Physical enrichment research for captive fish: Time to focus on the DETAILS

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Abstract
Growing research effort has shown that physical enrichment (PE) can improve fish welfare and research validity. However, the inclusion of PE does not always result in positive effects and conflicting findings have highlighted the many nuances involved. Effects are known to depend on species and life stage tested, but effects may also vary with differences in the specific items used as enrichment between and within studies. Reporting fine-scale characteristics of items used as enrichment in studies may help to reveal these factors. We conducted a survey of PE-focused studies published in the last 5 years to examine the current state of methodological reporting. The survey results suggest that some aspects of enrichment are not adequately detailed. For example, the amount and dimensions of objects used as enrichment were frequently omitted. Similarly, the ecological relevance, or other justification, for enrichment items was frequently not made explicit. Focusing on ecologically relevant aspects of PE and increasing the level of detail reported in studies may benefit future work and we propose a framework with the acronym DETAILS (Dimensions, Ecological rationale, Timing of enrichment, Amount, Inputs, Lighting and Social environment). We outline the potential importance of each of the elements of this framework with the hope it may aid in the level of reporting and standardization across studies, ultimately aiding the search for more beneficial types of PE and the development of our understanding and ability to improve the welfare of captive fish and promote more biologically relevant behaviour.

Keywords
environmental complexity, environmental enrichment, fish husbandry, fish welfare, structural complexity, structural enrichment

1 | INTRODUCTION

Fishes represent important laboratory animals, with increasing numbers of species used as model organisms in research (Braasch et al., 2015; Laland et al., 2011; Powers, 1989; Schartl, 2014; Utne-Palm & Smith, 2020). Increasing the diversity of model organisms can be a boon for research (Alfred & Baldwin, 2015) and fishes, as the most numerous group of vertebrates, are of interest to many researchers. Fishes encompass a range of important ecological roles and specific niches with exceptionally diverse communities, for example in coral reef fishes (Stuart-Smith et al., 2013) and rift lake cichlids (Muschick et al., 2012), and represent a considerable diversity of morphology, behaviour and reproductive biology (Fernö et al., 2020; Helfman et al., 2009; Wootton & Smith, 2014). In addition to research...
opportunities, a large variety of species of fish is also kept in captivity for aquaculture and ornamental pets. When keeping animals in captivity, housing conditions play an important role in the welfare of captive animals and environmental enrichment is an important component of these conditions (Mason, 2010; Newberry, 1995; Shepherdson et al., 1999; Swaigood, 2007). However, relatively little is known about what enrichment to provide for most fishes in captive settings or the effectiveness of the different kinds of enrichment available. Comparatively few studies on the effects of enrichment have been conducted on fish, with an analysis of the literature in 2007 revealing that fish were subjects in less than 0.5% of all enrichment studies conducted on vertebrates (de Azevedo et al., 2007). Of those studies involving fish, most are focused on relatively few species, with a focus on salmonids and zebrafish, Danio rerio (Hamilton 1822) (Näslund & Johnsson, 2014). This relative lack of knowledge is increasingly important to address as there is a mounting drive to improve and regulate welfare for fish species kept in captivity for research, aquaculture or ornamental reasons (Browman et al., 2018; Jacobs et al., 2018; King, 2019; Saraiva et al., 2019; Sloman et al., 2019; Sneddon et al., 2017; Stevens et al., 2017).

Physical enrichment (PE), also referred to as structural enrichment, is a form of environmental enrichment that generally refers to any form of physical complexity added to housing for captive animals. Physical structure has long been known to provide potential benefits for fish and a heterogeneous environment can provide shelter from water currents, reduce aggression from other fish and act as landmarks around which to establish territories (Kalleberg, 1958). Knowledge of the importance and potential positive effects of PE has increased as research interest and effort has grown. It is now understood that adding PE to fish housing can have significant effects and may provide a range of potential benefits, both in terms of welfare for the fish, but also for research validity, where different housing and rearing environments can result in behavioural differences across studies involving the same species (Webster & Rutz, 2020). Experiments on effect of enrichment can also be relevant for the aquaculture industry as some studies of common aquaculture species have highlighted positive effects of enrichment. For example, PE has been shown to result in lower levels of cortisol in captive Atlantic salmon, Salmo salar (L. 1758), and Chinook Salmon, Oncorhynchus tsawytscba (Walbaum, 1792) (Coguiati et al., 2019b; Näslund et al., 2013; Rosengren et al., 2016), and is a commonly ascribed tool to reduce stress in captive fish and improve welfare (Sneddon et al., 2016; Stevens et al., 2017). When discussing potential benefits of PE, we need to be clear what the beneficial outcomes can be for the fish in terms of welfare, better health, more stimulating environment, and also for scientists and aquaculturists where benefits may include improved survival and more ‘natural’ behaviour and physiological responses. Whether or not PE provides any benefit also depends on what that benefit is, how the ‘benefit’ is being valued and its connection to the goals of the enrichment programme. For example, a detailed study of the effect of PE on Atlantic salmon, S. salar, showed a welfare benefit for the fish from PE with reduced levels of cortisol and stress from disturbance, while mean growth was lower than in unenriched tanks (Rosengren et al., 2016). Decisions as to what PE to add to housing for fish must also take into account the pragmatic consideration of the need for usability and ease of maintenance (Lidster et al., 2017). Research into the effects of PE is the primary way to inform these decisions.

There is a host of potential benefits afforded by enriched environments. Shelter provided by PE can reduce metabolic costs (Chrétien et al., 2021; Finstad et al., 2007; Millidine et al., 2006). This, in conjunction with reduced levels of stress, may result in improved growth rates observed in Oncorhynchus mykiss (Walbaum, 1792) (Voorhees et al., 2020; White et al., 2019) and other species provided with shelter (Batzina & Karakatsouli, 2012; Zhang, Bai, et al., 2019). The presence of PE can result in less physical damage to fishes, for example less dorsal fin damage was observed in structurally enriched tanks (Berejkian, 2011), and reduce the frequency of potentially damaging escape-related behaviours (Zimmermann et al., 2012). Provision of PE may even increase survival in disease epidemics, for example juvenile S. salar reared in enriched environments showed greater survival in an outbreak of fish pathogen Flavobacterium columnare (Davis 1922) than fish raised in standard hatchery conditions (Rihâhâ, 2019). A physically enriched environment can also promote the development and expression of more varied and more ecologically relevant behaviours (Braithwaite & Bergendahl, 2020; Brown et al., 2003; Sundström & Johnsson, 2001; Ullah et al., 2017), affect brain physiology and development (Arehavala-Lopez et al., 2020; DePasquale et al., 2016; Fong et al., 2019; Mes et al., 2019; Salvanes et al., 2013; Ullah et al., 2020), and promote learning and performance in cognitive tests (Carbia & Brown, 2019; Roy & Bhat, 2016; Salvanes et al., 2013; Strand et al., 2010). Such positive effects of PE can result in improved survival in programmes where fish are raised in captivity for eventual release into the wild (Hyvärinen & Rodewald, 2013; Johnsson et al., 2014; Lorenzen et al., 2010; Mes et al., 2019; Salvanes & Braithwaite, 2006). However, enrichment is not always found to increase post-release survival (Brockmark et al., 2007; Solas et al., 2019; Tatara et al., 2009). Moreover, as Näslund and Johnsson (2014) pointed out in a comprehensive review of PE there are many nuances that can impact the effects of PE on fish behaviour and welfare. The presence of PE is not always beneficial. While some studies showed improved cognition and brain growth in fish kept in structured environments, other studies found no effect (Brydges & Braithwaite, 2009; Näslund et al., 2019; Toli et al., 2017) or even negative effects (Burns et al., 2009) of exposure to PE. Similarly, despite zebrafish (D. rerio) displaying preferences for PE in choice tests (DePasquale et al., 2019; Schroeder et al., 2014), heavily enriched aquaria can lead to increased aggression and lower growth in the same species (Woodward et al., 2019). Despite these many examples of positive effects found in studies of enrichment, knowledge gaps remain, highlighted by contradictory findings. There is limited knowledge on the types of enrichment that have effects and how they work (e.g., physiological and neurological processes). The general level of understanding might be summarized as some PE is better than none, some of the time.

What are the proximate reasons for fish to benefit from physical structure in captivity? In the most general sense structure can provide
shelter and protection from the physical environment and protection against other animals. The availability of shelter may be enough to provide benefits. One study showed that Atlantic salmon rested outside of shelters and suggested that the mere presence of a shelter was enough to significantly reduce metabolic rates (Millidine et al., 2006). There are many studies that show that fish use structure as a form of antipredator refuge, and this may be the ultimate driver for use of and benefit from structure where protection from currents was secondary to protection from predators (Valdimarsson & Metcalfe, 1998). PE may afford refuge from many other things, including artificial lighting (McCart et al., 1997), intraspecific competition and aggression. Physical heterogeneity can potentially reduce aggression in territoriality species by, as in the rose bitterling Rhodeus ocellatus (Kner, 1866), affording landmarks that can be used to delineate territories, leading to reduced aggression between rival individuals (Smith, 2011). Similarly, individuals within a population can show specific characteristics which can lead to individual differences in shelter use. For example, in the wild older (and larger) female sockeye salmon, Oncorhynchus nerka (Walbaum, 1792), were shown to prefer and utilize deep-water refuges (Camacho & Hendry, 2020) while fish of other ages and sex clustered in different depths. These differences were attributed to the fact that larger females are more vulnerable to predation from bears when they return to spawn. Knowing the function of shelter use for a given species could allow researchers to select the optimum types of PE.

Despite the potential importance of PE, a survey of articles published in fish biology-focused journals (between 2003 and 2013) suggested that more than 70% of studies did not use any PE (Näslund & Johnsson, 2014). This is no doubt partly driven by one of the major challenges of using PE: adding PE to a tank can increase the difficulty of and time required for cleaning. A recent survey of husbandry practices in research laboratories highlighted this issue, with more than 60% of survey respondents considering provision of PE a challenge that required intensive labour and was thought to lead to an increased chance of disease (Lidster et al., 2017). Developing forms of PE which can provide welfare benefits while reducing maintenance costs is an important challenge that will require further research into the various factors that can impact the costs and benefits of PE. It will also require the improvement of the standardization and reproducibility of studies exploring enrichment.

1.1 | Aims and scope

In this article we look at the current state of the research into PE, focusing on the specific forms of enrichment provided in studies. We conducted a survey of the recent literature to collate a representative selection of published articles and record the level of methodological detail currently reported. We point out issues that are commonly lacking when reporting results and make some recommendations for future work based on the survey results and recent publications which point towards potentially useful avenues of research for the field of enrichment. Our survey and review are focused on recent studies, those published since 2015 when Näslund and Johnsson (2014) highlighted several important considerations for the field. Most pertinent to this article, they revealed that the effects of PE vary markedly across studies and suggested that future studies should attempt to differentiate more nuanced effects of different PE. The aim of our review is to extend this idea, specifically highlighting the need to understand what and why specific items of PE are used in studies. We provide a framework which we hope will help to guide researchers to consider and report more of the characteristics of the enrichment they use. We think more refined reporting, resulting ease of attaining higher levels of standardization and a deeper understanding of what PE to use at fine-scale levels will address the issues raised by Näslund and Johnsson (2014) and other authors (Huntingford et al., 2006; Toni et al., 2019).

2 | SURVEY APPROACH

To examine the current status of PE research in fish biology and the levels of reporting of PE details, we conducted a nonexhaustive survey of published research articles where PE was the focus or an important part of the aim of the study. In line with our aims this survey was used to collect a representative sample of papers currently published in the field rather than to conduct a formal meta-analysis. To do this one author (NJ) used Web of Knowledge to search for all papers with the terms ‘physical enrichment’ and/or ‘structural enrichment’ and/or ‘environmental enrichment’ and ‘fish’ from 2015 to May 2020. The resulting research papers that described experiments which included investigation of the effect of PE on captive fish were selected and included in the survey. For each paper, the introduction and methods sections were checked for the methodological details they reported, focusing on the description of PE used. We chose to collect data from the last 5 years to get a snapshot of the more recent PE-focused work and further the comprehensive review by Näslund & Johnsson (2014) which highlighted the importance of and nuances that can impact the effects of PE on captive fishes.

For each study we recorded the category of PE reported, for example whether a particular item of PE was a substrate or shelter, then recorded the general type of PE where an item of PE belonging to a substrate category could be gravel, sand or mud. For each type of PE, we recorded whether additional details were provided, such as the manufacturer and name of plastic plants, species name of live plants or some description of the shelter provided (e.g., clay pot or PVC pipe). For each of these specific types of PE we recorded whether the specifications of those PE items were provided, for example the grain size and colour of gravel, length and diameter of PVC pipe, or the number, colour and size of leaves on plastic plants. We also recorded the amount of these PE items, for example numbers of plants added to the aquarium or the depth of gravel substrate. In addition, we recorded whether the rationale for the use of the PE was explicitly stated, essentially whether the PE used was chosen based on previous studies or in an attempt to mimic certain, normally wild, conditions.
| PE category | Type/rationale                          | Details                                      | Amount/dimensions | Duration | Water parameters                                                                 | Photo-period/lighting details | Fish density*/parasite check | Species | Stage/origin | Study               |
|-------------|----------------------------------------|----------------------------------------------|-------------------|----------|---------------------------------------------------------------------------------|------------------------------|----------------------------|----------|--------------|---------------------|
| Plants      | Plastic/No                            | Green and red Hairgrass, Petco Animal Supplies, San Diego, CA | Yes/Yes           | 21       | °C, conductivity, pH, alkalinity, ammonia, nitrite, nitrate                      | 14:10 L:D/No                 | No/Yes                    | D. rerio | A/CB         | Collymore et al., 2015 |
| Substrate   | Gravel/Yes                            | No                                           | Yes/Yes           | V        | No (natural source flow-through)                                                | 0:24 L:D/Dark                | No/No                     | S. salar | L/H          | Evans et al., 2015   |
| Shelter     | In-tank structure/No                  | Plastic bricks                               | Yes/No            | 14       | No                                                                              | No/No                       | No/No                     | O. fasciatus | J/H           | Makino et al., 2015  |
| Plants      | Plastic/No                            | Mock seagrass, Tanaka Sanjiro                | Yes/Yes           |          | °C, pH                                                                          | 12:12 L:D/No                 | No/No                     | D. rerio | M/CB         | Manuel et al., 2015  |
| Shelter     | In-tank structure/No                  | Artificial rock formation                    | No/No             |          | °C                                                                              | 12:12 L:D/No                 | Yes/No                    | O. mykiss | J/H          | Bergendahl et al., 2016 |
| Substrate   | Gravel/No                             | Fine grain                                   | No/No             | V        | °C                                                                              | 12:12 L:D/No                 | Yes/No                    | C. gariepinus | J/H          | Boerrigter et al., 2016 |
| Shelter     | In-tank structure/No                  | Black plastic pots                           | No/Yes            |          | °C                                                                              | 12:12 L:D/No                 | Yes/No                    | D. rerio | J/CB         | DePasquale et al., 2016 |
| Plants      | Plastic/No                            | Plastic shelter                              | Yes/No            | 78       | °C                                                                              | 12:12 L:D/No                 | No/No                     | D. rerio | A/CB         | Giacomin et al., 2016 |
| Substrate   | Gravel/No                             | No                                           | No/No             |          | °C                                                                              | 14:10 L:D/No                 | No/No                     | D. rerio | A/CB         | Giacomin et al., 2016 |
| Substrate   | Sand/No                               | No                                           | No/No             |          | °C, pH, dissolved oxygen, hardness, alkalinity, ammonia                       | 14:10 L:D/No                 | No/No                     | D. rerio | A/CB         | Giacomin et al., 2016 |
| Shelter     | In-tank structure/No                  | Caps                                         | No/No             |          | °C                                                                              | 12:12 L:D/No                 | No/No                     | D. rerio | J/CB         | DePasquale et al., 2016 |
| Plants      | Live/No                               | Cabombaceae and Pontederiaceae               | Yes/No            |          | °C                                                                              | 12:12 L:D/No                 | No/No                     | D. rerio | J/CB         | DePasquale et al., 2016 |

*Fish density refers to the number of individuals or density of fish in the aquarium.
| PE category | Type/rationale | Details | Amount/dimensions | Duration | Water parameters | Photoperiod/lighting details | Fish density*/parasite check | Species | Stage/origin | Study |
|-------------|---------------|---------|-------------------|----------|------------------|----------------------------|-------------------------------|---------|--------------|-------|
| Substrate   | Sand/Partial  | Smooth yellow sand | No/Partial | V        | "C, pH, ammonia, nitrite, nitrate | 12:12 L:No | No/No | R. clavata | J/CB | Greenway et al., 2016 |
| Substrate   | Gravel/Partial | Course gravel | No/No            |          |                  |                            |                               |         |              |       |
| Substrate   | Plastic bottom/No | Grey plastic | No/No            |          |                  |                            |                               |         |              |       |
| Substrate   | Sand/No       | Black       | No/No            |          |                  |                            |                               |         |              |       |
| Substrate   | Sand/No       | White       | No/No            |          |                  |                            |                               |         |              |       |
| Plants      | Live/Partial  | Algae (Ascophyllum nodosum, Fucus vesiculosus) | No/No |          | "C, pH, ammonia, nitrite, nitrate | 12:12 L:No | No/No | O. mykiss | J/H | Kientz & Barnes, 2016 |
| Shelter     | In-tank structure/Yes | Artificial refuge (bricks with a plastic lid) | No/No |          |                            |                            |                               |         |              |       |
| Shelter     | In-tank structure/Yes | Vertically oriented round aluminium rods | Yes/Yes | 51         | "C, pH, dissolved oxygen, hardness, alkalinity, dissolved solids | No/No | Yes/No | O. mykiss | J/H | Pounder et al., 2016 |
| Other       | Water movement/Yes | Controlled water velocities in the tank | NA/Yes |          |                            |                            |                               |         |              |       |
| Substrate   | Gravel/No     | No          | No/No            |          |                  |                            |                               |         |              |       |
| Plants      | Plastic/No    | No          | No/No            |          |                  |                            |                               |         |              |       |
| Shelter     | External shelter/No | Overhead cover | No/No |          |                            |                            |                               |         |              |       |
| Shelter     | In-tank structure/Yes | Artificial refuge (shredded black polyethylene) | Yes/Yes | 231        | "C, dissolved oxygen | Natural light/NA | Yes/No | S. salar | J/CB (F1) | Rosengren et al., 2016 |
| Shelter     | In-tank structure/Yes | Eucalyptus tree logs | Yes/No | 60         | No | Natural light/NA | Yes/No | P. lineatus | J/H | Saraiva & Pompeu, 2016 |
| Plants      | Plastic/No    | Artificial macrophytes; plastic bags cut into strips | Yes/No |          |                            |                            |                               |         |              |       |
| Plants      | Live/Yes      | Bacopa sp. and Ambula sp. | Yes/No | <1         | "C, pH, ammonia, nitrite, nitrate | Natural light/NA | NA/Yes | C. auratus | J/CB | Sullivan et al., 2016 |
| Plants      | Plastic/Yes   | Model Bacopa and Ambula | Yes/Partial |          |                            |                            |                               |         |              |       |
| Substrate   | Sand/No       | Coarse white sand | Yes/Yes | 60         | "C, pH, conductivity, alkalinity, nitrate, nitrite | 12:12 L:No | No/No | D. rerio | J/CB | Wafer et al., 2016 |
| Plants      | Plastic/No    | Plastic Hygrophila leaves | Yes/Yes | V         | "C, pH, conductivity, alkalinity, nitrate, nitrite | 12:12 L:No | No/No | O. mykiss | J/H | Bergendahl et al., 2017 |
| Plants      | Plastic/No    | Plastic grass | Yes/Yes |          | "C | 12:12 L:No | No/No | O. mykiss | J/H | Bergendahl et al., 2017 |
| Shelter     | In-tank structure/No | PVC pipes | Yes/Yes | 60         | "C | 12:12 L:No | No/No | O. mykiss | J/H | Bergendahl et al., 2017 |
| Other       | Novel objects/Yes | Weekly presentation of objects (e.g., a ball, plants, bottle lid) | No/No |          | "C | 12:12 L:No | No/No | O. mykiss | J/H | Bergendahl et al., 2017 |

(Continues)
| PE category | Type/rationale | Details | Amount/ dimensions | Duration | Water parameters | Photo-period/ lighting details | Fish density^a/ parasite check | Species | Stage/ origin | Study |
|-------------|---------------|---------|-------------------|----------|-----------------|-------------------------------|-------------------------------|---------|-------------|-------|
| Shelter | In-tank structure/No | Plastic tube | Yes/Yes | 3 | °C, dissolved oxygen, pH, nitrite, nitrate, ammonia | 12:12 L:D/ No | No/No | A. agassizii | A/WC | Kochhann & Val, 2017 |
| Substrate | Pebbles/No | No | No/No | 70 | °C | 24:0L:D (constant)/ No | Yes/No | G. aculeatus | M/CB (F1) | Toli et al., 2017 |
| Plants | Plastic/No | No | No/No | No/No | No/No | Tor putitora | J/H | Ullah et al., 2017 |
| Shelter | In-tank structure/No | Plastic cylinder | Yes/Yes | 120 | No (natural source flow through) | No/No | No/No | J/H | Abbey-Lee et al., 2018 |
| Substrate | Sand/No | No | No/No | 180 | °C, salinity | 16:8 L:D/ No | No/No | G. aculeatus | M/CB (F1) | Barcellos et al., 2018 |
| Plants | Plastic/No | No | Yes/No | No/No | No/No | D. rerio | A/CB | Lee et al., 2018 |
| Other | Novel objects/ No | Variety | Yes/No | 15 | °C, pH, dissolved oxygen, ammonia | 14:10 L:D/ No | No/No | D. rerio | A/CB | Sanhueza et al., 2018 |
| Other | Image of gravel/ No | No | No/No | 63 | °C, pH, conductivity, ammonia, nitrate, nitrite | 12:12 L:D/ No | Yes/No | O. niloticus | J/H | Maia & Volpato, 2018 |
| Other | Thermal variability/ Yes | Wide range (Tmin 9.6°C to Tmax 16.4°C) and restricted (Tmin 11.3°C to Tmax 12.7°C) | Yes/Yes | V | °C, dissolved oxygen, pH, nitrite, nitrate, ammonia | 12:12 L:D/ No | Yes/No | S. salar | M/H | Marcon et al., 2018b |
| Shelter | In-tank structure/Yes | Clay plot | Yes/Yes | 17 | °C | 14:10 L:D/ No | Yes/No | D. rerio | A/CR | Sykes et al., 2018 |
| Plants | Plastic/No | All Living Things Turtle Grass | Yes/No | 63 | °C, pH, ammonia, nitrite | 12:12 L:D/ No | Yes/No | D. rerio | A/CR | Marcon et al., 2018b |
| Substrate | Gravel/No | English sea stones (+ 'photo) | Yes/Yes | 14:10L:D/ No | Yes/No | D. rerio | A/CR | Marcon et al., 2018b |
| Plants | Plastic plants/ No | 'photo | Yes/Yes | 14:10L:D/ No | Yes/No | D. rerio | A/CR | Marcon et al., 2018b |
| Substrate | Gravel/No | Plants Plastic/No | Shelter In-tank shelter/No | Details | Amount/dimensions | Duration | Water parameters | Photo-period/lighting details | Fish density'/parasite check | Species | Stage/origin | Study |
|-----------|----------|------------------|---------------------------|--------|------------------|----------|------------------|-----------------------------|-----------------------------|---------|-------------|-------|
| English sea stones (+'photo) | Yes/Yes | Yes/Yes | Yes/No | 183 | C, pH, dissolved oxygen | 12:12 L:D/No | No/No | C. auratus | J/NA | Abreu et al., 2019 |
| Resin boat | No/No | Yes/Yes | Plastic ‘ruin’ | 35 | C, dissolved oxygen | 10:14 L:D/No | No/No | S. aurata | J/H | Arechavala-Lopez et al., 2019 |
| Resin boat | No/No | Yes/Yes | Artifical log | 300 | C, salinity | 12:12 L:D/No | Yes/No | K. marmoratus | M/CB | Berbel-Filho et al., 2019 |
| Fine sand | No/No | Yes/Yes | Seagrass Zostera muelleri | 365 | No | No/No | Yes/No | B. cocosensis | J/WC | Carbia & Brown, 2019 |
| Formation with live oysters and shell fragments | No/No | Yes/Yes | Snell and mussel | 200 | C | Natural light/NA | Yes/No | O. tshawytscha | J/H | Cogliati et al., 2019 |
| Shell grit with larger stones | No/No | Yes/Yes | Tidal mimicking mechanism | 270 | C | Natural light/NA | Yes/No | O. tshawytscha | J/H | Cogliati et al., 2019 |
| Vertically oriented round aluminium rods | Yes/Yes | Yes/Yes | | 127 | C, pH, dissolved oxygen, hardness, alkalinity, dissolved solids | No/No | Yes/No | O. mykiss | J/H | Crank et al., 2019 |
| Suspended coloured spheres | Yes/Partial | | | | | | | | | |

(Continues)
| PE category | Type/rationale | Details | Amount/dimensions | Duration | Water parameters | Photoperiod/lighting details | Fish density/parasite check | Species | Stage/origin | Study |
|-------------|---------------|---------|------------------|----------|------------------|-----------------------------|-----------------------------|---------|-------------|-------|
| Substrate  | Sand/No       | No      | No/No            | 8        | C, pH, ammonia, nitrite, nitrate | 12:12 L:D/No               | No/No          | D. rerio | A/CB       | DePasquale et al., 2019 |
| Other      | Water movement/Yes | Tidal mimicking mechanism | Yes/Yes |                      |                      |                             |                             |         |             |       |
| Plants     | Plastic/No    | No      | No/No            |          |                  |                             |                             |         |             |       |
| Substrate  | Gravel/Partial | Light-coloured | No/Yes | V     | C             | 12:12 L:D/No               | Yes/No          | P. reticulata | A/CB   | Fong et al., 2019 |
| Plants     | Live/No       | Java moss (Taxiphyllum sp.) | Yes/Yes |                    |                           |                             |                             |         |             |       |
| Other      | Heterospecific/Partial | Water snails (Planorbis sp.) | Yes/No  |         |               |                             |                             |         |             |       |
| Other      | In-tank structure/Partial | Artificial maze | NA/Yes |         |               |                             |                             |         |             |       |
| Substrate  | Gravel/No     | No      | No/No            | <1       | C, pH, ammonia, nitrate | 12:12 L:D/No               | Yes/No          | D. rerio | A/CB       | Jones et al., 2019 |
| Shelter    | External shelter/Yes | Overhead plastic cover | Yes/Yes |  |                           |                             |                             | G. aculeatus | A/WC   |             |       |
| Plants     | Plastic/Yes   | No      | Yes/Partial     |          |                  |                             |                             |         |             |       |
| Substrate  | Gravel/No     | Aquarium gravel | Yes/Yes | V     | C, pH, conductivity, ammonia, nitrate, nitrite, filter flow rate | 12:12 L:D/No               | Yes/Partial | D. rerio | M/CB    | Lee et al., 2019 |
| Plants     | Live/Yes      | Several species with sp. name | Yes/Yes |       |                           |                             |                             |         |             |       |
| Shelter    | In-tank structure/Yes | Rocks | Yes/Yes | 50     | C               | Natural light/NA            | Yes/No          | S. salar | J/H       | Mes et al., 2019 |
| Plants     | Plastic/Partial | Eight black fronds | Yes/Yes |       |                           |                             |                             |         |             |       |
| Shelter    | In-tank structure/Yes | Bundles of back polythene strips | Yes/Yes | 231    | C, dissolved oxygen | Natural light/NA | Yes/No | S. salar | J/CB (F1) | Näslund et al., 2019 |
| Shelter    | In-tank structure/No | Bricks | Yes/No | V     | C, dissolved oxygen, ammonia, salinity | No/No          | Yes/Yes          | E. marginatus | J/H | de Oliveira et al., 2019 |
| Shelter    | In-tank structure/Yes | Flat stones | Yes/No |  |                           |                             |                             |         |             |       |
| Shelter    | In-tank structure/No | White PVC pipe | Yes/No |         |                           |                             |                             |         |             |       |
| Shelter    | In-tank structure/No | Brown PVC pipe | Yes/No |         |                           |                             |                             |         |             |       |
| Substrate  | Gravel/No     | No      | No/No            | 15       | C, dissolved oxygen | No/No          | Yes/Partial | S. salar | J/H       | Räähä et al., 2019 |
| Shelter    | In-tank structure/No | No | No/No       |          |                  |                             |                             |         |             |       |
| Other      | Water movement/No | Changes in flow direction | No/No |         |                           |                             |                             |         |             |       |
| PE category | Type/rationale | Details | Amount/dimensions | Duration | Water parameters | Photo-period/ lighting details | Fish density* / parasite check | Species | Stage/origin | Study |
|-------------|---------------|---------|-------------------|---------|-----------------|-------------------------------|--------------------------------|--------|-------------|-------|
| Substrate   | Gravel/Yes    | Gravels of mixed shape and of greyish colour originated from river Rhine, purchased from a materials trader. Quartz and flint splinters removed by hand. | Yes/Yes | V | °C, dissolved oxygen | No/No | Yes/No | O. mykiss | M/CB | Reiser et al., 2019 |
| Shelter     | In-tank structure/No | Plastic tube constructions | Yes/Yes | V | No | 24:0LD (constant)/ No | No/No | S. salar | J/CB | Solas et al., 2019 |
| Shelter     | In-tank structure/Yes | Green box | Yes/Yes | | | | | |
| Shelter     | In-tank structure/No | Bundles of wood | Yes/Yes | 66 | °C | No/No | Yes/No | S. trutta | JH | Watz, 2019 |
| Shelter     | In-tank structure/Yes | Vertically oriented round aluminium rods | Yes/Yes | V | °C, pH, dissolved oxygen, hardness, alkalinity, dissolved solids | No/No | Yes/No | S. trutta & O. mykiss | J/H | White et al., 2019 |
| Shelter     | In-tank structure/Yes | Vertically oriented round aluminium rods | Yes/Yes | | | | | |
| Shelter     | In-tank structure/No | Upturned plant pot | Yes/Partial | 63 | °C | 12:12 L:D/ No | Yes/No | D. rerio | A/NA | Woodward et al., 2019 |
| Plants      | Plastic/No | | Yes/No | | | No/No | | |
| Shelter     | External shelter/Yes | Opaque covering on one side of tank | Yes/No | | | | | |
| Plants      | Live/No | Potted Vallisneria gigantea and Echinodorus | Yes/Partial | V | °C, pH, dissolved oxygen, conductivity | 14:10 L:D/ No | Yes/No | S. notomelas | A/WC | da Silva et al., 2020 |
| Shelter     | In-tank structure/No | Suspended balls of wool | Yes/No | | | | | |
| Shelter     | In-tank structure/No | driftwood | Yes/Partial | | | | | |
| Shelter     | In-tank structure/No | PVC pipe | Yes/Yes | | | | | |
| Shelter     | In-tank structure/No | Tree branches | Yes/Partial | | | | | |
| Shelter     | In-tank structure/No | PVC pipe | No/Yes | 100 | °C, pH, dissolved oxygen, ammonia, nitrite | 12:12 L:D/ No | Yes/No | O. niloticus | J/H | Favero Neto & Giaquinto, 2020 |
| Plants      | Plastic/No | Artificial water hyacinth | No/No | | | | | |
| Plants      | Plastic/No | Red and green artificial plant | Yes/Partial | 21 | °C, conductivity, hardness, alkalinity, dissolved oxygen, ammonia, nitrate, and nitrite | 14:10 L:D/ Partial | Yes/Yes | D. rerio | A/NA | Krueger et al., 2020 |

(Continues)
| PE category | Type/rationale | Details | Amount/dimensions | Duration | Water parameters | Photoperiod/ lighting details | Fish density’/ parasite check | Species | Stage/ origin | Study               |
|--------------|---------------|---------|-------------------|----------|-----------------|-------------------------------|-------------------------------|---------|---------------|---------------------|
| Shelter      | In-tank structure/No | Bricks | Yes/Yes           | 5        | No              | 12:12 L:D/ No                 | Yes/No                        | A. australis | J/H           | Rae et al., 2020   |
| Plants       | Plastic/Yes   | Artificial seagrass | Yes/Yes         |          |                 |                               |                               |                      |               |
| Shelter      | In-tank structure/Yes | Apparatus that mimicked floating algae | Yes/Yes       | 20       | C, pH, dissolved oxygen, ammonia, hardness, alkalinity | 12:12 L:D/ No                 | Yes/No                        | D. rerio | A/NA          | Soares et al., 2020 |
| Substrate    | Gravel/No     | No      | Yes/No            | 90       | C, dissolved oxygen, ammonia | 12:12 L:D/ No                 | No/No                         | T. putitora | J/H           | Ullah et al., 2020 |
| Plants       | Plastic/No    | No      | Yes/Partial       | <1       | C, pH, dissolved oxygen, ammonia, nitrate | No/No                         | V/No                          | X. variatus | A/CB          | Vanderzwalmen et al., 2020 |
| Shelter      | In-tank structure/Yes | Vertically oriented round aluminium rods | Yes/Yes       | 116      | C, pH, dissolved oxygen, hardness, alkalinity, dissolved solids | No/No                         | Yes/No                        | O. mykiss | J/H           | Voorhees et al., 2020 |
| Other        | Novel objects/ Yes | Plastic loops | Yes/Yes          | 192      | C, oxygen, pH   | 12 h L:D/Yes                  | Yes/No                        | C. macropomum | J/NA         | Pereira et al., 2020 |
| Plants       | Live plants/No | No      | No/No             |          |                 |                               |                               |                      |               |
| Shelter      | In-tank shelter/ No | Resin boat | No/No            |          |                 |                               |                               |                      |               |
| Substrate    | Gravel/No     | No      | No/No             |          |                 |                               |                               |                      |               |
| Substrate    | Gravel/No     | Multicoloured river stones/gravel | Yes/Yes      | 90       | C, oxygen, pH   | 12:12 L:D/ No                 | Yes/No                        | C. idella | J/H           | Murtaza et al., 2020 |
| Shelter      | In-tank shelter/ No | Cobbles | No/No            |          |                 |                               |                               |                      |               |
| Plants       | Plastic/No    | No      | No/No             |          |                 |                               |                               |                      |               |
| Substrate    | Stones/No     | No      | No/No             | 62       | C, oxygen, pH   | No/No                         | Yes/No                        | P. scalar | J/CB          | Diniz et al., 2020  |
| Plants       | NA/No         | No      | No/No             |          |                 |                               |                               |                      |               |
| PE category | Type/rationale | Details | Amount/Dimensions | Duration | Water parameters | Photo-period/ lighting details | Fish density/ parasite check | Species | Stage/origin | Study |
|-------------|----------------|---------|------------------|----------|-----------------|-----------------------------|----------------------------|---------|--------------|-------|
| Substrate  | Gravel/No      | Pea gravel substrate | Yes/No | 56 | C, pH, ammonia, nitrite, salinity, dissolved oxygen, conductivity | Yes/No | S. schlegelii | J/H | Zhang et al., 2020 |
| Shelter    | In-tank shelter/No | Plastic tube | Yes/No | 14:10 L:D/ No | Yes/No | N. furzeri | M/CB | Thoré et al., 2020 |
| Plants     | Plastic/Yes    | As used in previous studies | Yes/Yes | 60 | C, salinity, dissolved oxygen | Yes/No | S. aurata | J/H | Arechava-Lopez et al., 2020 |
| Substrate  | Stones/Yes     | Clear photo | No/Yes | 12:12 L:D/ No | Yes/No | S. trutta | M/H | Yaripour et al., 2020 |
| Shelter    | In-tank shelter/No | Plant-fibre ropes | Yes/No | 12 h L:D/ No | Yes/No | P. reticulata | A/CB | Masud et al., 2020 |
| Pea gravel substrate | Plastic tube | Flowerpot | Yes/No | 12 h L:D/ No | Yes/No | P. reticulata | A/CB | Masud et al., 2020 |
| Plastic plants/ No | Plastic reeds | Flowerpot | No/No | 14:10 L:D/ No | Yes/No | N. furzeri | M/CB | Thoré et al., 2020 |
| Plastic plants/ No | Plastic reeds | Plastic tube | Yes/Yes | 56 | C, pH, ammonia, nitrite, salinity, dissolved oxygen, conductivity | Yes/No | S. schlegelii | J/H | Zhang et al., 2020 |
| Plastic/T-shaped tubes | Plastic T-shaped tubes | Flowerpot | Yes/Yes | 14:10 L:D/ No | Yes/No | N. furzeri | M/CB | Thoré et al., 2020 |
| Plastic/Yes | As used in previous studies | Plastic/Yes | Yes/Yes | 60 | C, salinity, dissolved oxygen | Yes/No | S. aurata | J/H | Arechava-Lopez et al., 2020 |
| Plastic/Yes | As used in previous studies | Plastic/Yes | Yes/Yes | 60 | C, salinity, dissolved oxygen | Yes/No | S. aurata | J/H | Arechava-Lopez et al., 2020 |

Note. V, varied; NA, not applicable; for stage: J, juvenile; A, adult; L, larvae; M, multiple stages; for origin: CB, captive bred; H, hatchery bred; WC, wild caught. Duration is given in days unless specified otherwise.

In some studies density is not reported and is included as no, but this may be due to fish being kept in isolation where density is not required.
In addition to the characteristics of each PE item reported we collected information on associated aspects of each study. We recorded the fish species tested and life stage exposed to PE and origin. We also recorded information regarding factors that are known to be or may also be important to consider in studies of the effects of PE, including whether the density of fish and the duration of the exposure to PE was reported for each study, photoperiod and lighting details, water quality parameters and evidence of whether or not pathogen checks were made.

3 | SURVEY RESULTS

3.1 | Reporting details of the PE used

Across the 65 studies surveyed we collected reporting details for 159 types of PE used (Table 1). Most studies reported some level of detail about the PE items used. In 68% of the cases either amounts or dimensions were reported. However, descriptions of both amounts and unit dimensions were reported in only 30% of occasions. Similarly, a rationale or justification for the use of specific types of PE was reported in less than half (39%) of the studies.

3.2 | At the study level

Of the species of fish tested in the studies, the majority (56%) were salmonids (30%) or zebrafish (26%). This reflects the major use of these fishes in aquaculture and research spheres and is similar to the level of research effort in studies published before 2015 (Näslund & Johnsson, 2014). Again, some potentially important details were frequently not recorded. For example, while most of the studies surveyed (79%) reported the photoperiod fish were kept in, only four of the 65 studies gave any further details of the lighting used.

4 | TOWARDS A MORE REFINED UNDERSTANDING OF PE

This survey of the literature revealed room for improvement in reporting details of PE provided for captive fish. Our results clearly demonstrate that in studies which investigate the effects of, or preferences for, PE there is often a lack of information on the details of the enrichment used. Using PVC pipes as an example, while commonly used as shelter for many fishes, the colour, size and diameter of the PVC pipes are not frequently considered in much detail. They are likely to be important, however, and a study with dusky grouper Epinephelus marginatus (Lowe, 1834) showed colour-biased preference between PVC tubes, favouring brown over white; potentially the fish preferred the lower colour contrast provided by the brown tubes (de Oliveira et al., 2019). Lack of understanding of these elements may hinder the standardization of research methods and the ability to develop optimal housing and welfare for the fish species kept in captivity. In this section we offer our approach to address this. First, we propose the DETAILS reporting framework to develop our understanding of specific characteristics of objects used as PE in studies and act as a guide for more standardized and nuanced reporting of PE. Second, in conjunction with this framework, we make recommendations that may help direct further research and help researchers determine the cues or characteristics of particular PE that fish respond to.

4.1 | The DETAILS reporting framework

Using selected examples, we can showcase the potential importance of reporting the aspects of PE where DETAILS (Dimensions, Ecological rationale, Timing of enrichment, Amount, Inputs, Lighting and Social environment) matter.

4.1.1 | Dimensions

What are the dimensions of shelter provided by the PE? What diameter of substrate grain do fish prefer or length of fronds of plants? Fine-scale characteristics of physical structures including the dimensions of shelter they afford is one important but frequently overlooked component and may help to account for studies which showed no effect of enrichment on behaviour or welfare. Two case studies are suggestive. The first is from a study of a small ‘shell dweller’ cichlid species from Lake Tanganyika, Neolamprologus multifasciatus (Boulenger, 1906), that uses empty shells to shelter from predators and also as brood chambers for their eggs. The cichlids show preferences for specific shell attributes, including size and level of intactness (Bose et al., 2020). Similarly, sand gobies, Pomatoschistus minutus (Pallas, 1770), show preferences for certain sizes of clay pots that are used for nesting sites (Lehtonen & Wong, 2020). Certainly, grain size can be an important consideration when providing substrate, for example specific differences in gravel diameter were shown to affect the mortality of rainbow trout fingerlings (Reiser et al., 2019). Fine-scale differences in dimensions between enrichment types may contribute to conflicting findings, for example where welfare benefits of PE are found in some but not all studies of zebrafish (Stevens et al., 2021).

4.1.2 | Ecological rationale for the PE

The ecological and evolutionary factors underlying the observed preferences for and benefits of PE are not well studied, and where they are this is typically not explicitly part of the rationale used in many husbandry or welfare studies. However, this should be a fundamental aspect when selecting objects to use as PE. A recent study showcased the potential importance of ecology on use and preference for physical structures. A comparative study of 20 species of Lake Malawi cichlids showed that scores in standard behavioural assays, including
amount of time spent away from shelter in an ‘open field test’, were associated with the specific microhabitat that the species is commonly found in (Johnson et al., 2020). Moreover, the authors suggest that the behavioural preferences may be linked to the microhabitats those species are associated with. Species which preferred edges or corners in experimental assays tend to favour narrow crevasses and caves characteristic of rocky habitats in the wild.

Substrate preferences are an area where ecological factors are relatively well known. The characteristics of the substrate used as PE for epibenthic species can be important, for example rays that actively bury themselves in substrates show strong preferences for substrates type, sand over gravel (Greenway et al., 2016). The importance of substrate colour to reduce predation risk is also crucial where fish that match the colour of the background substrate are less likely to be predated (Browman & Marcotte, 1987; Ostrowski, 1989; Sumner, 1934). This has led to recommendations for salmonid aquaculture to acclimate fish raised in hatcheries to backgrounds with similar coloration to the gravel in the habitat where they will eventually be released (Donnelly & Whoriskey Jr, 1991). Besides colour, brightness of a substrate can also be important factor in fish preferences (Wu et al., 2020), most likely for similar reasons. Substrate preferences can be driven by other aspects of an animal’s ecology, for example three-spined sticklebacks, Gasterosteus aculeatus L. 1758, prefer complex substrates (with heterogeneous topography and colour) over simple substrates (homogeneously coloured and textured), but only when they are not satiated, suggesting preferences are linked to foraging preferences (Webster & Hart, 2004).

Many forms of PE that have welfare benefits may not have direct connection to the ecology of the fish, for example novel objects, behavioural engineering and stimulation. Water flow, or regulated changes in water flow, is one such form of enrichment that can promote exercise for fish with many associated benefits to welfare and growth (Huntingford & Kadri, 2013). Provision of water flow or other forms of enrichment which promote swimming and exercise will still benefit from considering ecological aspects, for example the maximum swimming and flow speeds may be based on natural water conditions.

4.1.3 | Timing of enrichment

There are three aspects of time which can affect whether or not PE has an impact or the size of the effect. First, the age or developmental stage of a fish can be particularly important. A recent study of the burrowing behaviour of the European eel, Anguilla anguilla (L. 1758), highlights the importance of understanding the different enrichment requirements across life stages, in this case substrate preference. Eels of different life stages showed preferences for different substrates in which to burrow: yellow eels preferred fine gravel (diameter 1–2 mm), with glass eels and elvers preferring coarse gravel (diameter 8–12 mm). They also showed different levels of use of burrows: glass eels showed greater urge to burrow than yellow eels (Steendam et al., 2020). Similarly, Alnes et al. (in review) showed that Atlantic salmon at the fry life stage show no response to structural enrichment stimuli but did so on reaching early parr stage 3 months later. The second aspect to consider is time of year or seasonality. Fish may use and benefit from PE at specific times in their lifecycle, but also at certain times of year, for example juvenile Atlantic salmon switch from being highly active, showing little usage of physical refuges, in summer to showing strong preference for antipredator refuges in winter (Valdimarsson & Metcalfe, 1998).

The duration of exposure to enrichment (or lack therefore) is the other synergistic aspect to consider when designing and reporting studies of enrichment. A study of rainbow trout, O. mykiss, showed that fish kept in enriched conditions for longer durations performed better in cognition assays (Bergendahl et al., 2016). However, even short periods of exposure to PE can have effects as long as the fish were exposed to the enriched environments very recently prior to testing. For example, swimming agility and performance in behavioural assays improved even after relatively short exposure to enrichment (Bergendahl et al., 2016, 2017; dos Santos et al., 2020). Duration of studies can also be connected to social environment (discussed further below), where development of familiarity can lead to aggression as per Amazon mollies, Poecilia formosa (Girard, 1859) (Doran et al., 2019), or reduce aggression in other species (Utne-Palm & Hart, 2000; Webster & Hart, 2006, 2007). Aggression can also increase at specific periods over the course of the development of hierarchies or changes in the reproductive cycles of fishes. For example, in the cooperatively breeding cichlid, Neolamprologus pulcher Trewavas & Poll, 1952, levels of aggression, and chemical signals that initiate or moderate aggression, have been shown to vary as a temporary response to changes in the hierarchy and social context (Bayani et al., 2017; Wong & Balshine, 2011). Requirements and preferences for physical refuge are likely to depend on the reproductive stage and length of time within a tank in such systems.

4.1.4 | Amount

How much PE is needed to provide a welfare benefit? Knowing the percentage surface area to cover in shelter or volume estimates of substrate required per tank can help to create more efficient setups. Benefit should be maximized while keeping costs in terms of material and maintenance down. Until recently studies exploring PE in fishes have tended to focus on comparisons between enclosures with PE versus those that are completely barren, but the use and benefit of PE may depend on just how much of a particular type of enrichment is available. In the wild zebrafish have been observed in open water as frequently as amongst vegetation (Spence et al., 2006) and having some unenriched space may be beneficial. For some species open unstructured areas might be more valuable than structure, and welfare can deteriorate with too much enrichment. For example, in captive sharptooth catfish, Clarias gariepinus Burchell, 1822, aggression (and resulting physical damage through biting) increased when tanks were provisioned with physical structure in the form of PVC tubes (Boerrigter et al., 2016). Similarly, zebrafish kept in aquaria with ‘medium’ levels of enrichment performed better in welfare assays than fish from ‘highly enriched’ aquaria (Woodward et al., 2019).
4.1.5 | Inputs

Inputs such as food and water are, of course, fundamental for maintaining fish in captivity. The physical and chemical properties of the water are also crucial, where water quality parameters such as dissolved oxygen and pH can impact stress and affect the underlying physiology, behaviour and ultimately welfare of fishes (Huntingford et al., 2006; McIntyre et al., 2008; Stevens et al., 2017; Williams et al., 2009). Fishes exposed to even relatively short fluctuations in water quality in confinement showed behavioural changes with associated welfare implications (Vanderzwalmen et al., 2021). As such, water quality parameters are frequently well reported in studies of enrichment, but not to the same level across studies. Differences in reporting of water quality likely reflect differences in fish species requirement but also enclosure type, for example studies using naturally fed flow-through tanks frequently report fewer water parameters. However, measuring and reporting the details of water chemistry are important in determining the effects or benefits of PE and affording more comparative or reproducible studies. Diet and differences in food types can also be important. Levels of dietary nitrogen can have impacts on welfare (Conceição et al., 2012) and sources of nitrogen from specific diet formulations can affect growth and other welfare parameters (Bonaldo et al., 2015). Live prey may be worth considering as a form of enrichment and can be fundamental to survival for many species (Ruyet et al., 1993). Larval Pseudochromis flavivertex Rüppell, 1835, for example, do not survive without diets enriched with live prey (Olivotto et al., 2006). The provision of live prey can be especially important for species reared in captivity for later release into the wild (Brown et al., 2003).

Flow of water and current direction can in itself be a form of PE (DePasquale et al., 2019), as can water changes (Lee et al., 2018). Other environmental conditions can have subtle but important effects on fishes and may impact the findings of enrichment studies. For example, levels of turbidity can impact behaviour and level of social attraction and refuge use (Chamberlain & Ioannou, 2019; Fischer & Frommen, 2013). Temperature is an example of an easily measured and commonly included water parameter that has both direct and indirect effects on welfare. The provision of a varied thermal environment improved measures of welfare and growth in Atlantic salmon (Sanhueza et al., 2018). Temperature can also impact preferences for physical complexity, for example minnows, Phoxinus phoxinus (L. 1758) significantly increased the time spent in refuges when the temperature dropped (Greenwood & Metcalfe, 1998). Temperature differences within a tank afforded by physical complexity in aquaria can impact use of particular areas or refuges for fishes exhibiting behavioural fever (Boltaña et al., 2013; Huntingford et al., 2020). Thermal preferences can also depend on the level of structural complexity or micro habitat, as shown for coral reef damselfish, Chromis atripectoralis Welander & Schultz, 1951 (Nay et al., 2020). Various water parameters can also have interactive effects. For example, while high nitrate levels can reduce swimming speed and duration in juvenile silver perch, Bidyanus bidyanu (Mitchell, 1838), the effects can depend on or be masked by changes in temperature (Isaza et al., 2020). Other environmental toxins can impact the preferred temperatures of fish (Petersen & Steffensen, 2003; Skandalis et al., 2020).

Not all inputs are intentional, and parasites and other pathogens are an important welfare concern (Barber, 2007; Bui et al., 2019). Pathogens can have many effects on fish, including effects on their behaviour and measures of welfare and potentially use of shelter (Gabagambi et al., 2019; Martins et al., 2012). They can also impact other measures of behaviour, for example parasites can impact cognitive performance (Barber et al., 2017) and shoaling preferences. Three-spined sticklebacks, G. aculeatus, infected with the microsporidian, Glugea anomala (Moniez, 1887), for example, showed an increased shoaling tendency (Ward et al., 2005).

4.1.6 | Lighting

Light, the intensity, wavelength and amount (photoperiod), is an important factor that is often overlooked in studies of PE. Light levels can have a large impact on fish behaviour, playing a crucial role in their behavioural ecology (Cerri, 1983; Keep et al., 2020; McCartt et al., 1997; Santon et al., 2020), and can drive the use of shelter and shade. Light levels can impact levels of aggression (Valdimarsson & Metcalfe, 2001), which in turn can have significant impacts on fish welfare (da Silva et al., 2020). Light can also impact growth (Boeuf & Le Bail, 1999). A study on blunt snout bream, Megalobrama amblycephala. P. L. Yih, 1955, showed that high light intensity caused stress, elevated oxidative rate and immunosuppression, but low light intensity led to depressed growth, antioxidant capability and immunity (Tian et al., 2015). Shade in aquaculture settings has also been shown to reduce levels of sea lice in pen-reared Atlantic salmon (Huse et al., 1990).

Larval development and growth rates of zebrafish can be significantly impacted by light conditions (Villamizar et al., 2014), and growth rate and aggression between individuals have been shown to improve with lower light intensity in other species too (Almazán-Rueda et al., 2004; Arambam et al., 2020; Boeuf & Le Bail, 1999; Rahman et al., 2020; Tian et al., 2015). Recent studies have focused on the effects of other aspects of light conditions on captive fish, such as the effects of acute bursts of light from photography (camera flashlight) (Knopf et al., 2018), but despite the importance of light conditions, and the relationship with PE which may provide shelter and shade from lights, most studies exploring PE tend to ignore light and provide very few details outside of photoperiod.

4.1.7 | Social environment

Density of individuals in aquaria has long been known to impact behaviour (Ellis et al., 2002), for example a recent study showed that killifish, Nothobranchius furzeri R. A. Jubb, 1971, exhibit differences in body length, activity, aggressiveness and feeding behaviour across different densities (Thoré et al., 2020). Beyond ‘simple’ fish density, social factors can impact the effects of or requirements for PE. Being a member of a group can provide many benefits (Ward & Webster, 2016), but most species of fish do not blindly form groups. Fish are able to differentiate between individuals and actively
moderate the composition of their groups (Ward et al., 2020) and habitat complexity can, in turn, have a strong effect on social behaviour (Rodriguez-Pinto et al., 2020). The benefit of social enrichment and preferred group sizes is species-specific (Saxby et al., 2010) and can depend on the level of sociality of a species. Highly social species, obligate shoalers, can show strong preference for forming groups with conspecifics, for example zebrafish (Spence et al., 2008), and can show well-developed discrimination between groups, preferring the larger group, for example Lamprologus callipterus Boulenger, 1906 (Durrer et al., 2020). Specific aspects of social context, including group size, makeup and dynamics, can be important and may impact any observed ‘benefit’ of PE. Social context may even reduce the requirements for any PE at all. For example, solitarily housed zebrafish may use and gain benefits from structure (Collymore et al., 2015), but in groups zebrafish showed no preference for PE (Jones et al., 2019; Kistler et al., 2011). Certain visual signs of activity of other fish can impact shoaling by zebrafish (Pritchard et al., 2001) and large amounts of structure in a tank can lead to increased aggression in zebrafish (Woodward et al., 2019) and other species (Boerrigter et al., 2016).

Aggression is particularly important in captive environments, with effects on body condition and growth, and can be closely tied to social context. Levels of aggression between conspecifics can increase in captivity where movement is restricted (Doran et al., 2019; Kelley et al., 2006), especially in territorial species (Perrone et al., 2019). Levels of aggression can depend on social dynamics, species composition, sex and stage of the individuals in a group (Bayani et al., 2017; Desjardins et al., 2012; McRobert et al., 2012; Sloman et al., 2011). While PE can reduce aggression by reducing line of sight between fishes or providing shelter from aggressors (Barley & Coleman, 2010; Torrezani et al., 2013), this depends on the species involved and the amount of PE provided. Dominant individuals or species may use aggression to dominate shelter afforded by PE, for example when kept in aquaria together the threatened tilapia, Oreochromis amphilaelas (Hilgendorf, 1905), lose access to shelter to the more aggressive O. niloticus (Linnaeus, 1758) (Champneys et al., 2020). Intraspecific aggression can increase with PE, as with butterfly splitfins, Anoeta splendens R. R. Miller & Fitzsimons, 1971, but with no increased aggression towards heterospecifics (Jones & Magurran, 2014). It is also worth noting that PE can have more nuanced effects on social behaviour. A recent study on a Serrapinnus notomelas (Eigenmann, 1915) showed no effect of PE or density of fish on level of aggression but foraging rates went up with increasing enrichment and group size, with potential benefits for growth (da Silva et al., 2020).

4.2 | Recommendations for future research

4.2.1 | Reporting DETAILS

Here we propose some simple examples of how and what authors might report for each aspect of the framework. The measures reported will depend on the type of enrichment used and the guidelines below (Table 2) are not exhaustive. Authors are encouraged to add further relevant details given their specific species and experimental conditions as appropriate.

4.2.2 | Fine-scale characteristics of PE used by fishes

When providing PE that is intended to be used as shelter, what are the fine-scale characteristics of physical structures that fish respond to? Recent studies, as with the previously discussed preferences for specific colours of PVC pipes (de Oliveira et al., 2019) or shelter dimensions (Bose et al., 2020), suggest that aspects of physical structure can be important to fish seeking shelter, and fish may pay attention and respond to relatively subtle differences in shape, colour and contrast to the surrounds of the captive environment and sizes of shelter.

Further research into such nuances may also help to determine if there are general cross-species ‘rules’ that govern fish preferences for PE. Is there, for example, a relationship between body length and optimum refuge size across fish species that use a cavity-type shelter? If there are such general rules we should expect similar responses to enrichment in several species and this might allow for general guidelines for setting up captive environments for species that have not been studied directly.

4.2.3 | The importance of incorporating and comparing multiple types of PE

Frequently studies focus on comparing aquaria with some form(s) of PE to unenriched aquaria, but preferences of fish may depend on the available alternatives. Following the DETAILS framework may allow comparative studies and expose nuanced preferences. An example illustrating the importance of testing potential combinations of PE comes from an ecology-focused study on the Lake Tanganyikan cichlid, N. pulcher. The cichlids favoured more complex habitats (rocks with crevices) independent of whether or not sand substrate was available, but when rocks were not available the presence of substrate became important and they showed strong preference for sand (Josi et al., 2018). Recent work has also shown that fish show preferences for specific combinations of PE. For example, zebrafish showed a preference for specific combinations of types of PE (plastic plants, in combination with sand substrate and directed water flow) over any one type of PE (DePasquale et al., 2019, 2020).

4.3 | Grey literature

4.3.1 | PE repository: A call to share grey information

Given the major goal towards providing better welfare and reproducible science we think fish researchers should be encouraged to...
publish or otherwise make public the enrichment requirements of their model species. In many cases research laboratories and professional aquarists have lots of experience with and good understanding of the PE requirements of their model species. We propose that scientists should be encouraged to publish this information to provide clear husbandry and PE requirements to act as guidelines for other researchers to use. While no doubt considered basic, low impact research, this can be fundamental to our understanding of the requirements of specific species and cross-laboratory standardization. We believe that scientists working with a species in captivity would like to share their knowledge on fundamental information so that future generations of fish in captivity and researchers can build on existing knowledge. To that end we propose a publicly available repository, similar to that of Saraiva et al. (2019), but where information on environmental enrichment requirements and rationale for use of specific types of PE can be shared. Such a database would help to reduce the time and effort to find optimal husbandry setups when starting to work with a new species. It may also contribute to more standardized conditions across institutes and studies.

### TABLE 2 DETAILS reporting framework: Guidelines for what measures to report in studies using physical and structural enrichment

| Dimensions | Substrate | Grain size (or range), specific colour hues. Perhaps some measure of mineral, or rock type. |
| Plants | Natural (species) or artificial (manufacturer, model), average height, width of stem (especially for leafy stem species such as Elodea) and number of stems. For large leaved plants the average leaf size and number per stem. |
| Other structure | Descriptive measurements, including size or volume of the whole object. Also, the number, position and dimensions of each of the openings/refuges.a |
| Ecological rationaleb | Substrate | State the general relevance of substrate for study species, i.e., benthic species or commonly associated with specific substrates. Is the substrate used in the study to mimic natural conditions for the species or for some specific reason(s)? |
| Plants | Are the live plant species associated with the natural habitat of the species or do the live/plastic plants have similar physical characteristics and dimensions to habitat specific species? State the reason(s) for using the chosen plants. |
| Other structure | State the reasoning for the use of the structure, relative to the goals of the study and ecology of the species. Explain why the number of items and their dimensions was selected. |
| Timing | Stage | Life history stage of species tested, and the season fish are collected and tested. |
| Duration | Duration of time individual fish spend in both housing and experimental condition(s). Include the acclimation time prior to specific assays. |
| Amount | Substrate | Surface area covered within the tank and depth of sediment layer. |
| Plants | Some indication of surface area of the tank covered by plants and/or the number of individual plants and density. |
| Other structure | The number of items per tank would be a minimum to report but we would recommend including a ratio of shelters to fish number per tank. |
| Inputs | Chemistry | Water chemistry parameters and temperature as standard, but include some measure of variation over time, especially for fish housed for longer durations. |
| Pathogens | Explicitly state whether checks for parasites or diseases were made. |
| Lighting | Photoperiod as standard, but include details of the lighting source, e.g., manufacturer, wattage, hue, luminance and intensity. |
| Social environment | Density of fish and sex ratio as standard, but also size (and size range) and relatedness. Include some measure of the level of sociality of the species, level of familiarity of fish housed and tested together, the social dynamics of the species, and how these may impact aggression and resource partitioning. |

aFor individual items of physical shelter, e.g., clay pots or tubes, dimensions should focus on the diameter of any openings fish may be expected to move through or rest within, but also the overall dimensions and size of the object, colour, and for less commonly used shelter types the texture of the material. bDecisions as to which objects to provide as enrichment can be relatively simple when there is direct ecological relevance, e.g., providing empty snail shells for shell-dwelling cichlids or plant species commonly found in the native habitat of the fish or artificial versions that mimic these plants. However, this information should be reported. Moreover, the specific details of particular items of enrichment may be informed by the ecology of the fish and help to connect with the details provided in other parts of the framework. For example, why are a set number of shelters used per tank, or per density of individuals? Why was one colour of substrate used?
5 | SUMMARY

We highlight the need for developing more nuanced understanding of the factors that drive the use of PE and contribute to welfare improvement for captive fishes. There is a growing awareness and demand for more empirical studies and quantitative measurements of fish welfare (Brydges & Braithwaite, 2009; Huntingford, 2004; Huntingford et al., 2006; Johnsson et al., 2014; King, 2019; Näsłund & Johnsson, 2014; Sloman et al., 2019; Sneddon et al., 2016; Tumbull & Braithwaite, 2012). Answering fundamental questions around PE is a crucial aspect of that: knowing what type, how much and when to provide structure to maximize the benefits associated with PE will help to improve the welfare outcomes for fishes. The proposed DETAILS framework may help to achieve these goals by focusing researcher attention on these questions and providing a memorable guide to reporting of PE used across studies. In conjunction with recent preparatory guidelines (Smith et al., 2018), our reporting framework may also benefit the reproducibility of empirical studies exploring the effects of enrichment. Ultimately, a more detailed knowledge of PE may allow the identification and implementation of design changes which can afford the benefits of PE while minimizing the costs associated with them, leading to benefits for the fish themselves and researchers, aquaculture industries and manufacturers of housing systems.

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AUTHOR CONTRIBUTIONS

Nick A.R. Jones Conceived the original idea, conducted the survey, and wrote the first draft. Mike Webster and Anne Gro Veia Salvanes contributed conceptual ideas to the initial outline, draft manuscript, and revisions to the full manuscript.

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