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A European eel (*Anguilla anguilla*) case study using structured elicitation to estimate instream infrastructure passability for freshwater fishes

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Abstract
Conservation efforts are hampered by limited understanding about how different types of instream infrastructure impact migration patterns and fish survival. We used a rapid, fully online IDEA protocol to elicit expert judgments for the passability of seven different in-stream infrastructures to elver European eels (*Anguilla anguilla*) in Great Britain. Nine experts provided judgments via our online survey, followed by a second elicitation via email for reflection and adjustment of initial estimates. We found that on average, bridges were judged the most passable (95% passability), followed by fords, non-perched culverts, weirs, sluices, dams, and perched culverts (7%). Results showed a high degree of agreement about how passable bridges and perched culverts are for elver eels, but less certainty about other infrastructure. Thirty-four distinct factors were identified that experts believed influence infrastructure passability for elver eels, including: the structure itself, hydraulics, elver characteristics, obstructions (e.g., debris accumulation), and vegetation (e.g., to aid climbing). We discuss how our rapid, online-only variation on the IDEA protocol compares with the more traditional protocol, and how the expert estimates generated in this study can be used in future scenario building and connectivity modeling, with a view to improving conservation to support species persistence.

1 | INTRODUCTION

Migratory fish species are an essential part of marine and freshwater ecosystems (Lennox et al., 2019), transporting nutrients and providing food to ecosystems and millions of people worldwide. However, human-induced pressures such as habitat loss and river fragmentation by dams and other infrastructure mean that migratory fish populations are declining (Deinet et al., 2020). Therefore, there is a need for sustainable infrastructure solutions to restore freshwater ecosystem connectivity for nature and people. Implementation of potential solutions is limited by a lack of spatial data for the locations and characteristics of instream infrastructure (Belletti et al., 2020) and by gaps in knowledge about how different types of structures (e.g., dams, weirs, and culverts) modify freshwater ecosystems and the species that depend on them (Lennox et al., 2019). In turn, globally, there are gaps in the capacity to make informed and timely decisions about removal or remediation of instream infrastructure that is ageing, poorly constructed, or causing environmental impacts (Januchowski-Hartley et al., 2020). Expert interpretation of available evidence into advice is important where data (e.g., direct observation of fish behavior or density, or characteristics of infrastructure; see McKay et al., 2017) are lacking, and in this article, we focus on the role of expert elicitation for improved understanding about the passability of different instream infrastructure by fish species.

European eel (*Anguilla anguilla*), hereafter "eel", is a charismatic catadromous species that migrate as juveniles from the ocean to fresh waters. Eels spend their adult life in fresh waters before migrating back to the ocean to spawn. Migratory river pathways, across the species' historical range, are obstructed by diverse instream infrastructure (Clavero & Hermoso, 2015). In Great Britain, despite eels being protected by legislation (Eels [England and Wales] Regulations, 2009), fewer than 1% of catchments are free of instream infrastructure (Jones et al., 2019). The latest assessment by Jones et al. (2019) also broadly overlooked the distribution of culvert infrastructure that likely greatly impact the movement and dispersal of eels. Critically, an understanding of the *passability* of these hundreds of thousands of infrastructure for eels is lacking, because of the sheer number of structures, lack of systematic surveys to document structure locations and characteristics, and limited ability to assess the influence of these on individual movement. These knowledge gaps hamper the ability of decision-makers to cost-effectively and systematically remediate infrastructure to support species persistence.

The aim of our study was to use structured expert elicitation to estimate the probability that elver (juvenile) eels would pass over or through different infrastructure types that are widely distributed along rivers in Great Britain, and across Europe more broadly (Figure 1). We surveyed nine eel experts (researchers and practitioners) about instream infrastructure, and the probability of passage upstream by elver eels, by implementing a rapid, relatively low-cost, and fully online version of the IDEA (Investigate, Discuss, Estimate, and Aggregate) protocol (Hemming, Burgman, Hanea, McBride, & Wintle, 2018). We discuss the implications of our findings in the context of spatial prioritizations of instream infrastructure remediations to benefit migratory fish species such as eels, as well as the utility of a modified IDEA protocol for informing environmental decision making.

2 | METHODS

2.1 | Context and online IDEA protocol

Globally, information on behavior, swimming ability, or infrastructure characteristics are often lacking for many

FIGURE 1 Examples of the instream infrastructure types (top row, L-R: dam, weir, sluice; bottom row L-R: bridge, ford, perched culvert, nonperched culvert) included in expert elicitation surveys about the passability of structures for elver European eels (*Anguilla anguilla*). Images were not provided to survey participants

migratory fish species and aquatic ecosystems (Januchowski-Hartley et al. 2013; Lennox et al., 2019). One way to overcome data gaps when field surveys are too costly or time-consuming is to use expert knowledge to translate available (potentially disparate) data and evidence into advice (Sutherland, 2006). Structured elicitation methods such as the modified Delphi process (McBride et al., 2012) and IDEA protocol (Hemming, Burgman, et al., 2018) are increasingly used in decision science and environmental conservation and management to elicit expert judgments (Adams-Hosking et al., 2016). These methods acquire data in phases, helping to reduce the influence of biases and enhancing the defensibility of resulting estimates (Hemming, Burgman, et al., 2018).

Our study was conducted between February and June 2020. We designed a fully online adaptation of the IDEA protocol (Hemming, Burgman, et al., 2018; Figure 2) to estimate the probability of elver eels swimming over or through seven infrastructure types in Great Britain: dams, weirs, sluices, bridges, fords, and culverts (perched and nonperched) when moving in an upstream direction. In brief, the *IDEA* protocol consists of four key steps, as follows (Hemming, Burgman, et al., 2018): the first step involves a diverse set of experts *Investigating* the research questions and providing their private estimates; next, the experts are encouraged to *Discuss* the results with the assistance of a facilitator; they then provide a second private *Estimate*, before the individual estimates are *Aggregated*. While our approach broadly followed the IDEA protocol described by Hemming, Burgman, et al. (2018), the COVID-19 pandemic necessitated some modifications, notably to the "Discuss" step, described in Section 2.4.

2.2 | IDEA protocol: Pre-elicitation

Following approval to conduct research involving human subjects (SU-Ethics-Staff-100320/226), we developed and piloted our survey with two experts: one researcher working on the impacts of instream infrastructure on fishes for over a decade, and one practitioner leading a national instream infrastructure fish passage working group. We then used a purposive sampling approach to recruit researchers and practitioners working with or knowledgeable about the movements of eels in Great Britain's rivers. We define expert knowledge as substantive information on a topic that is not widely known by others (Martin et al., 2012) and an "expert" as someone with training or experience in our topic of interest (Fazey, Fazey, Salisbury, Lindenmayer, & Dovers, 2006). We identified 22 potential participants (including academics and practitioners working for governmental agencies and nongovernment organizations) through a review of literature, online searches, and communications via Twitter. We invited these 22 people to participate via a personalized email that included the project description and guidance (Appendix S1), and they provided their consent to participate by email. To protect anonymity each participant was assigned a unique code for all communications and reporting of results.

2.3 | IDEA protocol: Elicitation 1 ("Investigate")

Of the 22 potential participants identified, 12 expressed interest in participating and were emailed a link to our survey on Survey Monkey (www.surveymonkey.com).

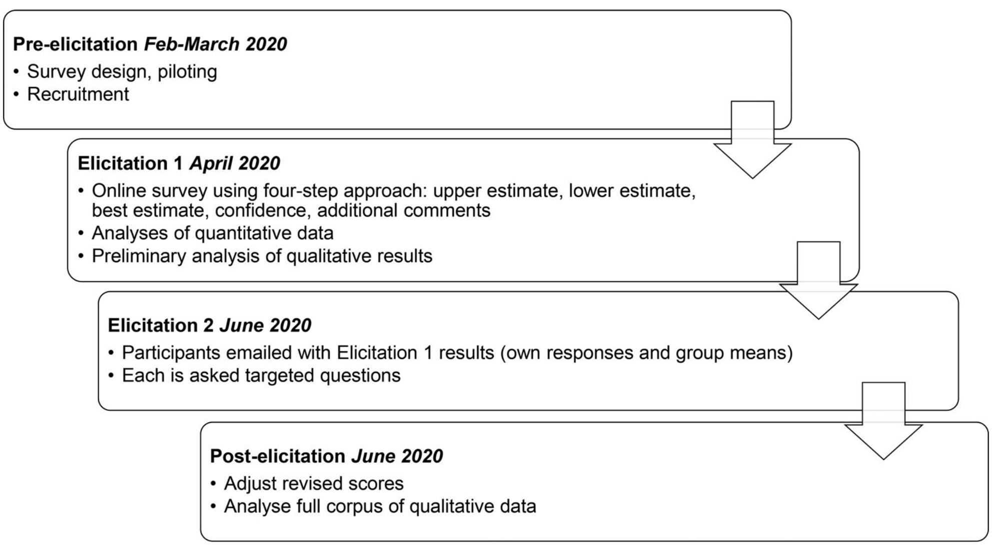

FIGURE 2 Work-flow of the fully online IDEA ("Investigate," "Discuss," "Estimate," and "Aggregate") protocol administered with European eel (*Anguilla anguilla*) experts

Our survey (Appendix S2) elicited perceptions of the probability that an elver eel would pass over or through each of the seven instream infrastructure types based on specific scenarios presented to them (e.g., "a 1 m high weir when swimming in an upstream direction under base flow conditions and with no fish passage facility present"). Scenarios were constructed to provide details of broad characteristics most likely to be encountered along rivers in Great Britain, and informed by previous work done by author SRJ to estimate the passability of infrastructure and fragmentation of rivers for different fish species at regional and national scales. Scenarios were also informed by the work of Baudoin et al. (2015) who determined that for dams and weirs, more specifically, extreme height value is the first element that determines whether a structure is likely to be passable for a particular fish species. For example, in France, Januchowski-Hartley et al. (2019) determined that most weirs along rivers were <5 m, and Baudoin et al. (2015) established that a maximum height value ≥1.0 m for dams and weirs would pose a passability challenge for eels swimming in an upstream direction. Drawing on these past experiences and knowledge, we framed scenarios to be broadly representative of commonly encountered characteristics (without fine-scale details such as vegetation presence that cannot easily be understood or estimated at a national spatial scale).

Using a four-step elicitation procedure (Hemming, Burgman, et al., 2018; Speirs-Bridge et al., 2010), experts were asked to provide their upper, and then lower plausible probability percentage (0–100%) that an elver eel would pass over or through the infrastructure type in question. They were then asked for their best estimate that an elver European eel would pass over or through the infrastructure, and finally, a degree of confidence for their upper, lower, and best estimates. Each scenario was accompanied by a free-text box for additional comments, knowledge or justification for estimates.

Nine participants completed the survey, providing 63 sets of judgments in total. We determined the arithmetic mean for lower, best, and upper estimates for each infrastructure and used linear extrapolation to adjust the upper and lower bounds to a standard 80% confidence level (see Hemming, Burgman, et al., 2018 for a discussion):

Lower standardized interval: $B - ((B - L) \times (S/C))$.

Upper standardized interval: $B + ((U - B) \times (S/C))$. where B = best estimate, L = lowest estimate, U = upper estimate, S = standardized confidence interval (80), and C = level of confidence given by the participant (sensu Hemming, Burgman, et al., 2018). The 80% confidence level was chosen for consistency with previous research, which typically standardizes to 80% or 90% intervals (Adams-Hosking et al., 2016; Hemming, Burgman, et al., 2018) and because it resulted in fewer truncated values than 90% confidence. The raw and standardized data are shown in Appendices S4 and S5.

We then undertook a preliminary analysis of the qualitative data returned in free-text boxes, using a mixed (grounded and structured) approach based on sensitizing concepts (Bowen, 2006). This meant that themes identified in the data were guided by concepts that we were aware of based on prior understandings of the topic. For example, an understanding that experts use different methods to reach their judgments (sensu Thomas, Pidgeon, Whitmarsh, & Ballinger, 2016), and that several parameters may affect passability (Baudoin et al., 2015; Januchowski-Hartley, Diebel, Doran, & McIntyre, 2014). From the qualitative data, we identified broad themes relating to: task complexity (e.g., estimating hypothetical infrastructures), rationale and methodology (e.g., drawing on prior experience), assumptions (e.g., a dam is a sheer wall), and parameterization (e.g., structure, hydraulics). These themes were used to guide questions for participants in elicitation 2 (Appendix S3).

2.4 | IDEA protocol: Elicitation 2 ("Discuss" and "Estimate")

We initially planned to combine online surveys with in-person discussions, but the COVID-19 pandemic necessitated that (a) all stages were conducted online and (b) experts' time commitment to our study was kept to a minimum. Thus, in contrast to the "Discuss" phase as described by Hemming, Burgman, et al. (2018), which facilitates (in-person or remote) discussions *between experts*, in our study we facilitated comments and discussion between our team and the participant rather than between participants. To enable this, we emailed participants with a figure summarizing their initial estimate and the group mean estimate for each infrastructure type, as well as individually tailored questions relating to their initial estimates and comments (Appendix S3). The figure and questions were designed to prompt discussion between our research team and participants, as well as provide an opportunity for experts to reflect on and adjust their initial estimates. This adjusted approach helped us keep the process relatively quick and easy for participants who could have been under altered work conditions during the pandemic, and allowed us to retain an element of participant feedback and adjustment. It was not compulsory for participants to revise their scores or answer these questions. Four participants (Experts B, E, G, and H) replied with additional qualitative comments and one (Expert H) adjusted their estimates for dam and sluice scenarios.

2.5 | IDEA protocol: Postelicitation ("Aggregate")

We adjusted Expert H's revised estimates and recalculated standardized group means. We used NVivo 12 to code the full corpus of qualitative data (including responses from Experts B, E, G, and H during the second elicitation) based on the themes identified from the first elicitation, including characteristics of infrastructure that could influence passability by elver eels (Appendix S6). These codes were explored and compared with the quantitative data.

3 | RESULTS

On average, participants judged bridges to be the most passable (mean best estimate 95%) for elver eels followed by fords, nonperched culverts, weirs, sluices, dams, and perched culverts (7%) (Figure 3). There was wide variation in estimates, particularly for nonperched culverts, weirs, sluices and dams. The most uncertainty surrounded weirs and sluices, while the least uncertainty was associated with perched culverts and bridges (Figure 3).

The qualitative data offered insights into the uncertainty of estimates for the different infrastructure types. Nearly 80% of free-text boxes were completed, with participants using them to discuss various factors that influence how they assess infrastructure passability for elver eels. For example:

> (H) *I've seen hundreds of weirs that present different challenges. If the weir is a concrete vertical face with no vegetation, then it is impossible to pass in low flows. If it is gently sloping with a good covering of moss, with no lips or sills, then it is pretty much fully passable.*

It should be noted that in response to follow up questions, Expert H clarified that this variability is the case with other structures as well as weirs—illustrating the value of follow-up questions and qualitative data. In

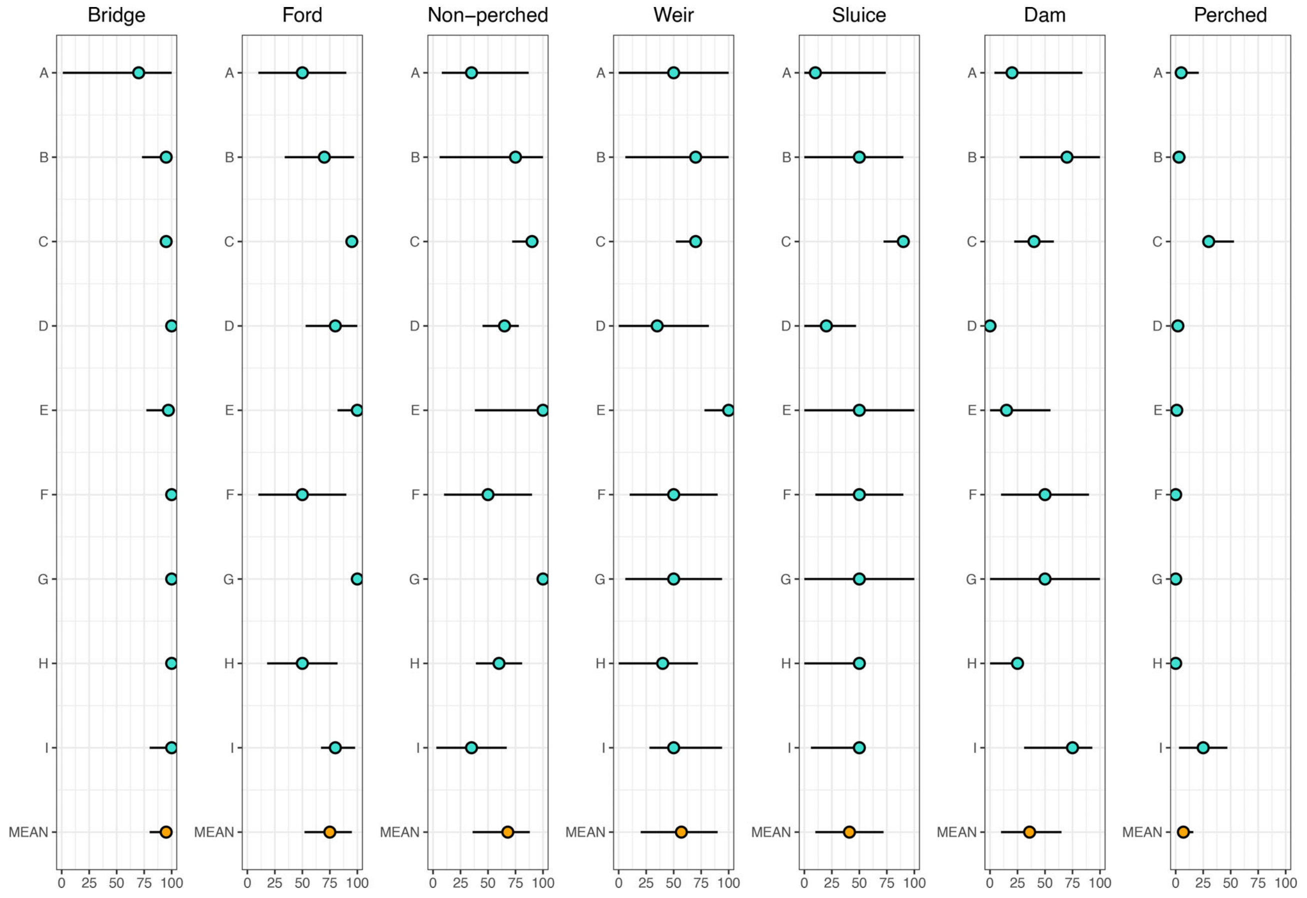

FIGURE 3 Experts' probability judgments for elver European eel (*Anguilla anguilla*) passage over or through seven infrastructure types, standardized to 80% confidence. Final individual responses (experts A–I) and group mean, showing individual best estimates (turquoise circles); upper and lower estimates (whiskers), group mean best estimates (orange circles, with mean lower and upper estimates). Perched and nonperched refer to the two types of culverts

the case of sluices, qualitative data contextualized the quantitative variability, elucidating that passability depends on whether a sluice is open or closed. Qualitative data also contextualized the complexities of elver eel behavior in high water flows, and how this can influence passability:

> (G) *elvers are relatively poor swimmers, strong flows would be a restriction, however, where flows are strong it is common for elvers to crawl around the edges if a suitable medium exists.*

Experts also noted the complexity associated with assessing infrastructure passability, and the desire for more detailed information to inform their estimates. We coded 34 distinct characteristics that influence the passability of infrastructure by elver eels, which we categorized into six groups (Table 1). Of these, experts most referred to the structural characteristics of the infrastructure ($N = 45$ references), followed by hydraulics ($N = 37$), elver eel characteristics ($N = 9$), vegetation ($N = 8$), obstructions ($N = 4$), and other factors ($N = 3$), illustrated in these exemplar quotes:

> (A) *The passability of a nonperched culvert can be highly variable, depending on the type of culvert (clear-span, box etc.)* [structure]

> (B) *Will depend on velocity over or beneath sluice* [hydraulics]

> (E) *the age of the eel and its muscle mass would be important older elvers would be more capable of passing compared with a glass eel* [elver eel characteristics]

> (H) *I'm assuming [...] no macrophyte growth on either side of the structure* [vegetation]

> (H) *I have only put an 80% chance as some culverts can [...] have obstructions related to them, but even then, elvers will be able to traverse most of these* [obstructions]

> (E) *Fords unless highly polluted would be virtually no issue. The lowest estimate is based on worst case pollution and high traffic crossing* [other]

TABLE 1 Factors identified by nine experts that are perceived to influence the passability of different types of instream infrastructure for elver European eels (*Anguilla anguilla*)

Parameter group	Variable
Structure	• Type of structure (e.g., hanging/nonhanging sluice) • Slope of glacis • Length • Height • Bed substrate including roughness • Channel cross-section • Construction material • Dry/wetted • Structure operation • State of repair • Presence of sills/lips
Hydraulics	• Flow • Velocity • Turbulence • Leakiness • Variation in flow • Depth/concentration of flow • Drowned/nondrowned • Laminar/broken flow
Elver characteristics	• Size • Age • Muscle mass • Life stage (e.g., glass) • Ability • Behavior (crawling, swimming, climbing)
Obstructions	• Blockage • Debris accumulation • Maintenance • Entrance conditions
Vegetation	• Presence/absence of vegetation to aid passage/climbing
Other	• Pollution levels • Traffic crossing • Habitat in river below bridge

4 | DISCUSSION

We carried out a fully online IDEA protocol to elicit expert perceptions and estimates of the passability of seven different types of instream infrastructures for elver eels in Great Britain. On average, experts agreed that bridges were most passable, followed by fords, nonperched culverts, weirs, sluices, dams, and perched culverts (least passable). While there was a high level of agreement around the passability of bridges and perched culverts, experts had less confidence about the passability of other infrastructure types for eels. Qualitative data contextualized and supported quantitative estimates, allowing us to scope the parameters experts perceived as important when determining passability.

From a methodological perspective, we have contributed to expanding literature that provides illustrative examples of how structured protocols can be used "within pressing time and resource constraints" to improve judgments for conservation and natural resource management decisions (Hemming, Walshe, Hanea, Fidler, & Burgman, 2018, p. 1). Our adapted fully online IDEA protocol represents a highly accessible and low-time investment method of elicitation, which can be adopted by researchers or practitioners—especially where face-to-face meetings are not possible. Our approach required relatively little time investment by both the research team and participants. From initial project planning in February 2020 until data analyses in June 2020, we estimate that our project team (formed of three people) spent a total of 10–20 hr/week on the study, depending on the phase of the study. This involved around 20 hr/week on survey development and analyses, and 10 hr/week on administering surveys and collating responses. We estimate that each participant invested 1–2 hr of their time to the study.

In a departure from the IDEA protocol described by Hemming, Burgman, et al. (2018), our second elicitation phase involved emailing experts with the average responses, their own calibrated responses, and targeted questions, rather than discussions *between experts*. We were concerned that in open discussions between experts there can be inequalities in the distribution of perspectives shared or weighting given to some perspectives over others (e.g., McGraw & Seale, 1988), and thus favored an individual rather than group approach. An alternative involves the facilitator compiling comments and questions and circulating the collated discussion via email each day, (Hemming, Walshe, et al., 2018) thus avoiding biases stemming from group dynamics. However, ultimately, our decision was influenced by changes to people's lives due to the COVID-19 pandemic (particularly in Great Britain where the experts were based). Our approach meant participants were able to contribute their expertise quickly and efficiently and were likely less inclined to drop-out due to time commitments. A drawback of this approach was the potential reduced opportunity for experts to discuss any ambiguities related to infrastructure parameters and assumptions.

A second limitation arising from our adjustment to the discussion phase of the IDEA protocol as set out by Hemming et al. (Hemming, Burgman, et al., 2018; Hemming, Walshe, et al., 2018), is that it could have led to lower engagement with the second round and/or influenced response biases, as a function of whom responded and whom did not (this is not solely a reflection of our approach, but often the case with expert elicitation studies broadly). However, we do not have counterfactual data on the likelihood that participants would have engaged to any greater extent if we had adopted a different approach, and it seems unlikely that extended email or on-line forum discussions would have been well attended during the pandemic. Indeed, we expect that some perspectives were not captured due to time pressures: one expert commented that her "inbox has been rather crazy dealing with the current situation" and did not manage to take part in the study despite her initial intention to do so. Therefore, we acknowledge that potential biases in this study could be complicated by the differing impacts that the COVID-19 pandemic had on (potential) participants, such as those with caring and familial responsibilities (Power, 2020). Previous research shows that the revision of estimates leads to higher accuracy (Hemming, Walshe, et al., 2018), and thus we would suggest that if there is sufficient time available to facilitate more in-depth discussion between experts or even between experts and the research team, this would likely be beneficial (see Hemming, Walshe, et al., 2018 for a discussion).

We also note that, as illustrated in our qualitative data, it can be harder for experts to make estimates for variable infrastructures than for those with more strictly defined parameters (e.g., a 1 m high weir with a discharge of 9 m^3/s, no vegetation, a 30% gradient etc.). While it is standard practice to carefully structure the quantity to be elicited and minimize the "mental acrobatics" required to make a judgment (Spetzler & Stael von Holstein, 1975, p. 343), in this study, as set out in Section 2, we provided scenarios to elicit estimates for a representative structure, most likely be encountered along rivers in Great Britain. This is because detailed parameters for thousands of infrastructures affecting eel passage in Great Britain (and elsewhere) *are not known*, and management decisions still need to be made where data are lacking (Januchowski-Hartley et al. 2019). However, studies that aim to elicit expert judgments at finer spatial scales with more closely defined parameters, potentially drawing upon those obtained through our qualitative data, could help to refine estimates further.

Despite the above-mentioned limitations, our approach generated meaningful data that can be used to improve estimates of river fragmentation as experienced by eels, and to inform associated decisions about removal or remediation, even in the absence of highly detailed infrastructure parameters. From an applied perspective, our study took place as part of a broader project to better understand where different types of instream infrastructure occur in Great Britain and to begin to identify and attribute how passable these are for different fish species. In this context, the study has provided estimates that offer an improved understanding of infrastructure passability beyond binary pass or no-pass assumptions often used in broadscale analyses when on-the-ground data are unavailable (see King & O'Hanley, 2016 for a discussion).

Our findings underscore the wide variation in passability of different infrastructure. For example, our finding that perched culverts are judged (on average) the least passable is particularly relevant considering that culverts are often neglected in studies of instream infrastructure (Januchowski-Hartley et al., 2020). Further, it is small infrastructure such as culverts that are most difficult to map and can be overlooked when estimating river fragmentation and planning conservation interventions, which tend to focus on large dams instead of smaller structures (Belletti et al., 2020; Januchowski-Hartley et al., 2014). The estimates provided by experts in our study could thus be used in future scenario building and prioritizing infrastructure for remediation or removal, such as that explored for stream resident fishes by O'Hanley, Wright, Diebel, Fedora, and Soucy (2013).

Finally, expert responses to open-questions in our survey suggested the need for: (a) regional-based assessments as experts would be more knowledge about specific structures in their patch and (b) providing images of structures. Our next step is to implement a single basin-scale assessment of expert knowledge about infrastructure passability that will integrate images (primarily from satellite-derived imagery). One goal with this next step is to evaluate if expert scores are different when focused on the basin-scale rather than the national-scale, and whether expert estimates differ when given text-based or image-based scenarios of infrastructure in the region. This will help us to better understand what can be captured with various levels of investment in expert elicitation processes for guiding and informing decisions in relation to infrastructure management. This spatial context could also be useful in future iterations of our approach for other freshwater fishes, enabling broader discussions about multiple rather than single species. In these ways, our current research and future directions stand to deepen understanding of infrastructure passability for eels and other species, ultimately guiding more effective conservation.

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CONFLICT OF INTEREST

The authors have no conflict of interest.

AUTHOR CONTRIBUTIONS

Stephanie Januchowski-Hartley and Sayali Pawar conceived of the study, led design, and recruitment. Sayali Pawar led on the quantitative analysis, and Merryn Thomas led on the qualitative analysis. Merryn Thomas and Stephanie Januchowski-Hartley led the writing. All authors made significant contributions to writing and revised the manuscript critically for important intellectual content and approved the version to be published.

ETHICS STATEMENT

This study was carried out under the approval of the Swansea University Ethics Committee (SU-Ethics-Staff-100320/226). All participants were aged above 18 years of age, gave their prior informed consent to participate, and the data were managed to ensure anonymity.

DATA AVAILABILITY STATEMENT

The following are accessible in the Supporting InformationSupporting Information: elicitation protocols (Appendices S1, S2, and S3), raw and standardised quantitative data Ttables (Appendices S4 and S5), and qualitative data code book (S6). The authors are solely responsible for the content and functionality of these materials. Queries (other than absence of the material) should be directed to the corresponding author. The qualitative data are available upon request from the corresponding author.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of this article.

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