

1 **Rapid visual assessment of spawning activity and associated habitat utilisation of**  
2 **sea lamprey (*Petromyzon marinus* Linnaeus, 1758) in a chalk stream: implications**  
3 **for conservation monitoring**

4

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24 **Introduction**

25

26 The anadromous sea lamprey (*Petromyzon marinus* L.) has a native geographic range  
27 extending across the Northern Atlantic, colonising the rivers of countries abutting  
28 coastal shores between Labrador, Canada to Florida in the West (Renaud 1997) and  
29 from Norway into the western Mediterranean to the East (Kottelat & Frehof 2007).  
30 Beyond its native range, the species has capitalised on the anthropogenically-engineered  
31 connectivity between the West Atlantic and the Great Lakes (Hartman 1972). In this  
32 extended range, it is invasive and considered a pest (Smith and Tibbles 1980). In its  
33 native range, however, their populations are in general decline through factors including  
34 river fragmentation, habitat loss and declining water quality (Renaud 1997; Almeida et  
35 al., 2002; Maitland et al., 2015). Correspondingly, it has conservation designations  
36 under Annex II of the EU Habitats Directive (Directive 92/43/EEC). These designations  
37 require their populations to be monitored regularly and conservation status evaluated.

38 The monitoring of *P. marinus* populations currently focuses on the cryptic, relatively  
39 sedentary and extended (~5-6 years) life stage of the ammocoetes (larvae) and thus  
40 attempts to quantify recruitment success and nursery mortality in these early life stages  
41 (Harvey and Cowx 2003; Quintella et al., 2003). Data validity, however, remains  
42 sensitive to the confidence associated with preferred microhabitat utilisation; most  
43 studies have focused in water depths below 1m (e.g. Malmqvist 1980; Potter et al.,  
44 1980; Beamish and Jebbink 1994; Beamish and Lowartz 1996; Almeida and Quintella  
45 2002; Sugiyama and Goto 2002; Torgersen and Close 2004; Lasne et al., 2010) yet the  
46 recent development of habitat utilisation curves suggests marked preferences for deeper  
47 nursery habitats (> 2m; Taverny et al., 2012). Moreover, there is little attention on their  
48 adult life-stages, despite the number of returning adults being potentially important for

49 the subsequent numbers of ammocoetes (Quintella et al., 2003). Whilst this may be  
50 understandable when the adults are at sea, their presence in freshwater potentially  
51 provides valuable monitoring opportunities that would provide complementary  
52 population level data, such as adult numbers, nest counts and upstream migration  
53 distances.

54

55 Consequently, the aim of this study was to utilise the *P. marinus* spawning migrants  
56 of an English chalk stream to provide initial assessments of (i) the value of nest counts  
57 as a population and conservation monitoring tool; (ii) distances moved upstream to  
58 spawn and in relation to potential blockages to migration; and (iii) identify the habitat  
59 utilisation of spawning adults. The value of these data are then discussed within a  
60 conservation context.

61

## 62 **Materials and Methods**

63

64 The study was completed in summer 2014 in the River Frome, a relatively small chalk  
65 river (48 km in length) in Southern England that rises in the Dorset Downs at Evershot  
66 and drains into Poole Harbour (Fig. 1). River widths are rarely greater than 15 m and  
67 depths rarely above 2 m depth.

68

69 Spawning of adult *P. marinus* in the river commenced in May and concluded in late  
70 June. At its conclusion, intensive observations on the numbers and spatial distribution  
71 of *P. marinus* nests were completed between 1<sup>st</sup> and 7<sup>th</sup> July through direct observations  
72 completed by surveyors with high experience in salmonid redd counting. Surveys  
73 comprised of walking along the top of the river bank, starting at the river's tidal limit

74 and continuing until the upstream limit of nest distribution was confirmed by extending  
75 the survey 3 km beyond the location of the last nest, which also incorporated two further  
76 potential instream barriers. During this period, river conditions were of low flow and  
77 high water transparency, and nest identification was assisted by surveyors wearing  
78 polarised sun-glasses. This meant the majority of nests were identified without the  
79 requirement to enter the river channel. On identification of each nest, its precise location  
80 was recorded using a hand-held GPS (Garmin 60 CSx), with nest dimensions (length  
81 and width) estimated to the nearest 0.1 m. These locations were used to calculate the  
82 distance of each nest from the tidal limit. Data on river discharge ( $\text{m}^3/\text{s}^{-1}$ ) and water  
83 temperature ( $^{\circ}\text{C}$ ) data were also available from an automated gauging station weir  
84 ( $50^{\circ}40'51.73''\text{N } 2^{\circ}11'20.97''\text{W}$ ) where recordings were taken every 15 minutes. These  
85 data were used to assess their influence in the timing of the upstream spawning  
86 migration.

87 Quantitative characterisation of spawning site selection and nest structure was  
88 conducted on 1<sup>st</sup> and 4<sup>th</sup> July 2014, with a sub-sample of 44 individual nests examined.  
89 Geo-referenced nests, which had been vacated by adults, were subject to the following  
90 measurements: Depression length (dL); Depression width (dW); water depth at  
91 upstream lip (usD); maximum water depth of depression (maxD); water depth at  
92 downstream lip (dsD); and excavation depth (DE). To characterise the ambient habitat  
93 in which spawning sites were selected, the following measurements were recorded one  
94 metre upstream of the leading edge of each nest: mean water column velocity (mV);  
95 mean column water temp (mT); and water depth (Dus). To explore any potential stimuli  
96 for spatial spawning site selection, water temperature was also recorded within the  
97 interstitial gravel of each nest. All length measurements were recorded using a metal  
98 rule (1m) to the nearest cm. Water velocity was recorded using an impeller flow meter

99 (Valeport 002) with  $\text{cm/s}^{-1}$  averaged over 30 seconds. Temperature was recorded using a  
100 hand held digital probe (Sper Scientific 800007). Excavated stones deposited at the tail  
101 of each nest were then measured without physical disturbance, achieved by placing the  
102 metal rule flush with the riverbed and the use of an underwater video camera (GoPro  
103 Hero 3) that collected 30 seconds of high definition video footage. Each video clip was  
104 then subsequently analysed on screen with the maximum axis dimension of a sub-  
105 sample of 10 stones measured using digital callipers, calibrated against the rule.

106

## 107 **Results**

108

109 The first *P. marinus* nest recorded in the River Frome in 2014 was on 16 May and the  
110 final spawners were observed on 25<sup>th</sup> June. The subsequent nest counts indicated a total  
111 of 98 nests had been excavated, between 1.8 and 17.3 km upstream of the tidal limit  
112 (Fig. 2). Of these nests, four were still being guarded by adult males. Spawning activity  
113 had been concentrated within the lower 9 km reach of non-tidal river, where 88 % of  
114 nests were recorded (86 of 98). Of these, 36 were concentrated within the 1km reach  
115 immediately downstream of a gauging weir (Fig. 2). Only 12 nests were observed above  
116 this gauging weir; six between this weir and the next major migration impediment, and  
117 a further six between this and the next major impediment (Fig. 2). The upstream limit of  
118 the survey extended 22 km upstream of the tidal limit, with all spawning activity  
119 confirmed to be limited to the lower 19 km of non-tidal river. The abiotic characteristics  
120 of the river changed markedly between March and the period of spawning activity (Fig.  
121 3), with flow decreasing from a maximum of  $16.16 \text{ m}^3/\text{s}^{-1}$  to a minimum of  $3.15 \text{ m}^3/\text{s}^{-1}$ .  
122 There were two notable flow peaks in this period, on 8 April ( $12.3 \text{ m}^3/\text{s}^{-1}$ ) and 28 April  
123 ( $10.3 \text{ m}^3/\text{s}^{-1}$ ). Over the same period, water temperature increased from a minimum of

124 7.7°C to 20.1°C. Evidence of first nest construction activity corresponded with a water  
125 temperature of 14.6°C and discharge of 4.6 m<sup>3</sup> s<sup>-1</sup>.

126

127 A total of 44 nests, distributed downstream of East Stoke Gauging Weir (Fig. 1),  
128 were examined on 1<sup>st</sup> and 3<sup>rd</sup> July. These were typically crater shaped with excavated  
129 stones deposited around the nest perimeter. The physical, physicochemical and  
130 hydrological parameters of the nests are provided in Table 1.

131

## 132 **Discussion**

133

134 Effective conservation monitoring relies on the ability of managers to detect  
135 population declines within sufficient timeframes that facilitate initiation of corrective  
136 interventions, i.e. before critical population thresholds are reached (Staples et al., 2005).  
137 Despite current European best-practice monitoring protocols acknowledging that annual  
138 monitoring is required to assess recruitment success of *P. marinus* (Harvey & Cowx  
139 2003), the ability to differentiate between the 0+ (<60 mm) life stages of *Petromyzon*  
140 and *Lampetra* species has been reported to necessitate euthanasia of individuals, with  
141 the identification of the smallest individuals also being constrained due to the  
142 requirement for genotyping (Taverny et al., 2005). This means if destructive sampling is  
143 to be avoided, either the costs of monitoring ammocoetes increases or imparts a  
144 minimum two year lag phase before recruitment success can be validated. This  
145 constrains abilities for initiating corrective interventions on *P. marinus* populations and  
146 thus other, complementary monitoring options are required. Correspondingly, our  
147 outputs suggest that annual nest counts should provide these complementary monitoring  
148 options and ought to be incorporated into their monitoring toolbox forthwith; given their

149 ability to provide information on long-term patterns in returning adult numbers, the  
150 extent of their spawning migrations and their habitat utilisation.

151

152 Whilst allowing for potential sources and magnitudes of sampling error (Dunham et  
153 al., 2001), the quantity and distribution of redds, the nests of salmonid fishes, have long  
154 been recognised as providing a cost- and time-efficient method for monitoring the size  
155 of their adult populations (e.g. Rieman and Myers 1997; Al-Chokhachy et al., 2005). As  
156 such, they are a strong predictor of subsequent levels of parr production (Beland 1996)  
157 and been used to, for example, evaluate the efficacy of habitat restoration efforts (Merz  
158 and Setka 2004) and the effects of catchment management practices and instream  
159 barriers on migration and spawning (House 1996). With spawning representing perhaps  
160 the least cryptic stage of the life history of lampreys then it is perhaps surprising that  
161 examples of the use of nests as a monitoring tool are limited. Examples specific to *P.*  
162 *marinus* tend to be restricted mainly to ‘grey’ literature sources, but include extensive  
163 monitoring to evaluate the efficacy of a range of control treatments for invasive  
164 populations across 10 tributaries of Lake Champlain, USA (Parren and Hart 2012),  
165 surveys which successfully confirmed the rivers supporting spawning activity in the  
166 Humber catchment rivers, UK (Bellflask Ecological Survey Team 2009), and the use of  
167 nests to identify spawning grounds and the characterisation of spawning habitat in the  
168 River Mulkear, Ireland (Igoe et al., 2004). More recently, however, Lasne et al., (in  
169 press) demonstrated the efficacy of nest counts for evaluating the effects of dam  
170 removal on the colonisation of a coastal river system in France by *P. marinus*.

171

172 The present study demonstrated that the rapid and cost effective collection (three  
173 ‘man’ days) of data can provide a temporal baseline on the spatial utilisation of

174 spawning habitats across an entire (albeit small) river catchment. Whilst the physical  
175 and physiological factors determining the ability and propensity of adult *P. marinus* to  
176 negotiate the passage of flow control structures was beyond this study, outputs clearly  
177 demonstrated that relatively short migrations were undertaken, with 88% of all nests  
178 distributed between the tidal limit and the first flow control structure that was only 9 km  
179 upstream. The availability of spawning habitat upstream of this structure was observed  
180 to be consistent with that downstream, and given the structure represented a relatively  
181 minor migration obstacle, this suggests that where suitable habitat is available, adults  
182 may consciously elect to spawn on the first appropriate habitat encountered in order to  
183 prevent unnecessary energy expenditure, so maximising investment in the reproductive  
184 process (Quintella et al., 2004).

185

186 Despite being the first study to describe spawning habitat utilisation in chalk streams,  
187 the results reported here are not dissimilar from the few previous studies extending  
188 across the range distribution of *P. marinus*. Particularly notable is the mean nest length,  
189 reported here as 1.2 m, which is identical to that reported from Ireland by Igoe et al.  
190 (2004). The size of gravels used for nest construction in this study ranged between 11  
191 and 154 mm (mean = 52.3 mm). This compares to ranges reported from the Great Lakes  
192 of 15 to 115 mm by Morman et al. (1980) and 9.5 to 50.8 mm by Applegate (1950).  
193 Water depth (as recorded 1 m upstream of nests) ranged between 0.3 and 1.0 m (mean =  
194 0.52 m) and compares with a preferred depth of 0.4 to 0.6 m reported by Hardesty  
195 (1986) and within the extremes 0.1 to 1.7 m reported by Applegate (1950). The  
196 observed mean water velocity of  $0.78 \pm 0.03 \text{ cm s}^{-1}$  and ranges of 0.47 to  $1.29 \text{ cm s}^{-1}$   
197 observed from this study also fit within the ranges reported from the Great Lakes  
198 catchments of 39.6 to  $158.5 \text{ cm s}^{-1}$  reported by Applegate (1950). No differences were



199 observed in water temperature between mean column and inter-gravel flows, suggesting  
200 nest site selection was not influenced by hyporheic or groundwater flows.

201

202 Whilst the adult life stage of *P. marinus* has to date been typically overlooked in  
203 favour of ammocoetes as providing a key indicator of population performance and  
204 conservation status, the present work highlights the value of nest counts as either an  
205 independent or complementary monitoring tool to track temporal trends in adult lamprey  
206 numbers in chalk streams and throughout other river catchments where nests can be  
207 easily observed (Igoe et al., 2004; Bellflask Ecological Survey Team 2009). In addition  
208 to the added value associated with expanding the currently limited and much needed  
209 knowledge of spawning behaviour across lamprey species (Johnson et al., 2015) and  
210 their habitat utilisation, dismissing the efficacy and cost effectiveness of incorporating  
211 nest counts within future condition assessment methodologies will compromise the  
212 protection of spawning habitats (Nunn et al., 2008) and the design of spatial sampling  
213 strategies to monitor ammocoete numbers and distributions.

214

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216

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224 **References**

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327

328 Table 1. Ranges, means and confidence (SE) associated with the physical,  
 329 physicochemical and hydrological parameters recorded for 44 *P. marinus* nests in the  
 330 River Frome, July 2014.

331

<b>Variable</b>	<b>Min</b>	<b>Max</b>	<b>Mean</b>	<b>SE</b>
Depression length (dL m)	0.5	1.7	1.2	0.055
Depression width (dW m)	0.6	2	1.09	0.05
Depth at us lip (usD m)	0.25	0.99	0.57	0.03
Max depth depression (maxD)	0.43	1.1	0.7	0.02
Depth at ds lip (dsD m)	0.23	0.84	0.45	0.02
Depth excavated (DE m)	0.03	0.22	0.13	0.01
Mean column velocity (mV cm s <sup>-1</sup> )	0.47	1.29	0.78	0.03
Mean column water temp. (°C)	15.5	16.8	16.25	0.08
Inter-gravel temp. (°C)	15.5	16.8	16.3	0.11
Water depth (usD m)	0.3	1.03	0.60	0.03
Substrate size (mm)	11	154	52.3	29.42

332

333 **Figure captions**

334

335 Figure 1. Map of study site showing lower (22 km) non-tidal section of River Frome  
336 and location of the following instream structures: (a) East Stoke Gauging Weir; (b)  
337 Bindon Mill; (c) East Burton Hatches; (d) Moreton Weir; (e) Hurst Weir. TL indicates  
338 upstream limit of tidal influence (tidal limit).

339

340 Figure 2. Frequency of *P. marinus* nests recorded on the River Frome 2014, versus  
341 distance from tidal limit. Dashed vertical lines represent the following instream flow  
342 control structures: (a) East Stoke Gauging Weir; (b) Bindon Mill; (c) East Burton  
343 Hatches; (d) Moreton Weir; (e) Hurst Weir. All nest counts conducted 1–7 July, 2014.

344

345 Figure 3. Daily mean values of river discharge ( $\text{m}^3/\text{s}^{-1}$  – solid line) and temperature ( $^{\circ}\text{C}$   
346 – dashed line) recorded at East Stoke Gauging Weir, River Frome, between March and  
347 July, 2014. Data generated from 15 minute data logs. Dashed vertical lines represent  
348 periods of: a: observed nest building activity, b: nest count survey.

349

350



Sea lampreys, *Petromyzon marinus*, belong to a group of fish called Agnathans, which lack a jaw. Although classified in the subphylum Vertebrata, this species lacks vertebrae, and their entire skeleton is cartilaginous. Commonly known for their smooth, scaleless physique and long cylindrical bodies, they are often misidentified as eels. Many European countries capture sea lampreys and use them in a variety of dishes. ("Sea Lamprey Management Program", 2010; Bryan, et al., 2005; "The Great Lakes Fishery Commission", 2000).

**Known Predators.** Rapid visual assessment of spawning activity and associated habitat utilisation of sea lamprey (*Petromyzon marinus* Linnaeus, 1758) in a chalk stream: Implications for conservation monitoring. Authors: Pinder, A.C., Hopkins, E., Scott, L.J. and Britton, J.R. Journal: Journal of Applied Ichthyology. Volume: 32. Issue: 2. Source: Web of Science (Lite).

Rapid visual assessment of spawning activity and associated habitat utilisation of sea lamprey (*Petromyzon marinus* Linnaeus, 1758) in a chalk stream: implications for conservation monitoring. Authors: Pinder, A., Hopkins, E., Scott, L.J. and Britton JR. Journal: Journal of Applied Ichthyology. Publisher: Blackwell Publishing. ISSN: 0175-8659.

**Abstract.** Lentic populations of larval sea lampreys (*Petromyzon marinus*) are suspected of being a major source of recruitment to parasitic stocks in some areas of the Great Lakes, and methods are needed to estimate habitat and population sizes. A deepwater electroshocker has been used to quantitatively assess larval sea lamprey populations in deepwater areas, however a method has not been developed to efficiently identify the most promising locations to sample in this environment. A remote seabed classification device (RoxAnn<sup>®</sup>) was used to identify soft substrates in a lentic area where sea la...