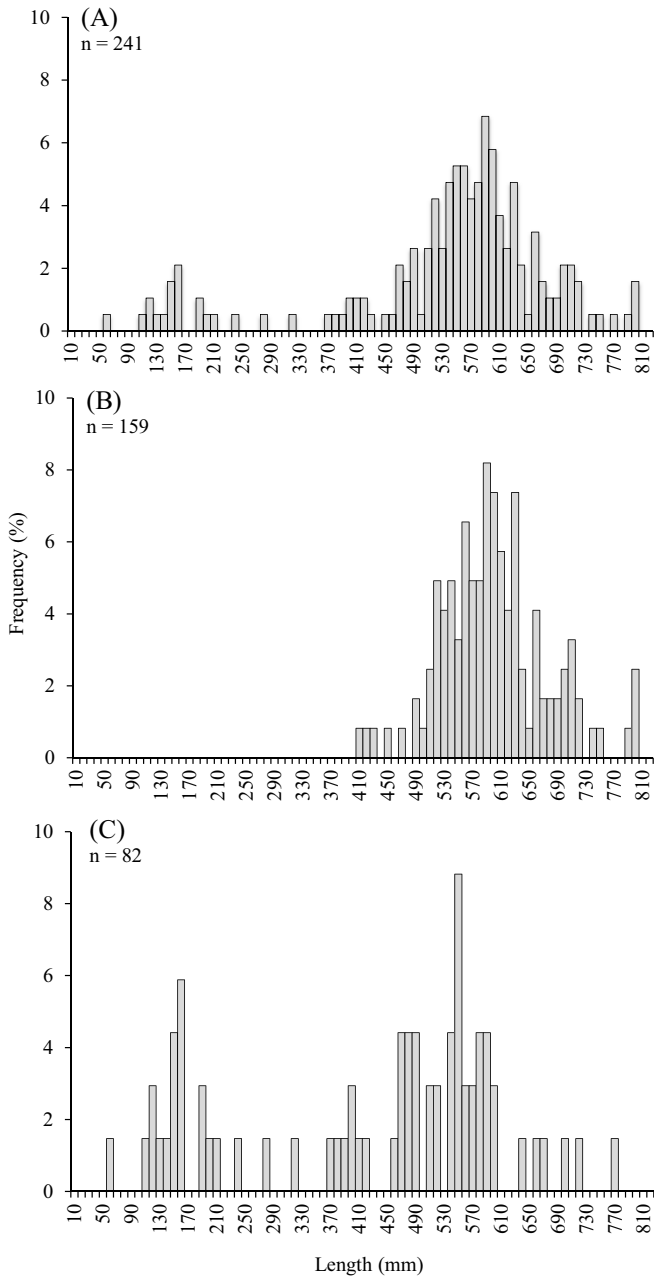
The growth data were analysed by two different methods. Firstly, analyses determined the mean standardized growth residuals for each reach according to lengths at the last annulus and length increment between age 1 and 2 years (Beardsley and Britton, 2012). Only one growth metric value per fish was used in each test to avoid pseudo-replication (Beardsley and Britton, 2012). For length at the last annulus, length at age data for all reaches and fish (age 1–15 only) were used in the log–log quadratic function of Vilizzi and Walker (1999) to determine the mean length at each age. This enabled the standardized residual of each individual fish to be calculated (Beardsley and Britton, 2012), with these then tested between the four reaches using a generalized linear model. Outputs were the mean standardized residuals per reach and the significance of the difference between them according to linearly independent pairwise comparisons with Bonferroni adjustment for multiple comparisons. The same method was then applied to the length increment between age 1 and 2 data, using the mean length increment over the four reaches to determine the standardized residual for each fish. Secondly, the von Bertalanffy growth model was applied to data from each reach to provide values of  $L_{\infty}$  and the

growth coefficient ( $K$ ). This used a two-parameter model of the form:  $L_t = L_{\infty}(1 - \exp^{-Kt})$ , where  $L_t$  was the actual length of each fish at observed age  $t$ ,  $L_{\infty}$  was the asymptotic length (*i.e.* maximum theoretical body size for the population) and  $K$  was the growth coefficient (*i.e.* its annual growth rate to  $L_{\infty}$ , referred to hereafter as the growth rate) and fitted using a nonlinear minimization of the negative log-likelihood of the form:  $-\ln = n \ln \sigma + n/2$ , where  $\sigma = \sqrt{\sum \frac{(L_i - L'_i)^2}{n}}$ , where  $L_i$ ,  $L'_i$  and  $n$  are the respective observed and predicted lengths-at-age, and the number of fish, and provided estimates of each parameter and their 95% confidence limits.

There were 241 fish captured in the study, with the majority captured from Reaches 2 and 3 in 2015 and 2016 (Tab. 1). The length range of fish captured by anglers was 410–800 mm ( $n = 159$ ; mean:  $599 \pm 22$  mm) and by electric fishing was 60–770 mm ( $n = 82$ ; mean  $423 \pm 30$  mm) (Fig. 2), with these length differences significant (GLM: Wald  $\chi^2 = 86.10$ ,  $P < 0.01$ ). Individual fish were aged to at least 20 years old. As fish  $> 15$  years old were omitted from growth rate analyses and some fish were unable to be aged due to all collected scales being regenerated, 189 fish were actually utilised in subsequent analyses.

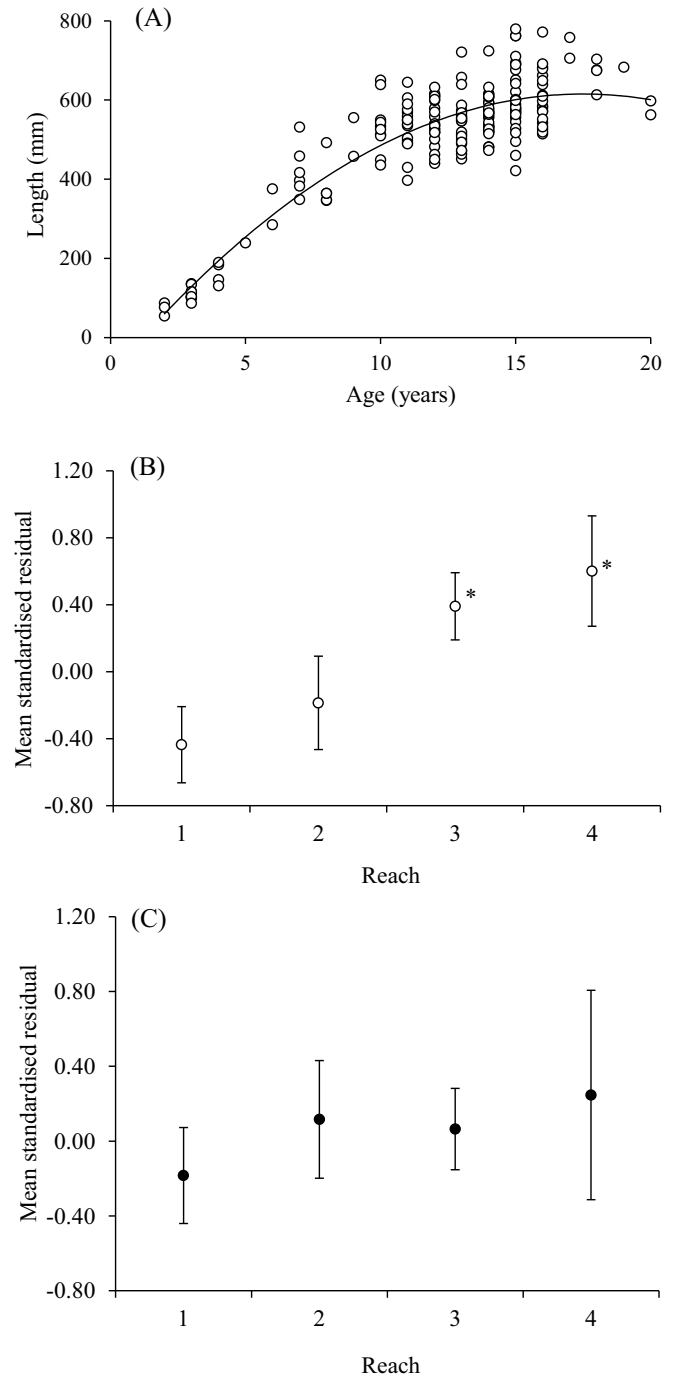
At the individual level, there was considerable variability in the lengths at the last annulus by age (Fig. 3A), with a significant relationship between reach and the mean standardised growth residuals of lengths at the last annulus (GLM: Wald  $\chi^2 = 32.98$ ,  $P < 0.01$ ; Fig. 3B). There was no significant difference between these residuals for Reach 1 and 2, or 3 and 4, but differences were significant between Reach 1/2 *versus* 3/4 ( $P < 0.01$ ; Fig. 3B). In contrast, the relationship between reach and the mean standardised growth residuals for the increment between age 1 and 2 revealed no significant differences (GLM: Wald  $\chi^2 = 3.08$ ,  $P = 0.38$ ; Fig. 3C). The 95% confidence limits of  $L_{\infty}$  of the von Bertalanffy growth model in Reach 3 were significantly and substantially higher than the other reaches (95% confidence limits Reach 3: 821–828 mm, other reaches: 690–729 mm). For  $K$ , there were no significant differences between Reach 1 and 2 (0.12–0.15), and 3 and 4 (0.09–0.11).

These results indicate that the scales contributed by recreational anglers to this study enabled significant differences in the spatial patterns of invasive *B. barbus* growth in this river sub-catchment to be revealed. Moreover, these scales would have been otherwise extremely difficult to collect by alternative methods, either due to fast flows and



**Fig. 2.** Length frequency histograms of: (A) all *Barbus barbus* sampled within this study from all reaches ( $n=259$ ); (B) *B. barbus* sampled by angling; and (C) *B. barbus* sampled by electric fishing.

shallow water (Reach 1 and 2), or very deep water (Reach 4). However, the angler catches were heavily biased towards larger fish and also resulted in relatively small sample sizes. This is important, as studies on the precision of age and growth data have suggested that, in *Argyrozona argyrozona*, 10 fish per 20 mm increments should be collected for high precision (Brouwer and Griffiths, 2005) and for the cyprinid fishes *Rutilus rutilus*, *Squalius cephalus* and *Leuciscus leuciscus*, Busst and Britton (2014) suggested precision of growth data was highest when samples comprised at least 10 fish per 5 mm increment. In the latter study, however, the fishes concerned are all relatively abundant in many lowland



**Fig. 3.** (A) Lengths at last annulus by age of *Barbus barbus* across the study sites (clear circles) and the modelled length at age (black line); (B) mean standardised growth residuals from length at last annulus per study reach, where \* denotes difference of the mean for that reach is significantly different to Reach 1 according to pairwise comparisons in the generalised linear model ( $P < 0.01$ ); and (C) mean standardised growth residuals from length increment between age 1 and 2 years.

ivers, with electric fishing and angling both generally able to provide samples capable of complying with these sub-sample requirements. In contrast, *B. barbus* is a large bodied cyprinid with riverine populations that are far less abundant than many other species. Although Hunt and Jones (1975) did utilise



much larger numbers of *B. barbus* in their age and growth study on Reach 4 in the 1960s, using both electric fishing and angling, this was during a period of rapid population expansion following their introduction, with large numbers of small *B. barbus* (<350 mm) captured by angling. In the current study, these size classes were absent from angler catches and proved very difficult to obtain by electric fishing. Thus, the limited sample sizes of the current study are a potential concern in terms of the precision of the growth data and so should be treated with some caution, but with the caveat that supplementing these samples with greater numbers of fish would be highly challenging.

Despite these inherent issues with sample sizes and fish lengths, the scale samples indicated that individual fish were present in the rivers to at least 20 years old, and potentially older given the inherent difficulties of ageing of large, slow growing *B. barbus* from scales (Britton and Pegg, 2011; Britton *et al.*, 2013). The growth data then indicated that differences in the growth rates of the fish between the reaches were primarily in relation to their adult growth and ability to grow to large body sizes. This suggests that across the four reaches, there were sufficient juvenile habitat and food resources but, thereafter, there was some variability in growth rates, with Reach 3 having fish with the highest  $L_{\infty}$  and lowest  $k$  values, where the river is impounded and relatively deep, with the only areas of fast flowing, shallow, riffle areas being in the lower River Teme and in a weir pool. Despite this contrast with typical *B. barbus* habitat (Huet, 1959; Britton and Pegg, 2011), the largest *B. barbus* captured from the river also tend to be captured from this reach, with individuals up to almost 8 kg in mass. Comparison of the von Bertalanffy growth parameters here to the estimates of Hunt and Jones (1975) also suggested that the fish in the river today grow to substantial larger body sizes but at a slower annual growth rate than in the 1960s. However, these comparisons are only really valid for Reach 4, where the Hunt and Jones (1975) study was completed, and where the sample size for 2011–2016 was very low.

In summary, recreational anglers provided scale samples that had high utility in assessing spatial variability in the growth rates of this invasive *B. barbus* population and revealed the largest individuals were present in the lower impounded section of the River Severn. The results also suggested that when angling is applied to obtain data in this manner, caution is required in relation to the size ranges of fishes they exploit and the sample sizes they can provide.

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