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When unlocking rivers results in building more infrastructure: A group mental model shares lessons from weir remediation in the United Kingdom

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Abstract

The last several decades have seen a rise in efforts to remove weirs, but there is little research investigating how projects are carried out, potential areas for improvement, or sharing of lessons to facilitate reconnection of more rivers. The aim of the study presented here was to explore how people involved in weir remediation perceive project processes, factors that facilitate or hinder action implementation, and possible ways processes could be improved to reconnect more rivers. We carried out semi-structured interviews with people ($n = 11$) who had been actively involved in weir remediation processes in the Severn River Catchment, United Kingdom, and used their responses to create a group mental model. The group mental model was created to support learning and communication about weir remediation projects between individuals and groups. We found broad agreement from those involved in creating the group mental model about weir remediation project processes and potential areas for improvement. One of the only points of divergence within the group mental model was associated with the impact of different weir remediation actions, particularly weir removal. Based on the group mental model, we set out three calls to action to reconnect more rivers in the UK. First, move beyond opportunistic projects and establish national goals and catchment-scale plans for weir remediation. Second, reform fish passage legislation and legislate weir ownership. Doing so would support more effective remediation solutions by recognizing the diversity of fish species that reside in UK rivers and help mitigate risks from hazardous weirs through owner accountability. Third, build cross-sector and public partnerships to encourage removal or improved fish pass designs. We direct the three calls to action to policy makers and anyone already engaged in or envisioning weir remediation projects in the UK. The calls also have potential implications and relevance to people in other countries in Europe and beyond.

KEYWORDS
decision making, Europe, freshwater, policy, rehabilitation, restoration, weir removal

1 | INTRODUCTION

Weirs (or low-head dams) are some of the most abundant and impactful structures to freshwater ecosystems (Morden et al., 2022), and there is a growing movement, particularly in Europe and North America, to remove weirs from rivers (Vahedifard et al., 2021). In Europe and North America, many weirs were constructed in the 18th and 19th centuries for mill, log, or industrial ponds, to divert water for irrigation or flood control, or to alter water levels for boat navigation (EA, 2013; Oliver & Grant, 2017; Smith et al., 2014). Many such weirs have exceeded their intended lifespan, do not meet human or environmental safety standards, or no longer deliver their intended purpose (e.g., diverting water for mills or industry). Existing weirs that exceed their lifespan are the primary targets of removal initiatives for reasons of public safety and liability, such as drowning or structural failure risk reduction, and to restore water flows and movement of sediments, materials, and species that have otherwise been altered for more than a century (Doyle et al., 2008; Oliver & Grant, 2017; Pejchar & Warner, 2001; Smith et al., 2014; Vahedifard et al., 2021).

Importantly, the complete removal of a weir is only one in a suite of actions (or inactions) associated with decommissioning of infrastructure (see Doyle et al., 2008), and it lies on the opposite side of the spectrum from abandonment (inaction) with other remediation actions in-between, such as retaining (which can include restoration or rebuilding of a weir), building fish passes (which can include rebuilding a weir), and partial structure removal. In this paper we refer to the suite of actions from retaining and restoring through to full removal of a weir, as remediation. While there are a growing number of examples in literature (Birnie-Gauvin et al., 2018) and media (see https://www.theguardian.com/environment/2022/may/16/record-number-of-dams-removed-from-europe-rivers-in-2021-aoe) about full removal of weirs, there are gaps in understanding about how weir remediation projects proceed and factors that influence why planned weir removals go ahead or not (Doyle et al., 2008; Vahedifard et al., 2020). There remains a need to consider and evaluate cases where planned weir removals have taken alternative trajectories, such as when a removal was intended but weir retention and construction of a fish pass resulted instead.

Modeling is a common tool for supporting our understanding of complex problems, such as weir remediation, that arise from interactions between people and nature (Elsawah et al., 2019; Moon & Browne, 2021). People's ability to describe a complex problem and the decisions that are made, such as whether and where weirs should be built, retained, or removed, are influenced by individual knowledge and group understanding about how the world works, should work, and the effects of actions on things they value (Elsawah et al., 2015). A person's values, beliefs, and aspirations structure their mental model, which exists in their mind as a small-scale model of how (a part of) the world works (Johnson-Laird, 1980). Mental models research focuses on developing methods to elicit and share people's complex knowledge structures and can reveal perceptions and assumptions that influence support for when, why, and how actions, such as weir removal, are done. Models that express decision making and underlying assumptions in a transparent way can foster individual and group learning and improve prospects for communication by providing decision makers an opportunity to link actions and effects and to reflect on their own practices and see the rationale behind the practices of others (Elsawah et al., 2015; Pahl-Wostl et al., 2007). As explored by Moon and Adams (2016) for invasive species management, physical representations of individual and group mental models could be useful to help decision makers better understand factors that influence weir removal, help minimize contentiousness of proposed actions, and identify areas for improvement.

Moon et al. (2019) identified three forms of mental models used and useful in environmental conservation decision making, including individual, team/group, and shared models. Individual mental models can reveal how someone understands and constructs their own model of a problem or system and can be used to identify and explore potential unintended consequences of conservation action (e.g., proposed weir removal). Mental models from individuals can also be compiled or elicited as a collective task to create a group mental model that conceptualizes a problem or system based on a group of people's collective knowledge. A group mental model can help us to better understand how a group of people makes decisions and to identify and visualize areas of agreement and disagreement in individual mental models (Moon & Adams, 2016; Moon et al., 2019). A shared mental model can also be elicited and visualized in a group setting, using methods such as focus groups or facilitated discussions, to conceptualize how people would like to experience or change a problem or system. These shared

models can be used to assist in decision-making, such as that associated with weir remediation, and are often elicited over time so to allow time for group discussion and agreement on how shared aspects of their individual mental models are represented in the shared model (Moon et al., 2019).

The aim of the study presented here was to explore how people involved in weir remediation perceive project processes, factors that facilitate or hinder action implementation, and possible ways processes could be improved to reconnect more rivers. To do this we developed a group mental model that could be used to support learning and communication about weir remediation projects between individuals and groups. The intention of our study was to explore, learn, and communicate (not to quantify or predict, see Elsawah et al., 2019) different people's perceptions of weir remediation. Specifically, we designed a fully online/remote mental model elicitation and visualization method (to accommodate COVID-19 regulations at the time). Our mental model elicitation and visualization method comprised a semi-structured interview schedule and model template that would return qualitative data on people's perceptions and conceptualizations of weir remediation. We led online and phone interviews with people who had been active in weir remediation projects, and used people's responses to our questions to create a group mental model that reflected their interpretations of project processes, potential ways to improve, as well as broader social–environmental context, characteristics of weir sites and people, and benefits and costs of such efforts.

We used weir remediation in the Severn River Catchment (SRC), United Kingdom (UK), as a case study. Among other weir remediation projects in the SRC was a 6-year initiative called Unlocking the Severn under which six weir removals were proposed. The Unlocking the Severn project included planning and co-ordination across government agencies and non-government groups as well as consultation with broader publics. The selection of weirs to remediate in the SRC was based on a common method used to select weirs for remediation in the United States of America and countries in Europe (de Leaniz & O'Hanley, 2022), which relies on local knowledge (primarily from river managers, engineers, and biologists but sometimes also broader publics) to select a weir or weirs for remediation. The intention of the organizations and agencies who initiated remediation projects in the SRC was to completely remove weirs that were obstructing migratory fish species movements to historic spawning areas. However, in the Unlocking the Severn project complete removal was not achieved at any of the targeted weirs, and we saw an opportunity to work with people engaged in weir remediation projects in the SRC to explore, and learn and communicate about, project processes and how those could be improved in future projects.

To our knowledge, our study is the first of its kind in the UK to explore perceptions and conceptualizations of weir remediation projects held by a group of people actively involved in multiple such processes within a river catchment. By engaging people active in weir remediation to understand similarities and differences in their mental models of those processes, we anticipate our results, inclusive of the group mental model, will encourage self-review and contribute to improved weir remediation processes to reconnect more rivers.

2 | METHODOLOGY AND METHODS

2.1 | Case study

The Severn River (Welsh, Afon Hafren) is the longest river in the UK (Figure 1). The Severn Estuary (Welsh, Môr Hafren) is a Special Area of Conservation (SAC) (2010) (https://sac.jncc.gov.uk/site/UK0013030) designated in England and Wales under the Conservation of Habitats and Species Regulations (2017) (https://www.legislation.gov.uk/uksi/2017/1012/2017-11-30). A primary reason for the Severn Estuary SAC designation is the presence of Annex II species: Twaite shad (*Alosa fallax*), Sea lamprey (*Petromyzon marinus*), and River lamprey (*Lampetra fluviatilis*), which are meant to be afforded strict protection under the European Union's Habitats Directive (1992) (see https://ec.europa.eu/environment/nature/legislation/habitatsdirective/index_en.htm). Despite the conservation status, Twaite shad and other fishes have been prevented from migrating up and down the Severn River and tributaries, because of weirs present on the river for more than 100 years (Canal and River Trust 2022). Among other weir remediation and restoration projects led by non-government and government agencies in the SRC, the Unlocking the Severn project was a 6-year initiative to restore riverine connectivity and migratory fish populations in the catchment. The Unlocking the Severn project focused on identifying weirs that were obstructing movement of Twaite shad in the SRC, because more than 100 years ago the species used to migrate up the river in large numbers but cannot jump or leap and the weirs built on the mainstem of the river and some tributaries prohibited individuals migrating upstream to spawn (see https://www.unlockingthesevern.co.uk/unlocking-the-severn-for-shad/). The Unlocking the Severn project

FIGURE 1 The Severn River Catchment case study area situated within the Severn River Basin on the island of Great Britain in the United Kingdom.

was led through a partnership between non-government/charity organizations (Canal and River Trust and Severn Rivers Trust) and government agencies (Environment Agency and Natural England) and focused on remediating weirs, many of which were lower in height (<5 m) and spanned entire river reaches (e.g., Diglis Weir in Figure 2). Through the project, four fish passes were constructed (such as the one at Diglis Weir shown in Figure 2), one weir was partially removed, and one rock ramp was installed (allowing fish to swim over a weir structure).

2.2 | Research position

We adopted a social constructivist perspective because we considered that each person interviewed would have their own understanding of what weir remediation 'looks like' and that an individual's understanding is a subset of how the world could be understood (Moon & Blackman, 2014). Our research perspective meant that we did not seek to generate a representative or typical sample of people to enable prediction from our findings to other situations or areas (Drury et al., 2011; Shenton, 2004); we discuss this further in relation to our study recruitment in Section 2.3.

Our method was designed to achieve a goal of exploration and learning rather than prediction and focused on a case study so to contextualize actual decision making and offer in-depth perspectives from different people involved in those processes. Such an exploratory approach can assist with building trust among interdisciplinary collaborators and others engaged in the research and deliver results that more thoroughly reflect uncertainty of the problem, and could increase adoption of results, particularly by people who are not the ones proposing weir removal or other forms of remediation (Elsawah et al., 2019). We drew on concepts and approaches from mental model research (e.g., Moon & Adams, 2016; Morgan et al., 2002; Thomas et al., 2016), which enabled us to account for people's complementary and contradictory understandings of weir remediation processes (Biggs et al., 2011; Moon & Browne, 2021; Walpole et al., 2020). We are also an interdisciplinary group of researchers (an environmental scientist who works to address questions about infrastructure remediation; a marine biologist; and two social scientists with broad knowledge and experience in designing interviews and models related to complex conservation problems), and we wanted the group mental model to have a perceived utility by people with a variety of views about weir remediation in the hope that it would be used to inform decision making.

We also used different terms (e.g., participant, stakeholder, community member, and interviewee) to refer to people involved in the study and in weir remediation more broadly and were not necessarily satisfied with any one specific term. We had settled on the use of the term stakeholder in some instances (e.g., a set of questions in the interview), and our intention behind using that term was clarified in recruitment and interview materials (i.e., we had those people active in weir remediation as well as broader publics in mind when using 'stakeholder'). When writing this manuscript we realized that the term stakeholder can be unnecessarily exclusionary (see https://www.fasttrackimpact.com/post/alternatives-to-the-word-stakeholder), and so we chose to use the term *people* in the final group mental model and in this paper.

2.3 | Study recruitment

We received approval to conduct research in April 2021 by Swansea University's Faculty of Science and Engineering

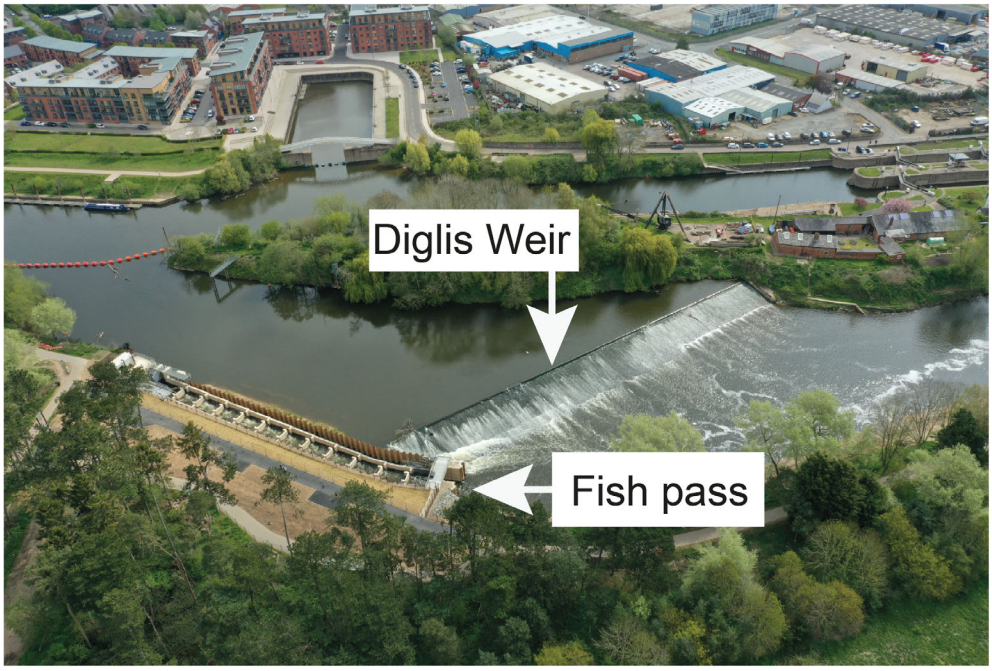

FIGURE 2 An overhead view of a fish pass installed alongside an existing weir (Diglis Weir) on the Severn River, United Kingdom. *Source*: Skynique.

Ethics Committee (SU-Ethics-Staff-050221/310). We invited people to our study who had been active in weir remediation in the SRC, including those who contributed knowledge to the Unlocking the Severn project. We aimed to maximize the diversity of important and relevant knowledge held about weir remediation, and so did not focus on a representative or 'typical' sample of people to contribute to our study (see Moon & Adams, 2016). Instead, we approached people who favored full weir removals, such as people working in non-government organizations/charities, consultancies, and academia, as well as people who did not favor full weir removals, such as those who were part of hydroelectric co-operatives and angling and kayaking groups.

We used purposive and snowball sampling methods to recruit individuals involved in weir remediation projects in the SRC to be interviewed for our study. We began by contacting people who worked for a non-government organization/charity (Severn Rivers Trust) who co-led the Unlocking the Severn project, as well as others who worked for a government environmental regulator (Environment Agency—England) on the same project. We used internet searches and requests at the end of interviews to identify people who were active in weir remediation processes in the SRC, including those who they believed had very different views to them (Guba, 1981; Moon et al., 2016). Based on our searches and other's recommendations, we invited 23 people to an interview, including: nine people who worked for environmental non-government organizations/charities; four people who worked for responsible government agencies; three people who worked for consultancy groups that build infrastructure; two people representing cultural non-government organizations/charities; two angling club members; one person representing a hydroelectric co-operative; one academic who studies fish movement; and one person representing a kayak group. Nearly half (11/23) of the people we identified as active in weir remediation in the SRC and invited to participate in our study, were interviewed.

From here, we use exemplar quotes to support our narrative about the group mental model. Quotes from specific people we interviewed are indicated with 'P' and a unique number (e.g., P1 if we refer to the first person we interviewed, and that is consistent throughout the manuscript). For anonymity reasons we summarize demographics of the 11 people we interviewed: everyone identified as white and British, there were three females and eight males, and they had a mean age of 47 years old.

2.4 | Elicitation and creation of a group mental model

Our method used to create the group mental model of weir remediation processes can be summarized in four phases. Figure 3 visualizes the four phases of our workflow, including who contributed to each phase (i.e., our research team, indicated in green or our team plus people we interviewed, indicated in purple) and how the template used to document responses in the interview evolved to be the final group mental model. A detailed video of the group mental model creation process is presented in a Figshare repository (Januchowski-Hartley et al., 2022:

https://doi.org/10.6084/m9.figshare.21229475.v3), and includes when our research team and the people who were interviewed had input to the conceptualization and how knowledge was represented in the model.

2.4.1 | Phase 1: design interview schedule and model template

The interview schedule and model template designs were led by our research team (Figure 3, Phase 1), and were designed to be delivered online through Zoom (or by phone as needed) to support two-way dialogue while also accommodating Covid-19 regulations in the UK at the time. While all decisions about the design were made by our research team, we did receive feedback from two pilot sessions with external colleagues who had knowledge of the topic and previous experience with interview design and delivery. We acknowledged that people would vary in their willingness to adopt an innovation such as weir removal or fish pass construction (Rogers, 2010), and so our interview schedule design, including the order and framing of questions, drew on mental models and diffusion of innovations research as well as infrastructure remediation (e.g., Jørgensen & Renöfält, 2012) and public engagement (e.g., Lorenzoni et al., 2007) literatures. Our interview schedule had seven sections and began by asking people to share their thoughts and feelings about rivers and weir remediation and then focused on specific research questions as the interview progressed (Morgan et al., 2002). We framed our questions so to encourage people to share narratives about their lived experiences, including those most memorable to them, because it can encourage sharing about what is most important or relevant to people, especially in situations where the answer is not necessarily obvious or is intangible in some way. In the seven sections of the interview schedule, we wanted to know:

1. What was on top of people's minds when asked about remediation, rivers, fish migration, well-being, flooding, dams, and weirs.
2. How people experienced weir remediation, including memorable projects, current job/role, and time working on weir remediation.
3. What people perceived to be the benefits and costs of weir remediation, who or what benefits or bears costs and the timescale over which benefits or costs operate.
4. Who was involved in weir remediation, including how people learn about the projects and how people respond to remediation.

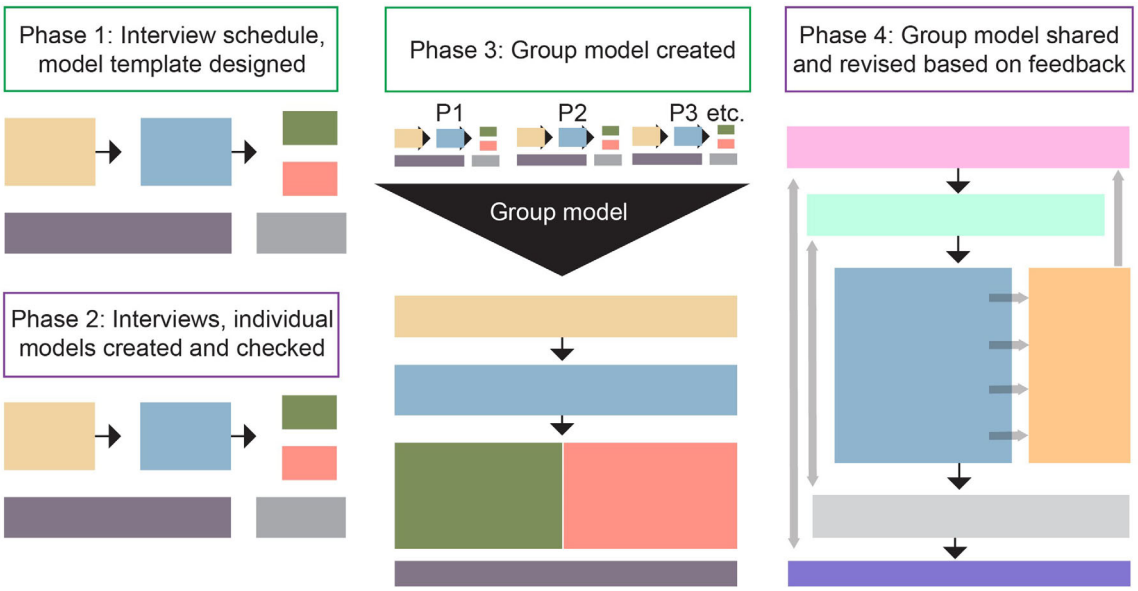

FIGURE 3 Four phases of the workflow to create a group mental model of weir remediation processes in Severn River Catchment, United Kingdom. The phases visualize how the weir remediation model template created by the research team was used to subsequently document responses in the interviews and populate the final group mental model. Contributions by the research team (open-green boxes) and by the research team and the 11 people interviewed for the study (open-purple boxes) are shown for each phase. In phases 1–3 the colored boxes in the template and models correspond to drivers (beige), processes (blue), benefits (green), costs (salmon), uncertainties (purple), and other factors (gray) associated with weir remediation. In phase 4, the colored boxes in the group mental model correspond to context (pink), characteristics (turquoise), project (blue), improvements (orange), benefits and costs (gray), and outcomes (purple) of weir remediation.

5. How weir remediation projects tend to work, and what defines success.
6. What factors influence weir remediation, such as the characteristics of the weir site, people who are involved, and how factors such as cultural heritage, ecology, national policies, or global context affect remediation.
7. Additional information people believed was relevant to weir remediation and to identify any opportunities for improved remediation processes.

We also designed a model template to complement the sections of the interview schedule and used it to visualize people's responses during the interviews. Our intention with the model template was to summarize the interview and to prompt further engagement and conversation between the person being interviewed and the research team. The model template used in interviews is visualized in Figure 3, Phase 1, and included social and environmental drivers/context (tan box); project processes—decisions, procedures, and successes (blue box); benefits (green box) and costs (salmon box); uncertainties (purple box); and other information (gray box).

2.4.2 | Phase 2: conduct interviews and create individual mental models

Our research team and everyone who was interviewed contributed to this phase of the workflow (Figure 3, Phase 2). Our research team conducted interviews between April and November 2021. All interviews were conducted by the first and second author either by Zoom (10 people) or phone (one person) and were 1.5 h in duration on average. All interviews were audio recorded. The first author led all interviews, and the second author populated the model template with responses shared throughout the discussion. People's responses to questions from all seven sections of the interview schedule were used to populate their individual model. The model template did not change during this phase (Figure 3, Phase 2), but the research team populated text within each section of the template to visualize each person's model based on their verbal responses. Once questions were completed, the draft model made by the second author was shared on the screen (in the case of the phone interview this was verbal), and any clarifications and adjustments were made by the second author and the person being interviewed. Each person was provided with time during their interview to comment on and suggest any changes to their individual model, and their agreement on the notes within the draft individual model was confirmed by the research team before closing the interview.

2.4.3 | Phase 3: group mental model created

The group mental model was drafted by our research team (Figure 3, Phase 3). Audio-recordings of the 11 interviews were transcribed by professional transcribers at TranscribeMe (https://www.transcribeme.com) and used to construct a first draft of the group mental model. The group mental model was initiated based on responses (the audio recording, transcript, and notes in the draft individual model) from P1 about social and environmental context and site and people characteristics (tan box); project processes and possible improvements (blue box), benefits (green box) and costs (salmon box) and uncertainties (purple box) of weir remediation (Figure 3, Phase 3). New perceptions were added to the group mental model as the researchers reviewed each transcript and individual mental model for P2–P11. Each time a person's transcript and draft model was reviewed, new perceptions were added to the group mental model, including new perspectives at odds with those added earlier in the model development. The sequential adding of perspectives shared by each person was done to represent points of agreement and disagreement in the group mental model. Initially, supporting quotes from each person were included in the group mental model to provide context, and as key messages solidified as more people's perspectives were added, the quotes were removed (see a visualization of this in the workflow video; Januchowski-Hartley et al., 2022). Any disagreements were included first on the model itself and then denoted by superscripts and notes. Iteratively, the model was condensed, and the structure and terminology modified for clarity and brevity. The group mental model underwent extensive iteration during analysis of all 11 transcripts until a draft model was agreed by the research team.

2.4.4 | Phase 4: Group mental model shared and revised

Once our research team agreed on a draft group mental model it was distributed by email along with a short series of questions to each of the 11 people who were interviewed. The purpose of that step in the workflow was to generate further two-way dialogue and to ensure people's knowledge was represented as they wanted it to be, and that the model reflected the diverse views of people interviewed. Five of the 11 people responded to the email and questions from the research team, which led to further adjustments to the group mental model. The group mental model also underwent adjustments based on ideas and feedback from everyone in the research team, and again based on feedback during the peer-review

process (minor adjustments to color, font, etc.). The current version of the group mental model is conceptualized in Figure 3, Phase 4 and shows linkages and feedbacks between social and environmental context (pink box); structure site and people characteristics (turquoise box); project processes (blue box); benefits (green box) and costs (salmon box); and potential improvements (orange box) to weir remediation processes in the SRC.

3 | RESULTS

The group mental model showed that weir remediation processes are influenced by wider social–environmental context, such as drivers of fish decline, culture and heritage and governance, and by characteristics of the structure site (such as the weir's form and size, and river hydrology) and of interested parties (such as weir ownership, and perceived benefits and costs) (Figure 4). The group model showed that weir remediation project processes in the SRC broadly fit within 10 stages, including: (1) project idea or opportunity; (2) weir identified, data gathered, and feasibility assessed; (3) funding secured; (4) solutions and designs scoped and selected; (5) weir or landowner permissions gained; (6) planning and insurance permitted; (7) con/destruction contracts tendered and awarded; (8) actions undertaken; (9) river monitored; and (10) public engagement and partnerships built throughout the process (Figure 4). No project is failure-proof, and the group mental model visualizes points where failure was experienced in weir remediation projects in the SRC, including when funding or permissions from land or weir owners was sought, permits or insurance was applied for, and when actions were taken (e.g., a weir being in worse condition than anticipated from preliminary assessments) (Figure 4). The group mental model also showed the types of benefits (e.g., gained eco-hydrological connectivity, human well-being) and costs (e.g., material and labor costs, and structure maintenance) that people perceived to result from different weir remediation projects in the SRC (Figure 4).

The group shared 10 ways to improve weir remediation project processes in the SRC, which require planning and actions to change broader social–environmental context (Figure 4). Below we present brief narratives for each of the 10 ways to improve weir remediation project processes as shown in the group mental model (Figure 4). We situate the narratives for the 10 ways to improve in relation to project stages, particularly those identified as potential failure points (Figure 4). We refer to the 10 ways to improve as those identified by the group, rather than highlighting the number of people who raised a point or not; exemplar quotes are used to support the narrative and attributed to the person who said it (P1, P2, etc.). We have taken this approach because what we summarize is a negotiated mental model and even the two points of disagreement to do with whether weir removal is an improvement (Figure 4), and drivers of fish decline (Figure 4) were reviewed and agreed by those people who responded to our circulation of the group mental model.

3.1 | Implement national and catchment-scale planning

Implementation of catchment-scale planning was identified to improve current approaches to weir remediation planning, because "you will never achieve catchment-wide restoration until there are policy drivers and government behind it" (P7). It was also argued that a coherent national strategy should shape where weirs are removed and where fish passes are built. People noted that catchment and systematic approaches were needed to reconnect water- and landscapes, rather than the status quo in the SRC and the UK more broadly, which is "randomly dealing with barriers" (P5) such as weirs, dams, and road culverts that obstruct river and species movements.

3.2 | Improve funding

Funding was perceived as a major point of failure in weir remediation projects (Figure 4) that is influenced by broader social–environmental context of governance, and public institutions and priorities (Figure 4), as stated by P7: "There isn't a lovely bank of river restoration just waiting to be tapped into. You have to [...] make a case and find a funding source all the time. [...] In this country our management of the environment [...] moves with what are the highest priorities at the time". Unlike other restoration actions, seeking funding to remove something like a weir was perceived to be challenging because "it is easier to raise money if you've got something tangible at the end. It is very hard to raise money when you say, I'm going to take away something, and you won't see anything at the end of it" (P7). The group suggested funding could be improved by allowing the build-up of funds over time to enable restoration works to be carried out in a coordinated way because, "sometimes you just get an amount, and you're trying to sort of fit a fish passage solution to that" (P5). They also suggested that there was a need for increased and directly allocated funding from government to support public engagement throughout project processes.

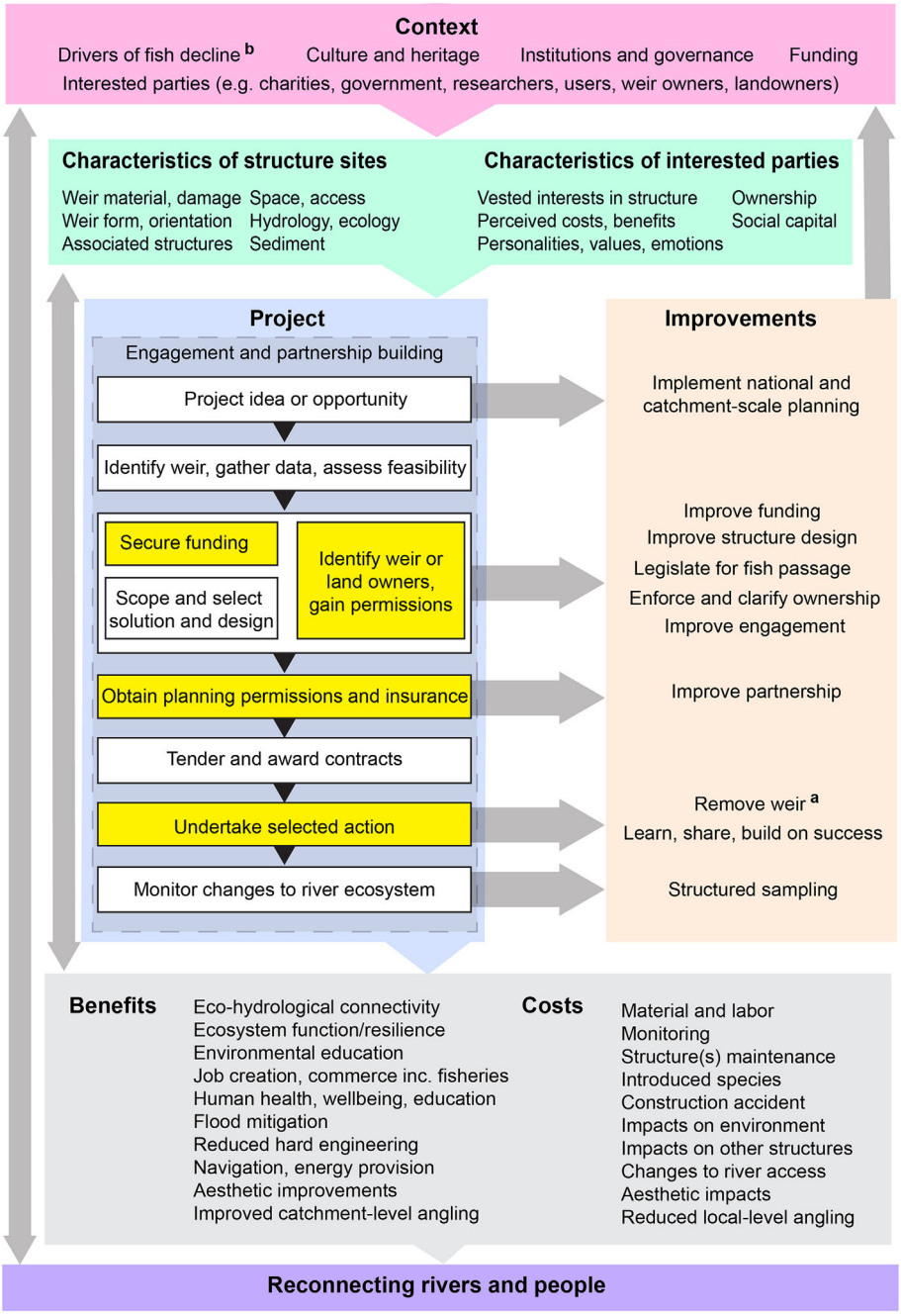

FIGURE 4 A group mental model of weir remediation processes in the Severn River Catchment, United Kingdom based on interview responses and individual mental models from 11 people actively involved in weir remediation in the Severn River Catchment. The model shows context, characteristics of structure sites and people, project processes and potential ways to improve weir remediation efforts, and benefits and costs associated within the reconnection of rivers and people. Context includes social and environmental factors that indirectly influence weir remediation project processes. Characteristics of structure sites (i.e., of the weir and its location) and people directly affect weir remediation project processes. Project is the process of weir remediation and consists of multiple stages, some of which can act as failure points that substantially delay or abort a planned action. Improvements are areas where people perceived project processes in weir remediation could be improved, and these require planning and actions to create change within the broader social and environmental context. Completed weir remediation projects generate benefits and costs that influence the reconnection of rivers and people. Single-headed arrows indicate how the model flows. Doubleheaded arrows show the linkages and feedback that can also occur between the different model components. Points of divergence in the group mental model are indicated with superscript letters. The visual presentation of the model was modified from Hughes et al. (2017).

3.3 | Legislate for fish passage

Currently in the UK, under the Salmon and Fisheries Act (1975) (see https://www.legislation.gov.uk/ukpga/1975/51) fish passes must be built at any newly constructed weirs, including pre-existing structures with more than half the length destroyed or modified. However, guidance under the Salmon and Fisheries Act (1975) does not apply to existing weirs that are not otherwise partially (>50%) destroyed or modified. It was suggested that things were "supposed to be changing with government legislation coming in stating that if you're an owner of a structure you need to provide adequate fish passage" (P2). The group agreed that remediation projects would be more effective if existing legislation extended to weirs that are already in place and enforced the maintenance of the structure by owners in ways that promote river health and fish passage.

3.4 | Enforce and clarify ownership

Locating and gaining permissions from land and weir owners was perceived as a major point of project failure in the SRC. As stated by P2, complications with weir ownership can result in project failure or result in eroding relations with surrounding community members: "We were going to put a fish pass on [the weir] and we had permission from the landowner, we had the funding in place, and when we got to it [...] the thing was falling apart. We couldn't put a fish pass on it. [...] So, we had permission from a landowner to take that [weir] down, which he wasn't particularly happy about [...]". More specifically, P7 stressed the impact that a lack of weir ownership can have on project planning and overall effectiveness: "you can have a weir that's been there for 300 years. And, yes, some of them are owned, normally only to the midpoint [of the structure]. [...] You end up with two weir owners [...] or they're not owned at all. There is no liability on the actual owner. [...] A weir is a liability. They are effectively dangerous in the sense of—for humans. But there is no ownership. There's no one who is liable for that. So that makes a big difference". It was stressed that improved weir ownership accountability would ensure impacts on people/nature are mitigated: "If I was going to walk into government and say, "Please do one thing", I would say, right, "Everything has to be owned. And if it isn't owned, then it should be removed" (P7).

3.5 | Improve engagement

Everyone acknowledged engagement with members of the public occurred in projects that they were involved with in the SRC. It was also acknowledged that engagement activities associated with the Unlocking the Severn project occurred from "concept development and feasibility study and then throughout at each stage [of the process]" (P1). The group also identified that if budgets were limited, engagement could happen "only at key times—e.g., scoping, undertaking action and completion" (P1). At the same time, current approaches to engagement were identified as something that could be improved, particularly in relation to how people are consulted, such as hosting earlier consultations to better understand and consider people's different perceptions and preferences in removal and/or fish pass scenarios.

3.6 | Improve partnership

It was suggested that greater partnership working across the many sectors involved in caring for rivers would improve weir remediation project processes. This could include working directly between government agencies (e.g., Environment Agency or Natural Resources Wales) and river-charities, as well as with landowners and angling groups, to improve fish habitat. The group agreed that cross-sector and public partnerships needed to form earlier in project processes (e.g., within planning stages) to ensure different perspectives are considered. They also suggested involving contractors who design and build the weirs when exploring different remediation options and working closely with landowners to anticipate problems associated to project implementation and to develop more acceptable outcomes.

3.7 | Improve structure design

All weirs and fish passes have a life expectancy, and it was noted that fish passes in the SRC "have a sort of 60, 70-year lifecycle to them" (P2), and that "the ones [...] on the main Severn I think have 100 years" (P7). Given that full weir removal had been limited in the SRC, concern was expressed by several people about weir retention and building more infrastructure alongside them. For example, P4 alluded to the need to improve the design and materials used so to minimize the footprint of structures and to increase their lifespan. For P10 it involved improving the design aesthetics, which is complicated by the requirements made by different local government authority requests to ensure newly built fish passes don't match the historic weirs they are built alongside. The need to consider bi-directional movement of species in fish pass designs (P4) and to engage engineers earlier in projects was suggested so that designs could be included in funding pursuits and minimize delays (P9).

3.8 | Remove structure

Agreement was not reached in the group as to whether full weir removal is an improvement over other remediation methods that tended to be used in the SRC, such as retain weirs and construct fish passes built alongside them (Figure 4a). Those who perceived full weir removal to be an improvement over other remediation methods noted that it is better for the environment and people than constructing fish passes, which are suboptimal for fish movement and have limited lifespans. These people also acknowledged the heritage values that others hold for weirs, stating that: "[...] a lot of weirs across the catchment [...] have links to our industrial heritage. They can't all be removed [...] but I'd like to see them removed to allow for the natural processes of the river to be able to be undertaken" (P2). P2 also shared disappointment about not removing weirs in the case of the Unlocking the Severn project: "The only sad thing, if I'm honest is that we couldn't take the weirs out... [... removal is] the absolute preference because no barrier—no fish pass—no maintenance, so it's an absolute permanent decision". Others believed the lack of removal "greatly reduced the benefit" (P9) or shared concern for the low number of weirs removed compared to fish passes constructed in the SRC, and UK more broadly: "I think we put fish passes on too many of them, and I say that as someone who designs fish passes for a living. I mean, I've designed or been involved in design [...] for probably 200 fish passes, and I think we've removed or been involved in the removal of five weirs" (P4).

People who did not believe more full weir removals would be an improvement over the status quo in the SRC also did not perceive weirs to contribute to fish declines (Figure 4b), stating that: "if [the weir] lasted 1,000 years like that, it's not really getting in the way much, is it? It's not stopping fish doing what they want to do or any other sort of wildlife. [...] Changing the weir would change that environment to something else which may be what was there before, or it may be something totally different. So, to my mind, doing nothing is certainly an option" (P10). Weirs were perceived by these people to be historical and environmental assets that have not contributed to fish declines, and that "there's a lot less [fish] than there used to be, but it's certainly not due to the weirs because weirs have been there 150 years" (P11).

3.9 | Learn, share, build on success

The group acknowledged project failure can occur while doing works in the river. For example, P4 shared that at one site in the SRC (not part of Unlocking the Severn project) they could not build a fish pass because of the condition of the weir and so the team removed the weir, and that resulted in a "big internal review about it as to whether [they] were doing a good enough job of ascertaining whether a weir could be removed". Learning from that failure, P4 went on to change decision-making processes related to weir removal: "in terms of really pushing [for] weir removal as the first option [...] because it's the best solution". In addition to this example, most people believed that weir remediation, and other restoration efforts, would benefit from more learning, sharing, and building on the successes in the SRC, other catchments, and countries, for example P4 noted that: "it always feels with fish pass work that every country is kind of siloed and doing its own thing, like the French do their thing their way, the Germans do their thing their way, we do our thing our way, the Americans do their thing their way, and [...] there isn't a great deal of learning from one another".

3.10 | Structure sampling

Sampling and monitoring of fish communities, movement, and the riverine habitat before, during, and after removals or construction, was perceived as something that would help inform future projects and measure the success of existing ones. Monitoring was seen as important, because "we will never learn what the best thing to do is until we understand what we have done and has it been helpful" (P7). Monitoring has also been part of the Unlocking the Severn project, but agencies and charities in the UK do not normally have monitoring budgets (P5, P7). It was perceived that monitoring, such as that established for Twaite shad, would benefit from increased and allocated funding, and such programs would broaden opportunities for engagement with people near and far through continued experiential learning.

4 | DISCUSSION

Weir remediation to improve connectivity within rivers is gaining traction around the world and governments are setting ambitious targets to reconnect rivers (e.g., https://environment.ec.europa.eu/strategy/biodiversity-strategy-2030_en), but there remains little research investigating how projects are carried out, identifying factors that facilitate or hinder action implementation, or possible ways that processes could be improved to reconnect more rivers. We interviewed and created a group mental model with 11 people actively engaged in multiple weir

remediation projects in the Severn River Catchment, UK and identified 10 ways weir remediation processes could be improved to reconnect more rivers. Our findings suggest there is a need to move beyond opportunistic projects and establish national goals and catchment-scale plans for weir remediation; reform fish passage legislation and legislate weir ownership; and build cross-sector and public partnerships to encourage removal or improved designs. These calls to action are directed at policy makers and anyone already engaged in or envisioning weir remediation projects in the UK and have potential implications and relevance to other countries in Europe and beyond.

4.1 | Calls to action to reconnect more rivers

4.1.1 | Move beyond opportunistic projects: establish national goals and catchment-scale plans

People actively engaged in weir remediation projects see a need for national and catchment scale coordination in the UK. National scale goals are needed to identify weir removal funding needs and directions, and this requires structured decision making that explicitly sets objectives (e.g., maximize outcomes for all non-human/human species under constraints), and considers costs, benefits, uncertainties, and feasibility of actions in certain regions or catchments (see Giakoumi et al., 2015). Currently, the selection of weirs for removal in the UK is opportunistic (de Leaniz & O'Hanley, 2022) and based on local knowledge from a subset of people. Although opportunistic decision-making can leverage local interests (Neeson et al., 2015), it is only at broader scales, such as catchments, that the cumulative impact of structures like weirs (and others: dams, culverts, etc.) can be addressed efficiently (Hermoso, Clavero, et al., 2021; Hermoso, Vasconcelos, et al., 2021).

We suggest there is a need for systematic approaches (e.g., Hermoso, Vasconcelos, et al., 2021) to catchment-based planning to account for the dynamic and interconnected nature of rivers with other fresh waters, land, and sea. This would help ensure that the weir remediation that does occur is effective in achieving the goals of reconnecting rivers for multiple species, including those that use the full extent of rivers (e.g., Atlantic salmon (*Salmo salar*) and Twaite shad among others) as opposed to only a local river reach (see Cañedo-Argüelles et al., 2019). Systematic approaches can also insure people's values and perspectives are explicitly accounted for in planning, and doing so has been shown to result in more efficient river restoration solutions compared to the opportunistic approach (Cañedo-Argüelles et al., 2019). In the UK, such systematic approaches would be implemented well within emerging catchment-based partnerships pursued through the Catchment Based Approaches (see https://catchmentbasedapproach.org/) in England and Wales.

4.1.2 | Push for change: reform fish passage legislation and legislate weir ownership

Our findings showed that there is a need for improved policies in relation to both fish passage in rivers and weir ownership. As stated in our first call to action, there is a need to align policies related to weir remediation in the UK to deliver the greatest benefit for all species, and there is a further need to ensure public safety.

In the UK, the existing fish passage legislation, the Salmon and Freshwater Fisheries Act (1975), divides salmon and 'migratory' trout from all other freshwater fishes. The legislation establishes that fish passes must be constructed and maintained when a weir is either completely or partially constructed in any waters "frequented by salmon or migratory trout". That means that rivers that either never did, or no longer do, support salmon or trout are not covered under the existing fish passage legislation. There is a need and opportunity to change this division of fish because rivers support more than salmon and trout and global biodiversity goals require that the full range of species are conserved. Additionally, fish species judged negatively by some could concurrently be considered important by others. Labels like 'sport fish' attached to specific species can give rise to a dichotomy in attitudes toward certain fish species (Rypel et al., 2021) and can create a zero-sum game mentality that leads to river management and policies (like the existing Salmon and Freshwater Fisheries Act (1975)) that are exclusionary and less effective (Sass et al., 2017). As stated, the Salmon and Freshwater Fisheries Act (1975) focuses the regulatory need for fish passes on the movement and migration needs of two strong swimming and economically important species—salmon and trout. It cannot be assumed that locations or designs selected for fish passes to benefit salmon or trout will benefit other species. Studies have shown that such assumptions about fish pass location and designs to benefit a single strong swimming species can lead to the exclusion of other fish species (Silva et al., 2018). Further, the Salmon and Freshwater Fisheries Act (1975) overlooks existing weirs, it focuses on the need for fish passes at construction sites of either completely or partially new structures. That means that the existing Salmon and Freshwater Fisheries Act (1975) does not cover most weirs in the UK. A reform is needed to the fish passage legislation to

clarify that priority be given to proposed weir remediation actions that deliver maximum benefit for all fish species, and that this extends to *all* rivers not only those frequented by salmon and trout. With a growing national (Jones et al., 2019) and international (Belletti et al., 2020) interest in weir removal and fish pass construction, now is a time to revisit the Salmon and Freshwater Fisheries Act (1975) to ensure it enables more effective solutions by recognizing the diversity of fish species that reside in UK rivers and that existing weirs can also obstruct the movement and habitat use of those fishes.

Finally, The UK needs more clarity on weir ownership. To our knowledge, and that of the people we interviewed, there is no existing legislation in the UK that ensures weirs are owned by someone—either an individual, collective, or the State. A lack, or lack in clarity, of ownership can result in complete derailing of planned weir remediation projects, because no one can or wants to take responsibility for a structure, and planned actions are aborted. Legislating to ensure weir infrastructure is owned would ensure greater accountability, transparency, and minimize barriers to action. Weir ownership policy is important to ensure proactive planning to identify weirs that are safety risks and promote public safety (Vahedifard et al., 2021 discuss this in relation to the United States) and is particularly important in the UK and Europe where many weirs are already beyond their projected lifespan (Habel et al., 2020). Currently, thousands of weirs *have not* been inventoried or evaluated for age or safety (see Jones et al., 2019). Addressing weir ownership legislation in the UK is critical for public safety.

4.1.3 | Build cross-sector and public partnerships to encourage removal or improved designs

Cross-sector and public partnerships in catchment-scale planning are essential for effective planning, design, and implementation of weir remediation actions, and is meant to be ensured under Europe's Water Framework Directive (Symmank et al., 2021). Working to improve and identify best practices for how to build lasting relationships across sectors and with broader publics will help to deliver the European Union's, and potentially responsible agencies in the UK, commitment to reconnecting at least 25,000 km of river across the continent by 2030 (see https://environment.ec.europa.eu/strategy/biodiversity-strategy-2030_en). Establishing cross-sector engagement and invitations for broader publics to be involved in catchment planning and prioritization, would generate opportunities for local people's knowledge to be integrated into weir remediation plans (Skubel et al., 2019) and potentially support greater buy-in for action (Tonitto & Riha, 2016). For example, in South Cumbria, UK, a non-government agency's proposal to remove a weir was agreed by local people as long as their ideas for interpretation materials to be installed at the weir's former location to highlight its historical significance were agreed as well (see https://www.bbc.co.uk/news/uk-england-cumbria-60602736).

Public awareness campaigns that establish the risks of aging weirs, highlight weir remediation impacts on human and non-human species, provide examples of successes to date, and that clarify steps people can take to become involved would help grow the community of people who support weir removal and champion successes for reconnecting rivers and people (see https://www.nature.org/en-us/newsroom/new-jersey-low-head-dam-safety-awareness-month-april-2022/ for an example of how that can be achieved). In the SRC, people we interviewed felt that small successes and communication about these led to broader public acceptance of larger, more effective projects in the catchment. Communication and knowledge of successful projects can action people's support of larger projects (Nash et al., 2017) and broaden the group of people who lobby government for fish passage and weir ownership legislation to support reconnecting rivers and people across the UK and beyond.

5 | FUTURE DIRECTIONS

Our study was a first step in understanding weir remediation in a catchment in the UK, and there is ample room for further studies in this area. We found broad agreement from those involved in creating our group mental model on the process for weir remediation and the areas for improvement. The overlap suggests our model is robust and can be a useful starting point to inform both weir remediation science and practice. One of the only areas of divergence within the group mental model was associated with the impact of different weir remediation actions. Further studies into the relative impact of different forms of weir remediation can help inform the public and generate greater consensus on the best solution for people and the environment. On the other hand, the 10 areas for improvement point to policy modifications which would facilitate the weir remediation process and the contribution of projects to global and local goals. The group mental model we have presented here can also be used as a starting point to work toward a shared vision for catchment-scale planning.

AUTHOR CONTRIBUTIONS

S.R.J., M.T., and M.M. conceived the idea and designed the study. S.R.J. and M.T. collected the data. M.T. and S.R.J. analyzed the data and wrote the manuscript with support from R.B. S.R.J. led the writing of the manuscript with support from M.T., R.B., and M.M. All authors approved the final submitted manuscript for publication.

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DATA AVAILABILTY STATEMENT

Due to confidentiality, interview files and transcriptions are only accessible to the authors.

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