Seasonal Water Level Manipulation for Flood Risk Management Influences Home-Range Size of Common Bream *Abramis brama* L. in a Lowland River

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Abstract

The increased threat of flooding from climate change requires ever greater management of rivers to alleviate flood risk. Although the impacts of river modification on fish communities are well documented, the effects of river management practices on fish behaviour have received relatively little attention. Here, a long-term (4 years) acoustic telemetry study was used to analyse the spatial–temporal behaviour of common bream in a lowland river system (River Witham, Lincolnshire, UK) in which water levels are artificially manipulated biannually as part of a flood storage strategy. Levels are lowered in the autumn and increased again in the spring, to increase in-river winter flood storage capacity. Home-range size varied according to season, with home ranges being larger in the spring and summer months in comparison with those recorded during the autumn and winter months. When water levels within the river system were artificially manipulated, the bream responded by altering their home-range size, increasing it after the levels had been raised and reducing it following the lowering of the river levels. This is in contrast to the cumulative overall distances bream were recorded to travel, which were unaffected by water level manipulation, suggesting water level manipulation did not affect activity levels. Although such changes in behaviour do not necessarily equate to a negative impact on fitness, reduced home-range size brought about by water level manipulation does have implications for habitat availability and the number of competitive, predatory and parasitic interactions encountered.

Introduction

Riverine ecosystems drain water falling on the earth's surface and conduct it to the sea (Welcomme, 1994). These systems are amongst the most human-degraded ecosystems worldwide (Malmquist and Rundle, 2002; Huckstorf *et al*., 2008) with biodiversity threatened by water extraction, flow regulation, channelization and habitat degradation (Welcomme, 1994; Pinder, 1997; Huckstorf *et al*., 2008). Although large lowland rivers support a significant proportion of the world's fish diversity (Huckstorf *et al*., 2008), the majority of these environments, especially in Europe, have been modified through direct interventions that alter river morphology and reduce longitudinal and lateral connectivity (Welcomme, 1994; Cowx and Welcomme, 1998), which have the potential to impact fish populations (Mann, 1988; Junk *et al*., 1989; Welcomme, 1994; Copp, 1997; Hadderingh and Bakker, 1998; Turnpenny, 1998; Buijse *et al*., 2002; Huckstorf *et al*., 2008). Many lowland rivers in Europe are also subject to flow and water level regulation (Buijse *et al*., 2002). The River Witham in Lincolnshire is one such river, which has its levels altered twice yearly as part of a flood risk management strategy.

The effects of river management on fish populations centre around the impacts brought about by changes in river morphology, such as the lack of functional floodplains and associated lateral habitats that are required by fish to complete important stages in their life cycles (Pinder, 1997). However, less emphasis has been placed on day-to-day or seasonal management activities, such as artificial river level manipulation. For example, weed cutting to reduce flood risk through improved conveyance can reduce the density of zooplankton and spawning/nursery habitats (Mann, 1988), which can negatively impact fish growth and abundances (Garner *et al*., 1996). However, there is a general paucity of evidence relating to the impact of routine river management actions on fish behaviour and ecology.

Home-range size (HRS), ‘the area over which an animal normally travels’ (Hayne, 1949), has been observed in many freshwater fishes (Baras and Cherry, 1990; Lucas and Batley, 1996; Clough and Ladle, 1997; Baade and Fredrich, 1998; Clough and Beaumont, 1998; Huber and Kirchhofer, 1998; Allouche *et al*., 1999; Lucas and Baras, 2001; Fredrich *et al*., 2003; Knight *et al*., 2008), including common bream *Abramis brama* L. (Lyons and Lucas, 2002). HRS has also been shown to vary with respect to season (Huber and Kirchhofer, 1998; Allouche *et al*.,1999; Knight *et al*., 2009), turbidity (Kuliskova *et al*., 2009) and available habitat (Woolnough *et al*., 2009). The home-range concept has been applied to the ecological impacts of habitat management on populations (Kavanagh *et al*., 2007; Knight *et al*., 2009), including river corridor fragmentation (Woolnough *et al*., 2009). Here, we use the home-range concept to study the impact of water level management on the behaviour of common bream in the lowland River Witham. The need for increased in-river flood storage capacity dictates that the level of the river is artificially dropped by 0.5 m in the autumn and raised again in the spring. On account of a 4-year acoustic telemetry study (Gardner *et al*., 2013), we were in a position to assess the effects of four episodes of artificial water level elevation and three episodes of artificial water level reduction on HRS. Given habitat size is associated with HRS in fishes (Woolnough *et al*., 2009), we predicted an increase in HRS following the spring rise and a decrease following the autumn reduction in water level. Despite difficulties of interpretation through the presence of confounding variables, river level manipulations on this scale afford a rare opportunity to examine their effects on fish behaviour *in situ* and thus have the advantage of maintaining maximum ecological relevance. To our knowledge, this is the first *in situ* study of this type.

Materials and Methods

Study area

The River Witham, in eastern England, rises near South Witham (52°45′44″N, 0°37′38″W), Lincolnshire, UK, and flows north to Lincoln and then south-east to Boston (52°58′53″N, 0°1′46″W), where it discharges into The Wash. The study area was 40 km of continuous (no barriers) non-tidal lower River Witham and associated tributaries between Short Ferry (confluence of Barlings Eau and the Witham; 53°13′38″N, 0°21′23″W) and the tidal limit (Grand Sluice in Boston; 52°58′53″N; 0°1′46″W). The main channel is trapezoidal and canalized with a depth of 2–4 m at normal summer level with a width of 30–40 m and usually hosts substantial macrophyte growth during the summer months. This uniform man-made channel is managed for the purposes of navigation and land drainage and has been straightened, widened and deepened (Wheeler, 1990) with high levees constructed (Environment Agency, 2008) 3–4 m from the water's edge on both banks (Forbes and Wheeler,1997). The River Witham presents fish populations with a variety of challenges such as poor in-river and marginal habitat, the absence of a functional floodplain, large floodwater discharge and high-flow events in the lower reaches (Environment Agency, 2008), which culminate in the flush-out of fish (Linfield, 1985). The study area is characterized by a typical lowland fish community, dominated by limnophiles such as roach*Rutilus rutilus* (L.) and common bream and also populated by pike *Esox lucius* L., perch *Perca fluviatilis* L., tench *Tinca tinca* (L.), silver bream*Blicca bjoerkna* (L.) and the European eel *Anguilla anguilla* (L.) (Forbes and Wheeler, 1997; Gardner, 2006, 2007; Gardner *et al*., 2013).

River levels are artificially lowered during the winter months to increase the rivers' flood storage capacity. During April–October, the normal river level is maintained at approximately 1.5 m above Ordnance Datum Newlyn (ODN), and from November–March, the level is reduced to and maintained at 1 m above ODN, during dry conditions (Gardner *et al*., 2013). These manipulations are effected on 1 April for spring manipulations, from winter level (1-m ODN) to summer level (1.5-m ODN), and on 1 November for autumn manipulations, from summer level (1.5-m ODN) to winter level (1-m ODN). The timing of these transitions from one stable water level to another is dependent on rainfall events and river flows, and as such, this change is rarely achieved within 24 h. Artificial water level manipulations induce hydrological change by altering water velocity, the wetted area and river width (by ~10 m in the River Witham). Because of the channel's trapezoidal profile, shallow marginal habitats are lost at reduced winter levels, and terrestrial habitats are disconnected from the river channel, thus devaluing the littoral zone for fishes and other wildlife.

Sampling and tagging procedures

Eighty-three adult common bream with a mean ± *SD* (range) fork length of 485.6 ± 16.8 mm (440–522 mm) and mass of 2.37 ± 0.25 kg (1.92–2.94 kg) were caught from the study area in seven groups by electrofishing (240 V, 4/5 A, pulsed direct current), rod and line or seine netting. Vemco (Nova Scotia, Canada) V9-2L-R64K & 256 and Vemco V13-1L coded acoustic tags (operational life of 80–330 and 526–621 days, respectively) were implanted into the peritoneal body cavity (tag weight in air represented 0.16–0.57% of the fish's weight out of water), a procedure regulated and licensed in the UK by the Home Office under the Animals (Scientific Procedures) Act 1986 (project licence number PPL 80/2016). Tagged fish were collectively released at the site of capture (Gardner *et al*., 2013).

The location of tagged fish was determined via automatic data logger receivers (VR2 and VR2W, Vemco) that were positioned in the channel margins maintained at approximately mid-water depth (Gardner *et al*., 2013). Receiver coverage increased as the study progressed, starting with seven, at the beginning of the study in November 2006, and increasing to 26 by April 2008 (Gardner *et al*., 2013). *In situ* range tests identified that V9 tags were detected up to ~200 m and V13 tags up to ~400 m. These different detection ranges were not thought to have influenced the patterns observed given the relatively coarse resolution of the tracking, with fixed receivers positioned 2–3 km apart. Data from the receivers were regularly downloaded onto a laptop computer using VR2PC and VUE (Vemco) software packages (Gardner *et al*., 2013). River levels were gauged by stilling well at Kirkstead bridge (53°8′35″N, 0°14′36″W), approximately midpoint of the study area, by The Environment Agency hydrometry and telemetry systems.

Data handling and statistical analysis

The distance (km) of each receiver (and thus fish recorded on the receiver) from the tidal limit (the point where the tidal cycle ceases to influence upstream water level) at Boston was measured using ArcMap (v9.1 Geographic Information System, ESRI Ltd, Redlands, CA, USA), allowing the location of individual fish to be determined. Tributary receivers were allocated the kilometre value measured to the mouth of the tributary (Gardner *et al*., 2013).

The calculation of HRS from fixed receiver data followed the approach of Crook (2004). Total linear ranges were estimated by determining the distance along the river channel between the outermost location coordinates for each individual fish (Young, 1999; Ovidio *et al*., 2000) to give the 100% HRS. In addition, 90% HRS, which is suggested to provide a better indication of the core habitat size regularly used by each fish as rare excursive movements are excluded (Hodder *et al*., 1998; Knight *et al*., 2008), were estimated for each fish by calculating the minimum linear distance containing 90% of the observed locations of each individual fish (Crook, 2004). The spacing of acoustic receivers can also affect the spatial resolution of data. As receivers were spaced by 2–3 km, the spatial resolution might be compromised as some fish might travel past a receiver (and be detected), but not sufficiently far upstream or downstream to be detected by the next receiver. Others may also venture beyond the outermost receivers. However, temporal resolution will be complete as receivers operate continuously. HRS was calculated on seasonal and monthly basis and for 10-day periods before and after water level manipulations (as discussed later). Only fish that had 100 or more locations (detections) in the sampling period (e.g. season, month and 10-day pre-level and post-level manipulations) were included in the analysis. Where data were combined on a seasonal basis, seasons were defined as follows: spring (21 March–20 June), summer (21 June–20 September), autumn (21 September–20 December) and winter (21 December–20 March).

To investigate the effects of water level manipulations on fish behaviour, HRSs were calculated for individual fish during a 10-day period pre-artificial and post-artificial water level manipulations. To assess if fish activity levels differed during these same 10-day periods, total distance moved, calculated as the cumulative distance moved between receivers by an individual fish, was determined. Seven water level manipulations occurred during the study, four elevations and three reductions. Manipulation from one stable water level to the resultant stable level often took a number of days (e.g. autumn 2007 took 5 days and spring 2008 took 18 days because of a rainfall event, Figure 1). In these cases, 10-day sampling periods were selected as near to the point of level change as possible to capture periods of stable water level pre-level and post-level manipulations (i.e. excluding the period of transition, Figure 1). During three water level change events, significant rainfall obscured changes; thus, transition periods of 18, 24 and 8 days respectively were imposed (Table 1). The number of tagged fish experiencing the spring manipulations was greater than that experiencing the autumn manipulations, as firstly, there were more spring events during the study and, secondly, because fish were tagged during the winter season and tags had a limited life, therefore, many tags had expired or fish had left the study area by the time autumn manipulations occurred. Details of the numbers of fish used to generate HRS calculations and the number of days between 10-day home-range calculation periods are given in Table 1.

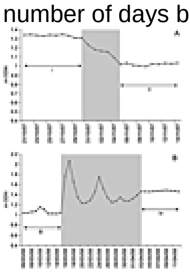

Figure 1. Water level (metres above Ordnance Datum Newlyn, m ODN) recorded at Kirkstead Bridge (midpoint of study area) during two of the seven artificial water level manipulations, illustrating the periods of flux in levels when changes are made and the selection of 10-day sampling periods before and after level manipulations. (A) Level manipulation in autumn 2007 (summer level to winter level), 5 days between sampling periods due to level flux, (i) 10-day sampling period pre-manipulation and (ii) 10-day sampling period post-manipulation. (B) Level manipulation in spring 2008 (winter level to summer level), 18 days between sampling periods due to rainfall events, (iii) 10-day sampling period pre-manipulation and (iv) 10-day sampling period post-manipulation. Shaded areas represent periods of transition

Level manipulation	**Number of fish used in 10-day home-range calculations (before pseudo-replication preventative averaging of results had occurred)**	**Number of days between 10-day home-range calculation periods**	**Reason for gap be 10-day sampling p**
Spring 2007	3	7	Natural runoff
Autumn 2007	10	5	Natural runoff
Spring 2008	19	18	Rainfall
Autumn 2008	12	24	Rainfall
Spring 2009	33	0	—
Autumn 2009	4	8	Rainfall
Spring 2010	5	0	—

Table 1. The number of individual fish and the number of days between 10-day home-range calculation periods used to determine the eff seven independent artificial water level manipulations

Differences in HRS between all seasons and months and gender differences were analysed with general linear model analysis of variance (GLM ANOVA) with *post hoc* Tukey tests used to identify differences between seasons. Differences between adjacent months were analysed with two sample *t*-tests (significance level of 0.004 following Bonferroni correction), as datasets were made up from months in different years during the study when different fish were being tracked. Differences between the home ranges and total recorded distance moved in 10-day periods before and after artificial water level changes were possible using data from the same individual fish tracked before and after level manipulations and were therefore analysed with paired *t*-tests (significance level of 0.008 following Bonferroni correction). For these analyses, by using paired data, individual fish that were tracked during spring and autumn level manipulations in different years were identified, and an average of results was taken to avoid pseudo-replication. This reduced the sample size at spring manipulations from 60 to 56 and during autumn manipulations from 26 to 24. The relationship between mean monthly HRS and mean 'monthly distance' moved (Gardner *et al*., 2013) was analysed with Pearson correlation. All means are given ±1 standard error.

Results

A dataset of over three million fish detections was collected. Individual fish were tracked from 40 to 629 days (mean = 266.0 ± *SD* = 146.7). Some tagged fish left the study area, being last detected at possible exits from the study area, but not all fish returned. Data for those fish that did not return were included in the analysis up to the point at which they were last detected within the study area (Gardner *et al*., 2013).

Home-range size

A two-way ANOVA on square root-transformed data (to normalize the data) revealed a significant effect of season on both the 100% HRS (GLM ANOVA, $F_{3,\,307} = 18.00$, $p < 0.0001$) and 90% HRS (GLM ANOVA, $F_{3,\,307} = 10.74$, $p < 0.0001$) with fish tending to have smaller HRSs in the autumn and winter months (Figure 2). Male fish had marginally larger 100% seasonal HRSs than female fish (mean HRS male fish = 10.59 ± 0.65, female fish = 8.91 ± 0.72; $F_{1,\,307} = 5.10$, $p = 0.024$), although this was marginally non-significant when 90% HRSs were analysed (mean HRS male fish = 6.51 ± 0.50, female fish = 5.49 ± 0.54; $F_{1,\,307} = 3.13$, $p = 0.078$). There was no interaction between month and sex for either the 100% or 90% HRS ($F_{3,\,304} = 0.39$, $p = 0.76$, and $F_{3,304} = 0.18$, $p = 0.93$, respectively). A *post hoc* Tukey test ($p < 0.05$) revealed spring and summer home ranges to be equivalent as were autumn and winter home ranges, for both 100% and 90% estimations. A similar analysis of monthly HRS (square root-transformed) data revealed both 100% and 90% HRS to vary with month (GLM ANOVA, $F_{11,\,682} = 17.08$, $p < 0.0001$, and $F_{11,\,682} = 11.09$, $p < 0.0001$, respectively; Figure 3), with HRS consistently larger from April to October than during the winter months. There was a significant effect of gender on both the 100% monthly HRS (male = 6.67 ± 0.32, female = 5.87 ± 0.37, $F_{1,\,682} >= 7.04$, $p = 0.008$) and the 90% monthly HRS (male = 4.38 ± 0.26, female = 3.58 ± 0.27, $F_{1,\,682} = 6.44$, $p = 0.01$), but no interactions between month and sex for either HRS estimate ($F_{11,\,671} = 0.51$, $p = 0.89$ and $F_{11,\,671} = 1.07$, $p = 0.38$, respectively). Monthly HRS and 'monthly distance' (bream activity; Gardner *et al*., 2013) were found to correlate for both 90% (Pearson correlation, $r = 0.611$, $df = 695$, $p < 0.0001$) and 100% (Pearson correlation, $r = 0.693$, $df = 695$, $p < 0.0001$); in effect, fish had larger HRSs when activity levels were high.

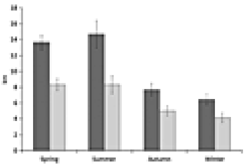

Figure 2. Mean seasonal 100% (dark grey) and 90% (light grey) home ranges (±*SE*) for common bream in spring (*n* = 92), summer (*n* = 32), autumn (*n* = 86) and winter (*n* = 98)

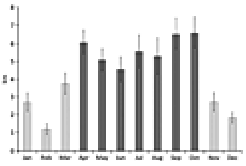

Figure 3. Mean 90% home ranges (±*SE*) for common bream in January (*n* = 75), February (*n* = 79), March (*n* = 98), April (*n* = 89), May (*n* = 83), June (*n* = 47), July (*n* = 29), August (*n* = 21), September (*n* = 19), October (*n* = 44), November (*n* = 40), December (*n* = 72). Months during winter level retention period are coloured light grey, and months during summer level retention period are coloured dark grey

Effects of artificial water level manipulations

During spring manipulations (winter level increased to summer level), both 100% and 90% 10-day home ranges for individual fish increased significantly (paired *t*-test, $t = 5.45$, $p < 0.0001$; $t = 4.93$, $p < 0.0001$, $df = 55$, respectively), with home ranges being significantly larger following the artificial increase in water levels. During autumn manipulations (summer level decreased to winter level), 100% and 90% 10-day home ranges for individual fish decreased significantly (Figure 4; paired *t*-test, $t = 5.00$, $p < 0.0001$; $t = 3.85$, $p = 0.001$, $df >= 23$, respectively).

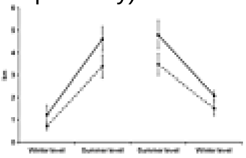

Figure 4. Mean 100% (solid symbols, solid line) and 90% (open symbols, broken line) home ranges (±*SE*) for individual common bream tracked during the 10 days before and after artificial water level manipulations. Level manipulations occurred biannually in spring (*n* = 56; winter level to summer level) and autumn (*n* = 24; summer level to winter level)

These 10-day differences were also reflected in monthly differences (Table 2). Thus, between March and April, when water levels were increased, HRS increased. Generally, there were no such increases in HRS detected between months either side of spring level manipulations, with the exception of February and March. However, there was no significant increase in HRS between April and May. Also, in the autumn, when water levels were reduced, there was a significant decrease in HRS between October and November. No such decrease in HRS was detected between the months preceding this, September and October, nor the months following, November and December.

Home-range estimate	Spring water level manipulation	Autumn water level manipulation

			February–March	**March–April**	**April–May**	**September–October**	**October–November**	**Novembe Decembe**
100%	Mean home ranges		2.55–5.32	5.32–9.55	9.55–9.55	10.26–10.41	10.41–3.74	3.74–3.1
		t	−3.28	4.00	1.70	0.11	6.11	0.90
	t-test results	*df*	162	172	164	47	71	79
		p	0.001*	<0.0001*	0.091	0.914	<0.0001*	0.373
90%	Mean home ranges		1.17–3.75	3.75–6.07	6.07–5.10	6.54–6.60	6.60–2.71	2.71–1.8
		t	−3.95	4.00	1.10	0.05	3.94	1.49
	t-test results	*df*	134	172	167	50	71	74
		p	<0.0001*	<0.0001*	0.271	0.960	<0.0001*	0.140

- Levels are manipulated biannually in spring (1 April) and autumn (1 November).
- *

Significance at <0.004 following Bonferroni correction.

Table 2. Two sample *t*-test results for adjacent month pairings around artificial water level manipulations

During spring manipulations (winter level to summer level), the total recorded distance moved by individual fish during the 10 days before and after artificial water level manipulations was marginally non-significant (paired *t*-test, $t = 1.97$, $df = 55$, $p = 0.054$), whereas the total recorded distance moved before and autumn manipulation (summer level to winter level) was statistically equivalent (paired *t*-test, $t = -0.09$, $df = 23$, $p = 0.929$; Figure 5). Thus, changes in water level significantly affected HRSs but did not statistically affect activity.

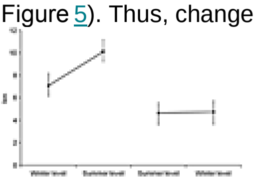

Figure 5. Mean total recorded distance moved (±*SE*) for individual common bream tracked during the 10 days before and after artificial water level manipulations. Level manipulations occurred biannually in spring ($n = 56$; winter level to summer level) and autumn ($n = 24$; summer level to winter level)

Discussion

Home-range size

Home-range sizes varied with season, being larger during the spring and summer months in comparison with the autumn and winter months. Mean monthly home-range estimates also correlated with mean ‘monthly distance’ moved, as a measure of fish activity (Gardner *et al*., 2013), indicating that during the warmer summer months when bream were more active, they also occupied larger home ranges. This is consistent with other studies of cyprinids in temperate riverine ecosystems (Huber and Kirchhofer, 1998; Allouche *et al*., 1999). These activity patterns are most likely the result of reduced metabolism by poikilothermic animals during the winter (Wieser, 1991; Huber and Kirchhofer, 1998). The HRSs observed here were larger than those reported elsewhere for bream (Langford, 1981; Lyons and Lucas, 2002). However, this is likely to be an artefact of physical barriers within the study areas limiting the maximum home range possible (also Woolnough *et al*., 2009) and the duration of study, which may also result in differences in HRS; the longer the study, the further fish are likely to travel.

Effects of artificial water level management

Water level changes affected HRSs; when levels were reduced in the autumn, HRS decreased, whereas in the spring, when levels were increased, HRS increased. Water level manipulations occurred during the spring and autumn seasons when fish metabolism is increasing and decreasing, respectively (Wieser, 1991). Thus, changes in HRS could reflect seasonal differences in bream activity and not a consequence of changes in water level. However, water levels change over a relatively short period, so the differences observed are unlikely to be related to seasonal changes in photoperiod or temperature. Activity levels of bream before and after water level manipulations, measured as total recorded distance moved, were statistically equivalent, although this was marginal in the spring, which may reflect an increase in bream activity in April (Gardner *et al*., 2013). This suggests that the differences in HRS before and after water level manipulation were not an artefact of differences in activity, although with this experimental protocol, it is possible that differences in HRS could reflect seasonal changes in biotic factors such as prey availability. Thus, to ascertain cause and effect of water level manipulation on HRS requires experimental control of water level manipulation throughout the year.

Although the impacts of river channel modification are well documented (Gregory, 2006), this is the first account of a flood risk management practice to affect fish behaviour. However, changes in behaviour do not necessarily equate to a negative impact on fitness, although reduced HRS does have implications for habitat availability and the number of competitive, predatory and parasitic interactions encountered (Woolnough*et al*., 2009).

Woolnough *et al*. (2009) performed a meta-analysis of 71 studies from 66 species of fish from around the world, showing that home-range estimates increased with body size and available water environment size. Water level manipulation of the River Witham reduced the volume of the water body; river width is reduced by ~10 m (~25%) and depth by 0.5 m, equating to a ~12% reduction at the downstream limit of the study area and a ~25% reduction at the upstream limit. Our study lends support to the notion that HRS is constrained by the extent of the available habitat (Woolnough *et al*., 2009). However, within our study, the length of the linear habitat remained unchanged; thus, differences in HRS appear to arise as a result of volumetric changes in the amount of habitat.

The lower River Witham is a heavily modified lowland river having been straightened, channelized and disconnected from its floodplain by artificial levee construction. Restoration of the floodplain has been shown to benefit fish communities (e.g. Grift *et al*., 2001) as such schemes allow river levels to behave more naturally, increasing the size and value of the aquatic–terrestrial ecotones. However, financial constraints and other anthropogenic considerations dictate that floodplain restoration of lowland rivers is often unrealistic (Buijse *et al*., 2002). Thus, more achievable management actions aimed at increasing the value of existing habitat types to fish populations are required. The seasonal manipulation of water levels to increase in-river flood storage capacity appears to be a historic practice. Therefore, river managers should carry out hydrological modelling to investigate if such actions really do benefit flood risk mitigation. If the practice is ineffective against flood risk mitigation, there is reason to discontinue such practice, as more natural river discharge and water level patterns will help maintain the natural biological community. Retaining the River Witham at summer levels throughout the whole year would increase the depths of tributaries during the winter, making them more accessible to common bream and other fishes during periods of cold weather and high main channel flow for overwintering and refuge (Gardner *et al*., 2013). Alternative strategies should be researched; rather than historical seasonal manipulation, levels could be lowered on an ad hoc basis before forecast rain events, thus minimizing behavioural impacts on resident fishes. On the River Witham, some preliminary modelling has taken place, which suggests that although there are implications for flood risk should the river be retained at the summer level all year round, mitigation against this increased risk may be straightforward, although a more detailed investigation is required (J. Brown, Environment Agency, personal communication). Although there are a number of conflicting interests surrounding the water level management of the lower River Witham, the principle of a more natural water level has gained support because of potential benefits to fisheries and wider riverine ecology and as such is being investigated within the context of the draft Lower Witham Catchment Management Plan, which aims to meet Good Ecological Status/Potential as stipulated by the European Union Water Framework Directive 2000/60/EC. We recommend that other affected catchments follow a similar strategy. Further to this, there is also involvement from The Environment Agency's National Capital Programme Management Service due to the potential need for the amendment of a parliamentary act if the current water level management of the lower River Witham were to be altered (Dr H. Barber, Environment Agency, personal communication).

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