CREW CENTRE OF EXPERTISE FOR WATERS

Methodologies for sampling fish populations

Nathan P. Griffiths, Vicky Johnson, Matthew Curran, Melanie Manwaring-McKay, Helen Miller, Victoria L. Pritchard, Bernd Hänfling

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Report and Appendices

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Contents

List of figures

List of tables

List of appendix figures

List of appendix tables

Executive Summary

Purpose of research

The aim of this project was to assess the currently available methodologies for sampling fish populations in Scottish freshwater lochs. Acknowledging the complexity and longstanding challenges with fish monitoring in standing freshwaters, the main objective was to produce practical guidelines which support the development of suitable fish assessment programmes. Through a review of current guidelines, followed by an expert-led workshop, the objectives of this study were:

- To identify the type of information required for a robust assessment of the fish populations within Scottish lochs;
- To review the suitability of currently available monitoring techniques to obtain the data required to make these assessments; and
- To provide evidence-based recommendations on the best approaches to monitoring fish populations under various circumstances.

Background

An understanding of the fish species present and their abundance in Scottish lochs is required for management and conservation purposes, and also to fulfil regulatory requirements. Furthermore, the recent increase in pumped storage hydro-electric development proposals involving large freshwater lochs has the potential to create additional pressures on fish populations. In order to address this, it is important that fish populations are properly assessed during environmental impact assessments and scoping. While a variety of established methods for fish monitoring exist, there is no 'one size fits all' method, therefore careful consideration is needed in order to determine the best approaches to monitoring. It is therefore important that we have an understanding of the ecological data requirements, and how best to attain these across space and time in order to ensure that fish populations in Scottish freshwater lochs are adequately protected.

Key findings

- No single sampling method is able to reliably obtain all the data required for fish monitoring programmes in Scottish freshwater lochs.
- This work highlights six key data components which may be required from fish survey methods: Presence Absence, Spatial distributions, Abundance/Biomass, Spawning locations, Age/Size structure, and independent population/ecotype assessments.
- This work identifies four suitable primary sampling methodologies, and six supporting sampling methodologies for the assessment of fish populations.
- Stakeholders identified high data quality and reproducibility as priorities for fish monitoring programmes, over ease of application, cost, and processing time.

Recommendations

1. Multiple sampling methods should be applied in parallel to obtain high quality data. As a general principle, the least invasive combination of methods which can fulfil data requirements should be prioritised.
2. Comprehensive baseline data should always be obtained in order to assess future potential impacts.
3. Consistent frameworks/guidance should be provided when requesting that fish assessments are carried out (e.g. Figure 9).

1 Introduction

1.1. Background and scope

This report considers the currently available methodologies for assessing fish populations in Scottish freshwater lochs. The project was instigated by the need to identify the potential impact of pumped storage hydroelectric developments on fish communities in freshwater lochs. This information is required for Environmental Impact Assessments (EIA) under The Electricity Works (Environmental Impact Assessment) (Scotland) Regulations 2017. Identifying potential direct and indirect effects of any proposed developments requires access, and adherence to, appropriate guidelines for fish survey and population assessment. In addition to providing robust data that can be used for EIA, all fish survey data should also be of sufficient quality to allow an assessment of the potential impact of any proposal against the requirements of the Water Framework Directive (in Scotland: WEWS Act 2003), and Habitats and Birds Directives. These are transposed into Scottish law via The Conservation (Natural Habitats, &c.) Regulations 1994. Several Scottish freshwater fish species are listed on the annexes of the Habitats Directive and on the schedules of other legally binding international conventions. Others are specifically protected within domestic conservation legislation, and others, such as Atlantic salmon, sea trout and European eel receive addition protection via fisheries legislation. Such species with specific legislative protection may require additional considerations when scoping for EIA.

There are a wide range of established fish monitoring and assessment methodologies which can be applied in freshwater lochs. These include active and passive netting methods (such as gill, seine and fyke nets) and the use of traps, (e.g. JNCC, 2015; Kubečka *et al.,* 2022). Additional methodologies include the deployment of hydroacoustics, acoustic cameras and passive acoustic monitoring equipment (e.g. Winfield *et al.,* 2009; Bolgan *et al.,* 2018; McCann *et al.,* 2018), and, in some cases, the use of electrofishing equipment (e.g. Vaux *et al.,* 2000). While these methods are well established, they are not without their limitations and biases (Perrow *et al.,* 2017). Such monitoring methods can be applied in isolation or used in parallel as complementary approaches to better assess fish populations (Winfield *et al.,* 2009). More recently, emerging methods, such as environmental DNA (eDNA) based monitoring of fish communities, have shown promise as both a standalone technique (Willby *et al.,* 2019, Sellers and Hänfling 2020) and complementary to other fish monitoring methods (Griffiths *et al.,* 2023). Despite these resources, it has proven challenging to develop specific guidance towards a standardised monitoring framework for fish populations in Scottish freshwater lochs. There is currently no 'one size fits all' approach, since the effectiveness, cost efficiency, suitability to habitat, species selectivity and ecological data outputs vary among methods. Furthermore, the invasiveness of some 'traditional' methods, such as gill netting, is becoming increasingly less acceptable to some fishery managers and regulators.

In practice, fish monitoring frameworks must account for the advantages and disadvantages of proposed survey methods and the degree to which they are context specific (Cowx, 1995). For example, the scoping of Environmental Impact Assessments (EIA) might favour methods which provide fish species lists. While the subsequent EIA of potential impacts on individual fish species or communities of interest might require methods which can provide information on age structure or absolute abundance. Similarly, the weighting of costs and processing time might depend on funding constraints and time-sensitivity, which may differ between statutory monitoring and industry-funded monitoring programmes. Additionally, site-specific characteristics may preclude some more invasive methodologies. In the context of project planning and survey design, it is therefore important to understand the specific requirements for baseline and indicator data. This knowledge would inform the appropriate deployment of assessment methods for fish species. Once the minimum data requirements are understood, survey methodologies can be systematically evaluated to understand the most appropriate survey techniques. Regulators and advisors in Scotland can then recommend monitoring approaches which are best suited to provide the data required to satisfactorily evaluate the potential impacts on fish populations.

1.2 Project objectives

This report aims to collate and draw on expert knowledge of current fish sampling and assessment requirements, with the intention of producing practical guidance on the application of sampling methods for gathering baseline fish data to inform EIA surveys in Scottish freshwater lochs. In line with the specification for this project, the objectives are:

- To identify the type of information required for a robust assessment of the fish populations within potentially impacted lochs;
- To review the suitability of current available monitoring techniques to obtain the data required to make these assessments; and
- To provide evidence-based recommendations on the best approaches to monitoring fish populations under various circumstances.

By addressing the above objectives, this project aims to bring together the breadth of current knowledge and expertise relating to fish monitoring requirements. This in turn can act as a framework for regulators/advisers to provide advice on which methodologies are best suited to individual proposals, and for developers to deploy methods in a way which allows them to properly evaluate the status of fish populations.

1.3 Structure of the report

This report integrates a range of current knowledge and guidelines for monitoring fish populations in standing freshwaters. The main body of the report includes a brief overview of the current monitoring techniques, alongside key findings obtained from an expert-led workshop. Based on this information, guidance on how these fish survey sampling techniques should best be deployed in Scottish freshwater lochs in line with the project objectives is provided. The detailed workshop methodology and outputs are included in the Appendices (Appendix A and B).

2 Research undertaken

2.1 Project overview

This report summarises existing knowledge from the grey and peer-reviewed literature, alongside additional information gathered from an expert-led workshop, to address the following key questions initially outlined in the project specification (Figure 1):

1. What fish sampling techniques are available for sampling fish populations in freshwater lochs?
2. What are the limitations posed by each method?
3. What monitoring techniques are most reliable and cost effective?
4. What method(s) is optimum under a given set of conditions?
5. What techniques are least invasive on fish populations?
6. What techniques provide good quality data that can be used robustly?

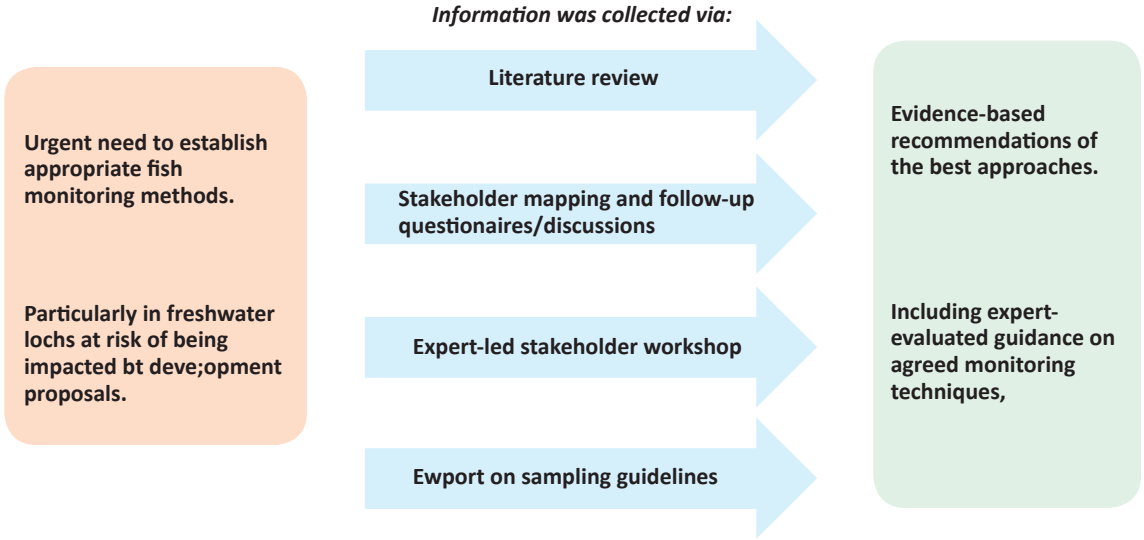

Figure 1: A visual overview of the project workflow.

2.2 Literature overview

Following from the key questions highlighted in Section 2.1, a range of reports and publications regarding the monitoring of fish in standing freshwaters were reviewed. During this process, key themes of overlap were identified, and these formed the basis for thematic discussions in an expert-led workshop.

2.3 Stakeholder mapping and questionnaire

Stakeholders were identified by the project team using a stakeholder mapping process (Figure 2). A total of 106 stakeholders were identified across various sectors (Government, Government Agencies, Industry, Academics, Non-Government Organisations (NGO) and Rivers and Fisheries Trusts/District Salmon Fishery Boards) within the UK and internationally. To add depth to the thematic discussions at the workshop, a pre-workshop questionnaire involving quantitative-ranked and qualitative questions was sent out to identified stakeholders (Appendix C). A total of 21 questionnaires were returned and thematically analysed to inform the workshop discussions. A subset of the identified stakeholders were invited to discuss the questionnaire findings at a one-day workshop.

2.4 Expert-led workshop

The expert-led workshop took place on 21st February 2024 and 22 registered expert participants plus the project delivery team contributed to the discussion. The workshop methods were aligned with participatory action research (See Reason and Bradbury 2008). The themes/questions to be addressed in the workshop and the resultant framework for decision-making were informed by existing literature and input from the questionnaires. The key themes addressed were: Data requirements; Suitability of survey methods; Site specificity; and Long-term considerations. Each of the expert stakeholders were coded with a unique identifier number so that their specific input into the participatory workshop could be traced through the analysis (Johnson and Nurick 2003).

The format of the workshop was designed as a 'world café' conducted in intersectoral groups, followed by sectoral focus groups. Participants were divided into four groups and the facilitated nature of the world café format ensured that all participants moved systematically between the four major thematic areas that had been derived from prior analysis of the literature and questionnaires (using team thematic analysis, Braun and Clarke 2006). All stakeholders participated in each theme

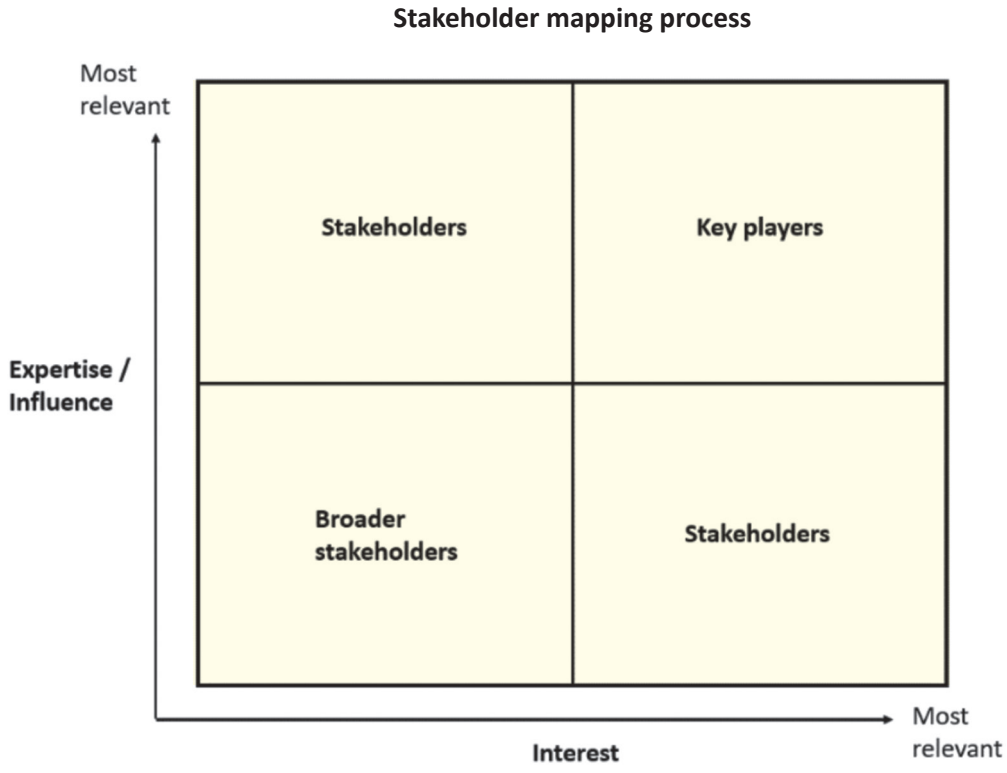

Figure 2: A visual representation of the stakeholder mapping process used to identify experts to attend the workshop. Interest is defined by evidence of 'engagement with target themes' of this project.

in turn, each hosted by a thematic facilitator. The prior analysis included key issues, challenges, and emergent questions. Participants, using their unique identifier code number, wrote their comments on sticky notes during the discussion so that their specific words and quotes could inform the overall findings. Hosts provided a summary of the overall analysis for each theme. Participants were then regrouped into sector-specific groups to address specific questions that arose from the world café session or that needed further discussion. Full methodology is outlined in Appendix A.

3 Findings

3.1 Overview of fish assessment methods (Literature overview)

Guidelines for monitoring fish populations in lochs already exist which can be broadly characterised as those which consider whole fish communities (e.g. Perrow *et al.,* 2017; Willby *et al.,* 2019; Kubečka *et al.,* 2022) and those which are more targeted towards specific species, such as e.g. Arctic charr and Coregonids (Bean, 2003a; Bean, 2003b; JNCC, 2015; Griffiths *et al.,* 2023). Both approaches are important when considering indicators of potential impact, particularly where protected species and habitats are present. However, this distinction is important as monitoring programmes are only fit for purpose if they have clearly articulated aims and therefore collect data suitable to informing them (Radinger *et al.,* 2019). This report focuses on the ecological data requirements and suitability of the sampling methods for both whole fish communities and targeted species. In addition, the impact of site-specific characteristics and long-term outlook of sampling programmes were considered.

Prior to the development of monitoring programmes and guidelines, it is important to understand the available methodologies which can be used to obtain data on fish communities. Section 3.1.1 provides an overview of the key monitoring methodologies which can be applied in freshwater lochs, hereafter referred to as 'primary monitoring methods'. Following this, the report considers methodologies which may be used in a more targeted way to obtain further information for specific fish species or in specific habitats, hereafter referred to as 'supporting methods' (section 3.1.2). It should be noted that due to the limited scope of this project, a comprehensive review of each method under all scenarios is not provided. For developers wishing to assess populations of Arctic charr or Coregonids within protected sites, species-specific guidelines can be found in Bean (2003a); Bean (2003b) and JNCC (2015). Below we provide a brief overview of the methods that are especially relevant for use in Scottish lochs, either as primary or supporting methods.

3.1.1 Primary methods

Gill netting

Correctly deployed gill nets are widely used throughout Europe as the main fish sampling methodology in large and deep lakes (Perrow *et al.,* 2017), making them a key consideration for monitoring fish in freshwater lochs. In addition to species composition and species diversity, gill netting can provide information on relative fish density and biomass estimations, and with sufficient sampling effort can produce abundance estimates which correlate with hydroacoustic assessments (Perrow *et al.,* 2017). Existing Common Standards/Condition Site Monitoring guidelines for monitoring Arctic charr and whitefish in Scotland apply gill netting in conjunction with hydroacoustics (Bean, 2003a; Bean, 2003b), highlighting the value of this method for the detection of rare priority species in addition to overall fish communities. A major drawback of gill netting however is that it is often destructive, causing fish mortality or significant injury. While impacts can be reduced by following appropriate guidelines, using reduced sampling effort, and combining with a complementary method (Bean, 2003a; Bean, 2003b; JNCC, 2015; Griffiths *et al.*, 2023), this may not always be appropriate or possible. Additionally, gill netting surveys may be more targeted by using specific approaches or mesh sizes, rather than multi-mesh surveys designed to sample whole fish communities (BSI, 2015). Despite this, serious consideration is needed regarding the impact of gill-netting surveys on the resident fish fauna. In England the Environment Agency has adopted a policy against the extensive use of gill nets (Perrow *et al.,* 2017). They are also often negatively viewed by other stakeholders including landowners/managers and the angling community. This means that gaining permission to apply this methodology, especially at the intensity needed for reliable abundance estimations, can be a limiting factor. While there are fewer restrictions for this method in Scotland at present, it may be necessary to consider less invasive methodologies.

Environmental DNA (eDNA)

Environmental DNA (hereafter eDNA) based monitoring is an emerging non-invasive method, proven effective in accurately characterising fish communities in lakes through molecular analysis of water samples (Hänfling *et al.,* 2016; Blabolil *et al.,* 2022; Lawson-Handley *et al.,* 2019; Sellers and Hänfling 2020). Compared to traditional sampling approaches, eDNA-based monitoring exhibits higher detection probabilities and less selective bias. However, the approach's high sensitivity can lead to occasional false positive detections due to environmental contamination (Hänfling *et al.,* 2016). When combined with DNA meta-barcoding, which involves targeted sequencing of taxonomically diagnostic DNA fragments, this method can determine the composition of the entire fish community. The outputs from eDNA metabarcoding offer semi-quantitative/relative abundance information. Nonetheless, consideration must be given to seasonal variations in DNA shedding, dispersal, and degradation when monitoring changes over time. As this can lead to seasonal shifts in detectability for some species (Lawson-Handley *et al.,* 2019).

Alternatively, the application of quantitative or digital PCR (qPCR & dPCR) enables the detection and quantification of DNA from specific priority species. While current eDNA-based approaches lack the ability to provide information on intra-specific diversity, future advancements may address this limitation. One main constraint of eDNA-based methods is the inability to obtain size/age structure data, which are typically obtainable through traditional 'fish in hand' methods. Despite these limitations, the non-invasive nature of eDNA monitoring makes it less likely to encounter permission restrictions. As such, it stands out as a promising option for acquiring baseline data at sites where existing data on the fish populations are lacking.

Hydroacoustics

Hydroacoustics is a particularly useful and non-invasive method for obtaining biomass density estimates in deep waters. Existing literature (BSI, 2014) provides practical guidance for survey design, including a recommendation that nighttime surveys during the summer period are preferred (Perrow *et al.,* 2017). Hydroacoustic surveys can include the use of vertically and/or horizontally oriented acoustic beams, meaning that this method can be used in both deep and shallow water habitats. A major limitation is that this method cannot solely be used to identify fish to species level. To overcome this, hydroacoustics are generally applied as a complementary method with another survey technique such as gill netting, that can validate/identify the fish species composition. Hydroacoustics, used alongside the deployment of short duration Nordic survey gill nets is routinely used to assess the status of vulnerable Arctic charr populations (e.g. Bean, 2003a; Bean, 2003b; Winfield *et al.,* 2009). The combined use of gill netting and hydroacoustic surveys provide information on fish species abundance while reducing the intensity of destructive sampling via gill netting. More recently, work has been undertaken to consider the use of eDNA-based assessment of the fish community in combination with hydroacoustic density estimations (Griffiths *et al.,* 2023). While this method is inherently non-invasive, the use of a powered vessel is required, which could lead to additional considerations in some sites. Additionally, the expertise and training required to correctly deploy this method may not always be readily available.

Seine netting

Seine netting is a well-established method which involves a wrap-around net with skirting, allowing for the non-lethal capture of fish in more open waters. This method is often deployed from the shore/bank (beach seining), but seine nets are also commonly operated from a boat or pontoon hauling platform (Perrow *et al.,* 2017). Seine nets are often large, generally 50m – 200m (Perrow *et al.,* 2017), with a float line at the top and a lead line at the bottom to keep them upright in the water column while hauling them in. The capture selectivity is generally determined by the net mesh size, however smaller mesh sizes are more prone to clogging and therefore a trade-off in practicality is required depending on the survey aims. This method is also hampered by obstructions, meaning they may be unsuitable in lochs with large quantities of submerged macrophyte growth, or boulder substrates. Semi-quantitative abundance estimations can be obtained with sufficient sampling effort; however, this is resource intensive in larger water bodies. Seine netting has the potential to cause disturbance, although with appropriate handling of specimens captured the impact on fish welfare can be minimised. The suitability of this method in deeper water is limited in comparison with shallow water, and additional methods need to be considered to assess the limnetic zone of deeper lakes.

3.1.2 Supporting methods

Electric fishing

Electric fishing involves the temporary immobilisation of fish by passing an electric current through the water between an anode and cathode. Affected fish (with impaired mobility) may then be captured using hand nets to enable assessment of relevant metrics. Electric fishing equipment can be easily operated in shallow water or fitted to a boat (in deeper water). This method is applicable to a wide range of waters, requiring adjustment of electric frequency, voltage and current depending on the target species and water conductivity. The main limitation is water clarity and the depth at which fish species can be practically retrieved by nets, around 2–2.5m (Perrow *et al.,* 2017). Therefore, this is not a suitable method to assess whole fish communities, particularly in deep lochs with narrow littoral zones. In shallow waters, however, it may be applied in a semi-quantitative manner using transects or PASE (point abundance sampling by electric fishing) (Perrow *et al.,* 2017). This method is particularly suited to surveying fish in littoral habitats and could be used to assess particular fish species which inhabit the tributaries or margins of lochs. While this may not detect rare or elusive species in margins, it could give an indication of the main fish species present in lochs. Electric fishing can cause local disturbance, but is extremely unlikely to result in significant fish mortality if carried out correctly.

Trawling

Trawling involves the use of towing boats to pull a catch net through the water column; this method can be applied with a range of netting gear sizes, shapes, and dimensions (Perrow *et al.,* 2017). Trawls must be towed sufficiently fast to overcome target species avoidance behaviours, hence this method requires specialist equipment and access to a suitable vessel. Due to the large sizes of towing vessels required, this restricts the use of trawling in smaller waterbodies and could lead to permission issues. There are relatively few comparison studies of trawling with other monitoring methods, although with sufficient coverage this method is semi-quantitative (Perrow *et al.,* 2017). This method has been used previously alongside hydroacoustics to assess the status of Arctic charr in Scotland (Bean *et al.,* 1996; Winfield *et al.,* 2002). However, given the cost and labour requirements, in addition to restricted use-cases, it has not been commonly applied to UK freshwaters and thus is considered a supporting method here.

Fyke nets

Fyke netting involves the placement of a 'funnel'-shaped net within the watercourse. This method is a passive sampling technique, which relies upon fish entering the trap and being unable to find their way out due to confusion by blind endings (Perrow *et al.,* 2017). Fyke netting is not a valid method to determine abundance or overall species composition due to its selectivity. As with many passive methods, capture efficiency is largely dictated by species- and season- specific fish activity. Some species may also exhibit stronger avoidance behaviour than others. At best, correctly standardized fyke netting may enable a relative Catch Per Unit Effort (CPUE) estimate to be made among sites. Nevertheless, fyke nets may be useful for establishing the presence of particular species in the littoral zone of lochs. For example, fyke nets are a low-cost and effective method for catching eels, which are not easily captured using other methods. In addition, with correct application, this method could be deployed to sample lacustrine species which spawn in inflowing and outflowing streams. Fyke netting is therefore included in this work as a supporting method.

Hook and line

Hook and line angling can be applied at a range of sites with minimal restrictions in terms of practicality, however this method is highly selective (Perrow *et al.,* 2017). Despite this, it can be used in conjunction with mark-recapture approaches to allow for estimations of population sizes. Furthermore, existing records from hook and line, in more intensively fished lochs, may be useful supporting data. Catch records from local anglers could therefore be used to inform baseline assessments of the fish community. Therefore, such data, where available, should not be overlooked.

Visual observations

In small, shallow and/or clear waterbodies, visual observations of fish species, for example via snorkelling, remote underwater vehicle surveys or incidentally while working at site, can act as supporting information (Perrow *et al.,* 2017). This is particularly true for large and readily observable species, which may be difficult to sample quantitatively by other means. While it is not currently recommended that specific monitoring programmes are designed around this method, confident observations of fish species through visual observation should not be discounted when

making assessments. Such observations may be recorded alongside other planned surveying, including associated habitat assessments. In a few select instances, visual observations have also been supported by the use of fixed underwater cameras (Perrow *et al.,* 2017). These methods are non-invasive and unlikely to have permission issues

3.2 Workshop outputs

3.2.1 Expert contributions

The workshop had representation of experts from different sectors relevant to the monitoring of Scottish freshwater lochs (Figure 3).

3.2.2 Questionnaires

The quantitative aspect of the pre-workshop questionnaires was used to identify stakeholder priorities when considering fish monitoring methods, with the quality and reproducibility of data being recognised as first and second priorities (Figure 4). These findings and the answers given to the qualitative questions were used to add depth to the four key themes of the workshop (Data requirements; Suitability of survey methods; Site specificity; and Long-term considerations) and to inform Figures 5 to 8. These formed the focus of the world café discussions of inter sectoral groups. The outcomes of these discussions are summarised in the sections below.

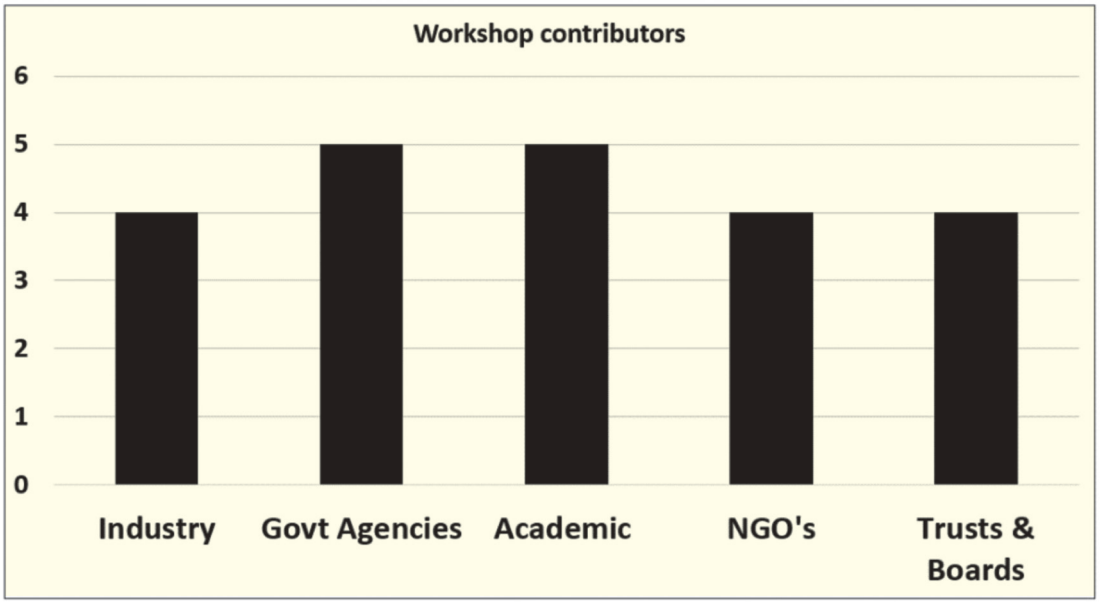

Figure 3: An overview of workshop participants by sector/group.

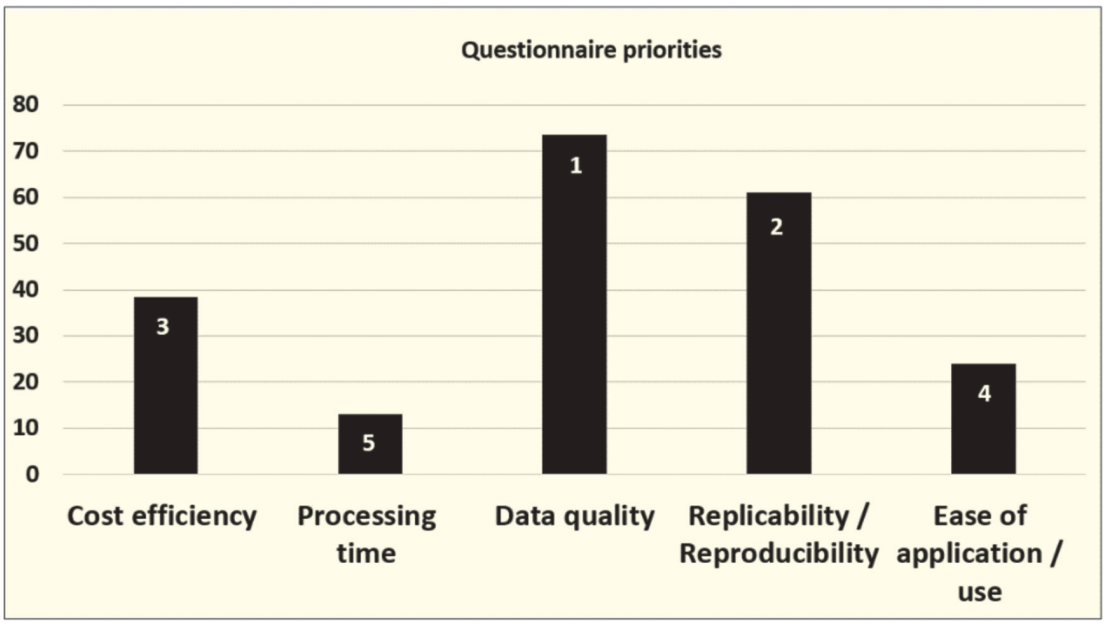

Figure 4: Stakeholder priorities when considering the use of fish monitoring methods (1 high - 5 low).

3.2.3 Ecological Data Requirements

When discussing Figure 5, all workshop participants recognised that no single sampling method could provide sufficient data necessary for a rigorous assessment of the status of lacustrine fish populations. The reasons given included that they may be too focused on a single species and fail to capture a representative picture of the entire fish community. Participants also felt that surveys were often impacted by poor sampling design and differing priorities of stakeholders involved, which impacted the quality of data. Attempts were made to prioritise the fish-specific metrics included in Figure 5. Presence and/or absence of species was given the highest priority. Historical fish data (in its current form – variable in quality and often inaccessible) and absolute abundance (or biomass) were considered of lower importance. Participants felt that the quality of data in the context of monitoring lentic freshwater environments is driven by the survey objective(s). For example, does it answer the question being posed by the surveyor(s)?, is it statistically robust and repeatable, is it able to capture temporal and spatial components?, and is it applied consistently from year to year within a water body, between water bodies, and between survey teams? Data were considered "meaningless without a baseline position". Historical data were considered useful in establishing baselines but should be considered with caution as it may be comprised of data collected using different methods and levels of surveyor effort/skill. It was strongly felt that having the datasets/reports generated by surveys (historical or current) publicly available would help produce meaningful baselines and improved consistency, and regulations should be designed to require mandatory data sharing. Good knowledge exchange between stakeholders could/would improve the consistency and quality of data collection and sharing. Detailed findings are provided in Appendix B.

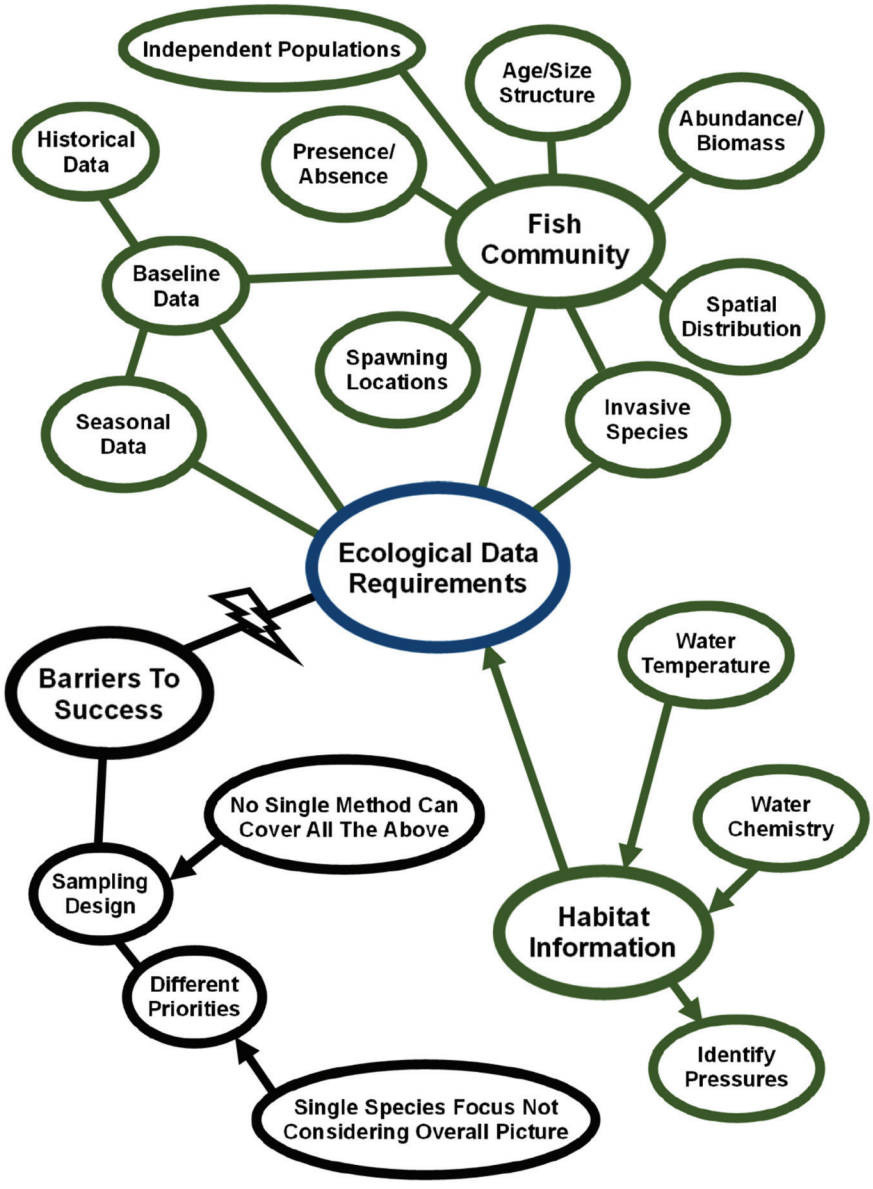

Figure 5: A visualisation of workshop discussions based on thematic analysis for data requirements.

3.2.4 Suitability of Survey Methods

When discussing Figure 6, workshop participants considered which methods could be used together or in isolation. Also discussed was the importance of these methods for producing data with sufficient statistical power (e.g. sufficient sample size or replicates) or confidence to support a decision-making/management framework.

Participants acknowledged that, while method selection *"needs to be matched to the question posed and data requirement"*, the constraints of a given location may impose compromise. Practices that skew survey findings and mask wider issues (e.g. targeting priority species or exemplar habitats) need to be avoided in baseline assessments and scoping. Instead, such targeted practices should only be used for species overlooked by less targeted methods. Methods chosen should be capable of producing consistent data across time and locations. Participants felt that the *"default position should be non-lethal sampling methods unless these cannot address the requirement for information"*. In particular, that gill netting should be replaced with alternatives (e.g. eDNA, hydroacoustic methods, electrofishing) wherever possible without compromising data requirements. It was felt that all methods are complementary and that combining methods may be the best approach to addressing survey objectives/questions. Participants suggested that the complementarity of methods may be optimised by having common standards, using methods that provide different but overlapping data and provide a balance between the quality of data gathered, ecological disturbance and costs/resources. Detailed findings are provided in Appendix B.

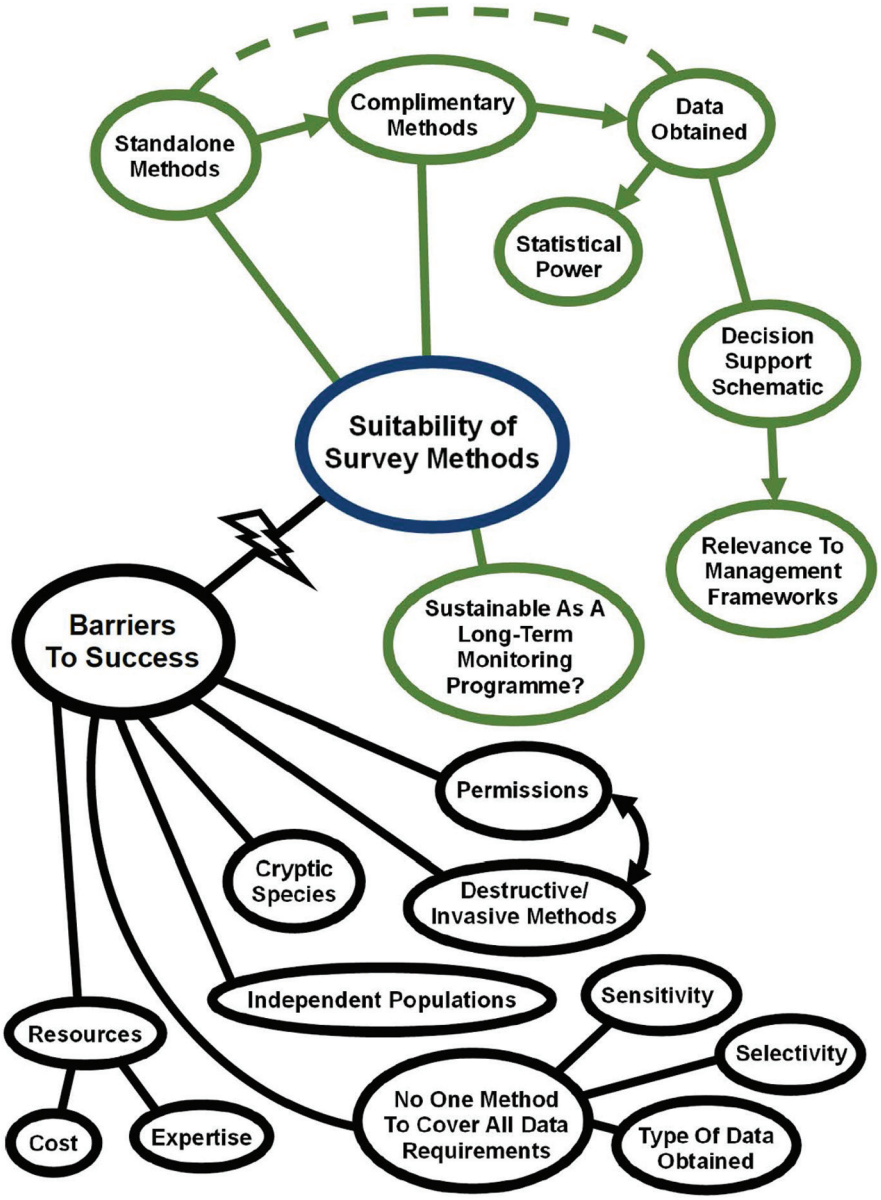

Figure 6: A visualisation of workshop discussions based on thematic analysis for method suitability.

3.2.5 Site Specific Characteristics

When discussing Figure 7, the main themes explored by participants related to baseline data, methodologies, and site-specific impacts. Other practical considerations included access restrictions, biosecurity (linked to the presence of invasive non-native species), and resourcing, including funding, capacity, and availability of expertise.

The collection of good quality data, habitat characteristics (e.g. size of waterbody, depth, hydrology), species characteristics (e.g. seasonality, life cycle), as well as land-use and land management (e.g. accessibility, authorisations) were discussed. These elements were also identified by participants as factors that could affect data quality, alongside potential condition changes linked to post-development or climate change. How the baseline is defined, as well as what is considered as low/high risk in terms of impact, were also considered relevant for this topic.

Themes around adaptation of methods for specific site conditions included data requirements, funding models and awareness of other water users. There were also practical considerations around using flexible approaches to monitoring and adapting methodologies to specific sites and species assemblages. Detailed findings are provided in Appendix B.

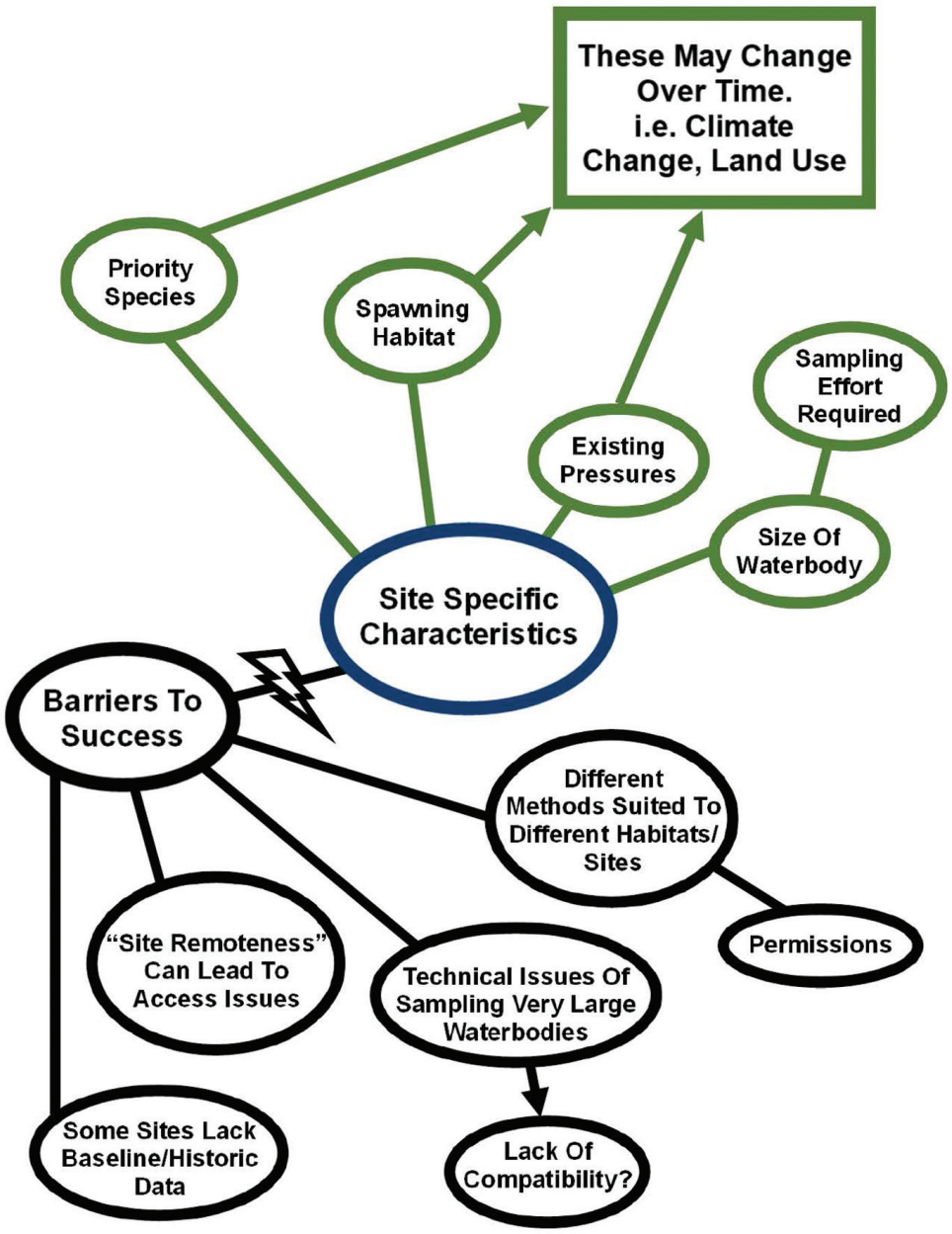

Figure 7: A visualisation of workshop discussions based on thematic analysis for site specificity.

3.2.6 Long-Term Outlook

When discussing Figure 8, the potential suitability of methods in 10–20 years' time was considered. It was thought there could be a shift away from methods that were seen as intrusive or lethal and there was concern around loss of expertise or training for technically demanding sampling methods (such as hydroacoustics), or a lack of a technical understanding of newly emerging approaches (such as eDNA). Adaptation of methods as the environment changes included comments that a multiple method approach should be used, and that the development of methods shouldn't be constrained to existing/established approaches. Multiple methods could be used as long as the data are complementary and comparable. Data analysis and the selection of appropriate statistical methods, was a concern, requiring standardised long-term training and support frameworks.

Biological protection being a higher priority in the planning process elicited discussion around developers being given information about what was required and clear guidance on what species are of particular concern. It was felt that good baseline data and long-term monitoring are essential prerequisites for the assessment of impact. Requirements to improve planning decisions drew responses around long-term planning and monitoring, and the importance of high-quality baseline data including monitoring before any additional construction. Determining the data requirements and getting plans in place to support development applications prior to submission was also seen as being important. Detailed findings are provided in Appendix B.

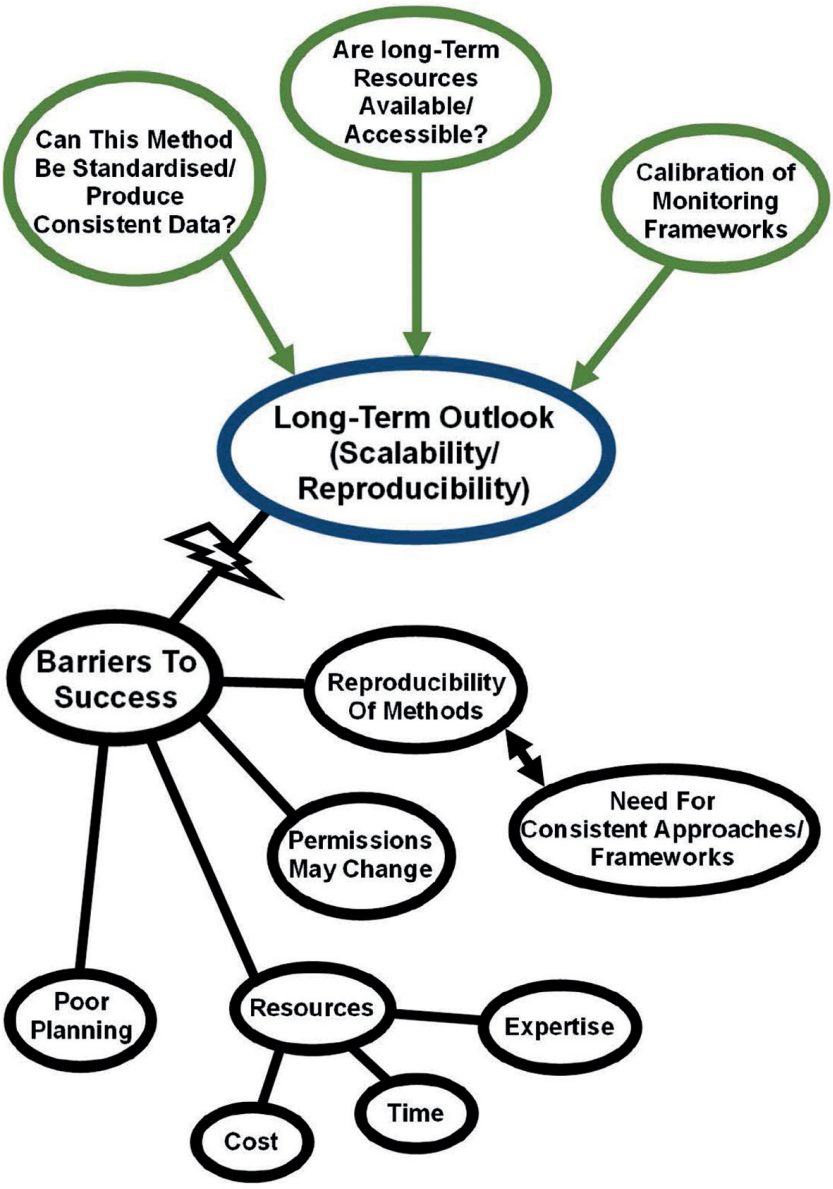

Figure 8: A visualisation of workshop discussions based on thematic analysis for long-term outlook.

3.2.7 Workshop sectoral discussions

The following questions arose from the world café intersectoral group discussions and were specifically addressed by workshop participants. Summarised below:

1. **Can we prescribe minimum data requirements? What would they likely be?**

   In most cases, discussions of minimum data requirements resulted in lists of necessary data. However, what species are present in a location was typically considered the minimum level of data that could be collected and there was general agreement that methods used, and data collected should be fitted to a specific question. This makes the practical minimum the least data necessary to answer a given question. A high-quality baseline (including a temporal dimension) and details of the distribution of species in the habitat were considered only marginally lower in priority.

2. **What is the process/mechanism to prioritise choice of sampling methods?**

   Data collection should begin with the identification of a specific question and/or aims/objectives of a survey, including which species and site characteristics are required and the level of detail required. Ideally, survey design should begin with the use of the least destructive/invasive/costly methods before moving on to using progressively more destructive/invasive/costly methods only where necessary. While the final choice of survey method will likely be a compromise between these ideals and considerations of feasibility, e.g. accessibility of the site, regulatory requirements, impacts of the season on accessibility and species lifecycles and/or behaviour, availability of expertise, and cost.

3. **How do we answer questions when method choices are restricted? (e.g. gill netting permissions)**

   Initially, the ethics of any data collection method should be considered and the importance of the use of low impact options considered early. There are many sampling techniques available and if more commonly used methods are unsuitable or inadequate to the task, other techniques should be substituted/considered. Finally, the use or development of new technologies and/or novel methods should be considered to replace such unsuitable/inadequate methods. By using multiple complimentary methods, less invasive survey designs could be achieved.

4. **Given the variables between sites, how do we provide standardised best practices?**

   The methods used should be accepted as suitable for a given survey question/objective. To facilitate this, methods should be considered in light of their capacity to provide species- or question-specific solutions. Data collectors and data users should review and reflect on the methods used and data collected to allow their application to be managed adaptively and changes accounted for. By standardising the required outputs/reports that surveyors must submit to regulators it may be possible to standardise the quality across surveys. Such outputs should be statistically robust to assist in comparisons between surveys and methods.

5. **Can we standardise methodologies through knowledge exchange + training?**

   Having open access to existing libraries of data from a range of methods would assist in exchanging knowledge about the (cost) effectiveness of different methods in gathering data required by survey objectives. This knowledge would contribute to discovering which methods are most effective and should be adopted generally or for answering particular questions. A standardised identification key and set of monitoring approaches could be developed for each species. Such "methods and techniques could easily be developed and delivered through training programmes" possibly through existing organisations.

6. **What are suitable processes for inclusion of broader stakeholders? Should data be more widely available, and how?**

   It was recognised that there is a need for a long-term central data archive/repository to include report outputs such as data collected for EIA. However, it was also recognised that funding would be required to run such an archive. It was felt that the developers, of developments that have the potential to impact fish populations, should contribute to the archive's upkeep. Participants also highlighted that the quality and depth of the data being shared should be made consistent across surveys through regulations, which should also require that survey outputs be publicly shared.

7. **What responsibilities do developers have to develop sufficient monitoring methods/ programmes, and should regulatory bodies provide more guidance?**

   It was generally considered that regulatory bodies should be providing more guidance, and that developers have responsibility to contribute to the overall process rather than just paying for their developments. The guidance that regulatory bodies provide could include: 1) a set of common standards; 2) the questions/objectives of surveys; and 3) methods that have been validated as suitable to address the questions/objectives of the survey. Any novel methods proposed by developers should be validated by regulatory bodies.Finally, developers have a responsibility to provide evidence about their impacts in relation to a fixed, standardised baseline condition. This permits potential impacts to be identified and avoids such impacts being masked where survey sites are already degraded.

4 Recommendations

This report produces guidelines and recommendations for the best approaches to monitoring fish populations in Scottish freshwater lochs. It should be noted however, that detailed method-specific protocols and considerations are beyond the scope of this work. For more specific explanations of methods see Kubečka *et al*. (2022), overviews of method suitability (e.g. Perrow *et al*., 2017; Table 1) should also be noted. Guidelines on established methods should be consulted when surveying priority species e.g. JNCC (2015), while standard practices should be followed when using emerging methods UKTAG (2021) to ensure reproducibility.

The guidelines provided in this report should be used to ensure that appropriate sampling methodologies are selected (Table 1, Table 2) and that surveys are properly designed to ensure data requirements are met (Figure 9).

Table 1. An overview of Primary Sampling Methods and the data they obtain.

Data Requirements	Primary sampling methodologies **Invasiveness →			
	eDNA	Hydroacoustics	Seine netting	Gill netting
Presence/ Absence	**Yes**; this is a highly sensitive method for presence/absence of individual species.	**No**; this method is unable to determine the species of fish as a standalone method.	**Yes**; but this method is selective and limited to certain habitats.	**Yes**; but this method can be selective and is almost always destructive.
Spatial distribution	**Yes**; with sufficient spatial sampling.	**Proxy**; this method is unable to determine the species of fish as a standalone method. But could inform overall habitat use/fish distribution.	**Yes**; with sufficient spatial sampling.	**Yes**; with sufficient spatial sampling.
Abundance/ Biomass	**Proxy**; relative abundance and DNA concentration can be used as metrics. However these are not absolute.	**Proxy**; with sufficient spatial sampling, however this is not species-specific abundance.	**Yes**; with sufficient sampling design semi-quantitative estimations can be obtained.	**Yes**; with sufficient sampling design semi-quantitative estimations can be obtained.
Spawning Locations	**Yes**; with sufficient spatial and temporal sampling. Peaks in eDNA signals are observed during spawning.	**No**; not possible to reliably determine using this method.	**No**; not possible to reliably determine using this method.	**No**; not possible to reliably determine using this method.
Age/ Size structure	**No**; not possible since no fish are captured for assessment.	**Proxy**; Size data can be obtained, however not for specific species.	**Yes**; fish are captured and this could be obtained.	**Yes**; fish are captured and this could be obtained.
Independent populations or ecotypes	**No**; not possible since no fish are captured for assessment.	**Unlikely**; not possible since no fish are captured for assessment. However, observations of spatially disjunct fish distributions could suggest the presence of independent populations.	**Yes**; fish are captured and populations could be assessed.	**Yes**; fish are captured and populations could be assessed.

Table 2. An overview of Supporting Sampling Methods and the data they obtain.						
Data Requirements	**Supporting sampling methodologies** ****Invasiveness →**					
	Historical/ existing data	**Visual observations**	**Hook and line**	**Fyke nets/traps**	**Electric fishing**	**Trawling**
Presence/ Absence	**Data dependant**; Note, existing data may not be temporally accurate but can inform scoping.	**Yes**; but this method is selective and limited to certain habitat conditions. Not good for community level assessment.	**Yes**; but this method is highly selective depending on the target species. Not good for community level assessment.	**Yes**; but this is a passive method with high species selectivity. Only suitable in certain instances/ locations. E.g. Eel surveys. Not good for community level assessment.	**Yes**; but this method is selective and limited to certain habitats.	**Yes**; but this method can be selective and is significantly more invasive that other supporting methods. Restricted at smaller sites
Spatial distribution	**Data dependant**; Note, existing data may not be temporally accurate but can inform scoping.	**Yes**; but this method is selective and limited to certain habitat conditions.	**Yes**; but this method is highly selective and therefore only suited to certain species assessments.	**Yes**; but this method is selective and limited to certain habitats. Needs to be used in conjunction with other methods for a full picture.	**Yes**; with sufficient spatial sampling. But this is limited.	**Yes**; but this method is selective and limited to certain habitat conditions.
Abundance/ Biomass	**Data dependant**; Note, existing data may not be temporally accurate but can inform scoping.	**Proxy**; anecdotal/ qualitative estimations in very small water bodies.	**Proxy**; this can be estimated if combined with mark-recapture approaches to assessment.	**Proxy**; at best, a relative CPUE estimate can be made between different sites if sampling is standardised correctly.	**Yes**; with sufficient sampling design semi-quantitative estimations can be obtained.	**Proxy**; relatively few comparison studies exist, although with sufficient coverage this method is assumed to be semi-quantitative in lochs.
Spawning Locations	**Data dependant**; Note, existing data may not be temporally accurate but can inform scoping.	**Yes**; fish spawning behaviour may be observed. This can be enhanced by the use of cameras.	**No**; not possible to reliably determine using this method.	**No**; not possible to reliably determine using this method.	**Proxy**; not possible to reliably determine using this method. But can be inferred from juveniles.	**No**; not possible to reliably determine using this method.
Age/Size structure	**Data dependant**; Note, existing data may not be temporally accurate but can inform scoping.	**No**; not possible since no fish are captured for assessment	**Yes**; fish are captured and this could be obtained.	**Yes**; fish are captured and this could be obtained. This method is selective however, and therefore may be biassed towards certain sizes.	**Yes**; fish are captured and this could be obtained. However, this is limited to the suitable survey area.	**Yes**; fish are captured and this could be obtained.
Independent populations or ecotypes	**Data dependant**; Note, existing data may not be temporally accurate but can inform scoping.	**Unlikely**; no fish are captured for assessment, however visual observations of morphological variation may suggest the presence of different ecotypes	**Yes**; fish are captured and populations could be assessed.	**Yes**; fish are captured and populations could be assessed. This method is selective however, and therefore may be biassed towards certain behaviours.	**Yes**; fish are captured and populations could be assessed. However, this is limited to the suitable survey area.	**Yes**; fish are captured and populations could be assessed.

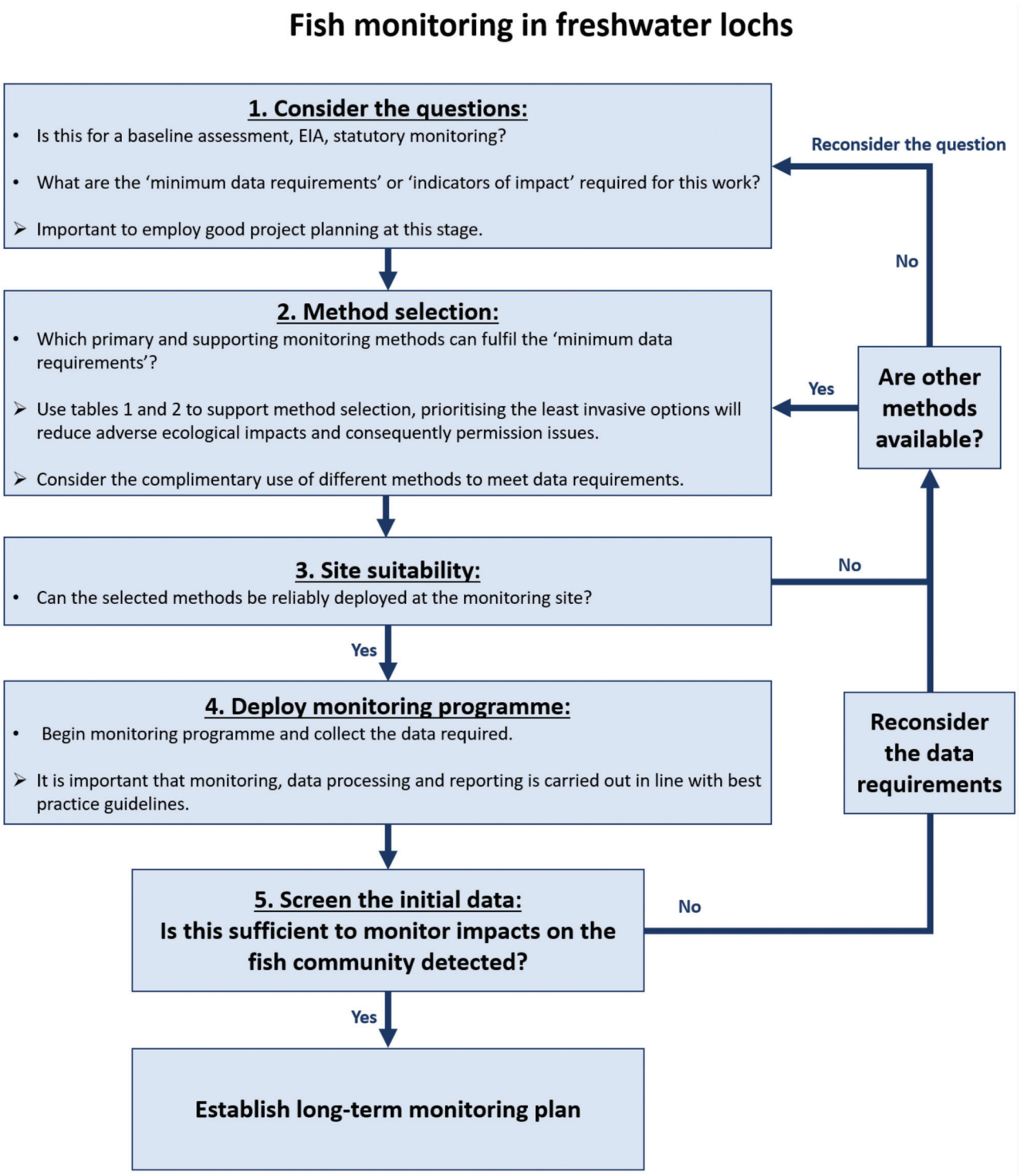

Figure 9: A monitoring framework for fish assessment in freshwater lochs.

5 Conclusions

This report provides an overview of methods which could be applied to monitoring fish populations in Scottish freshwater lochs (Table 1, Table 2). These methods should be considered with specific project aims and questions in mind when developing appropriate survey strategies. Furthermore, the framework outlined in Figure 9 highlights a logical approach to determine the most appropriate methods once data requirements have been considered. While this project incorporates a range of stakeholder and regulatory viewpoints, it is important to consider the application of any specific method against current/up-to-date best practices and ensure that all minimum reporting standards are met.

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7 Appendices

Appendix A: Workshop Methodology

A systematic literature review was carried out to address the key research questions, drawing on government reports/policy guidelines, and wide-reaching academic literature via a comprehensive search of key words relating to each of the specific questions and deliverables for this project. The outcomes from considering the questions that arose from the initial literature review and subsequent discussion with relevant experts, other stakeholders, and the project steering group, were then placed into the context of fish monitoring in freshwater lochs for EIA and policy needs.

The participants invited to the expert-led workshop were identified through a stakeholder mapping process. The latter was carried out following a consultation with the project steering group to ensure key stakeholders' views were incorporated early in the process, alongside the literature review. Stakeholder mapping and design of the workshop were informed by short but systematic discussions with a core group of experts in various sectors and disciplines and included representatives from the following:

Experts with technical knowledge such as:

- UK Government bodies including NatureScot, SEPA, Environment Agency staff.
- Fisheries Boards/Trust.
- Academics with expertise in biodiversity, fish ecology.
- Scottish Government Marine Directorate (SG-MD)
- Scottish Fisheries Coordination Centre (SFCC)

Additional stakeholders including:

- Industry (e.g. SSE)/consultants

The stakeholder mapping exercise informed both the broader range of literature reviewed and the selection of additional stakeholders to interact with the core group of experts initially consulted. The intention of this broader scope was to understand the wider impacts and viewpoints surrounding the fish monitoring methods discussed. Further consultation with the project steering group was carried out before finalising the list of invited workshop participants.

The discussions with the core expert group prior to the workshop ensured input from a range of sectors and engendered more ownership of the expert-led process and emerging results. For example, the workshop process added depth to the initial questions which were based on the literature findings. The key priorities to be addressed in the workshop emerged through these discussions so that the systematic desk-based research could be applied to policy and practice. Questions addressed in discussions were planned through thematic analysis of the pre-workshop questionnaires by the project team.

The expert-led stakeholder workshop was specifically targeted to determine the requirements of assessing fish populations in freshwater lochs, to conform with regulations e.g. EIA assessments, and the feasibility of each available fish sampling method to achieve this. This workshop was centrally located in Perth so that participants could travel for the one-day participatory session. The previous discussions with the core expert group fed into determining priorities. The facilitator team consisted of scientists and social scientists who have been involved in technical and community conversations in the UHI's research theme 'Nature and People'.

Starting with input from the literature and expert discussions, invited experts were split into inter-sectoral followed by sectoral groups to provide in-depth information on experiences and work on pre-identified priorities.

The groups were facilitated to share their experiences and contribute to the conversation, with thorough write-up of the discussions within the groups. There were also plenary sessions to cross-check and collate findings from the participatory thematic and focus group sessions.

The UHI research team collated the information obtained during the literature review, expert consultations, and expert-led workshop to form this detailed report highlighting the findings and considerations regarding fish population assessment methods in freshwater lochs. This report summarises the literature and workshop findings, and places these into the context of regulatory requirements to provide specific guidance and considerations on the sampling methods which can be adopted by developers.

Appendix B: Workshop outputs

Ecological Data Requirements

Responses to the pre-workshop questionnaire prioritised fish-specific metrics often providing considerable lists of metrics that should be considered such as species present or absent, abundance of species, and the size and age of individuals (Figure A1). The weighting of discussion in this theme is outlined in Figure A2. Habitat information was also considered a high priority for collection. It was recognised that no single method can account for all the data required as these may be focused on a single species and fail to capture a representative picture of the biodiversity of a water body. The barriers to successful surveys identified in Figure A1 are often impacted by poor sampling design and the differing priorities of the stakeholders involved.

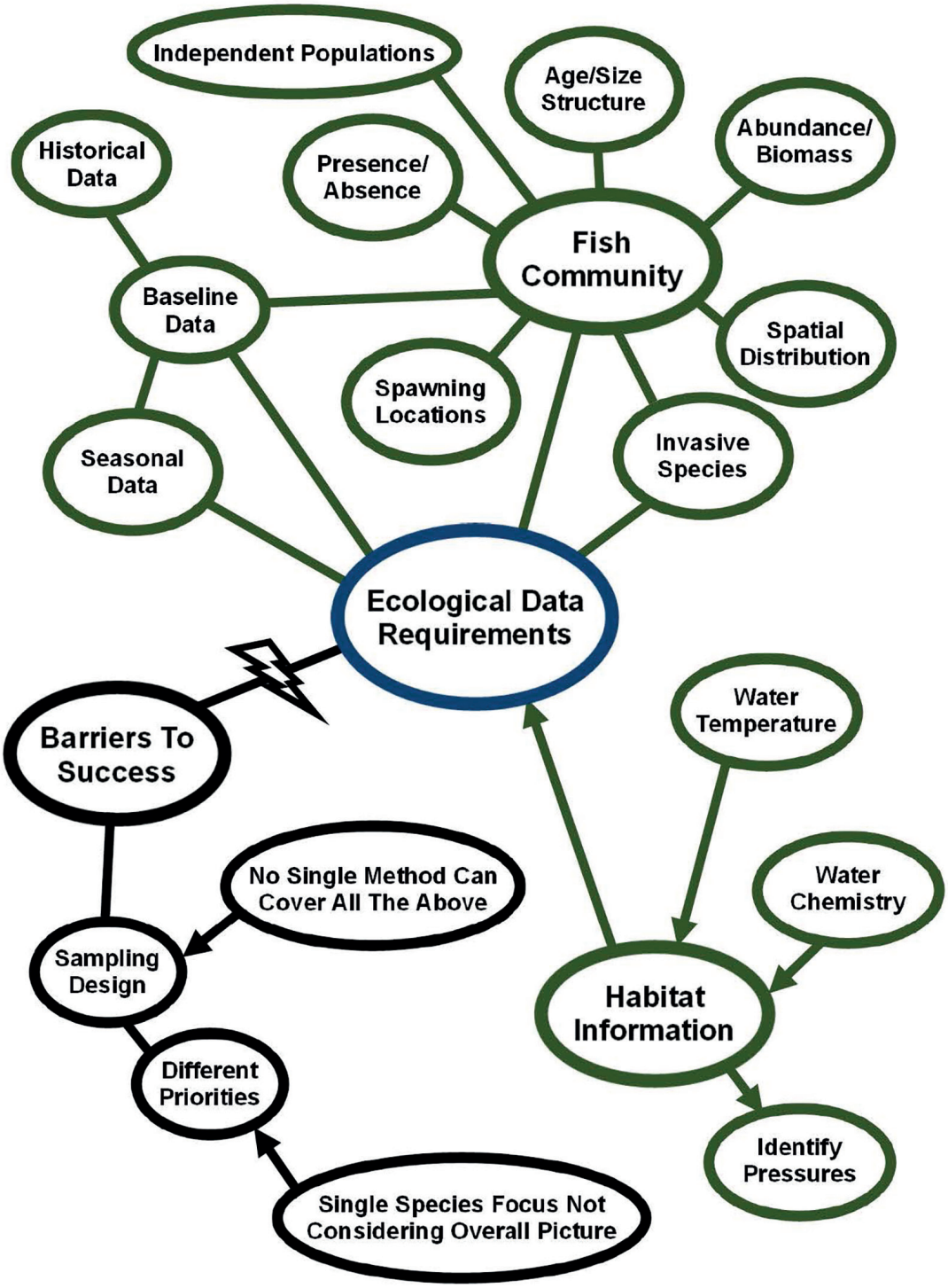

Figure A1: A visualisation of questionnaire responses/priorities based on thematic analysis for ecological data requirements.

In the workshop, NGOs responded the least (only three responses were recorded). The other four sectoral groups were roughly even in their response rate and were typically in broad agreement when discussing the findings drawn from the questionnaire.

The importance placed on the fish-specific metrics led to half of the participants (two discussion groups) attempting to prioritise these metrics. Summing the number of participants who applied their number to a given metric (Figure A2) gave a rough quantification of which metrics were considered most important during a survey relative to others by these two groups of participants. Presence and/or absence of species was given the highest priority. While, historical fish data, abundance or biomass, and considerations of the independence of populations were not annotated during these discussions. The spawning locations of fish were considered key by one group but only relevant in the context of specific survey objectives by the other. The other two workshop groups concentrated on discussing other aspects of the theme.

Overall, participants felt that quality data in the context of monitoring lentic freshwaters was driven by the survey objective(s) and with the power to answer the specific question being posed by the surveyor(s). The data must be statistically robust, repeatable, and sufficiently representative to capture all temporal and spatial components of these water bodies.

"Statistical power should be considered in any monitoring program. […] undertaking a monitoring program that does not have good statistical power is a waste of resources".

"Reliability, robustness and representativeness (information should characterise whole waterbody, not just its parts)".

The data collected should also be consistent from year to year within a water body, between water bodies, and between teams of surveyors. Participants felt that good Knowledge Exchange between stakeholders can improve the consistency and quality of data collection and sharing, with one participant expressing the opinion that data of any quality has no value if they are not communicated. It was felt strongly that having all datasets/reports generated by surveys (historical or current) publicly available would help in the generation of meaningful baselines and improved consistency between surveys and that regulations should be designed to require mandatory data sharing by surveyors.

The need for a reliable baseline arose regularly from discussions with one workshop participant stating that data was "meaningless without a baseline position". Historical data were considered broadly useful, particularly when trying to establish

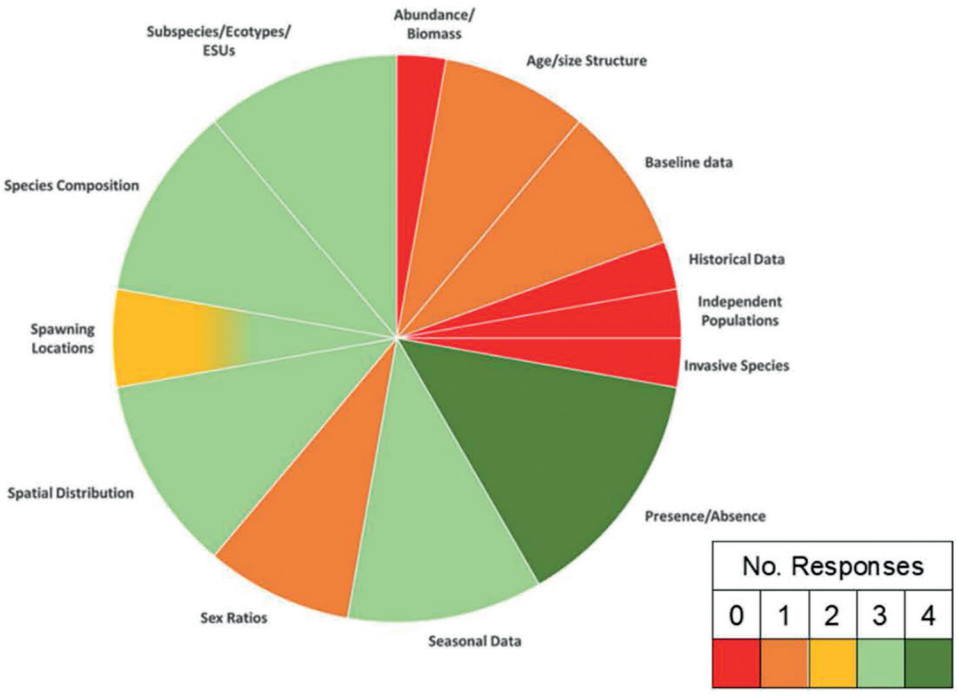

Figure A2: The relative importance of different fish-specific metrics as considered by two workshop discussion groups and measured by response rate during the discussions of these two groups. Spawning locations were the most divergent between the two groups with one only considering it an important metric if specifically embedded in the survey objectives.

a baseline, but needs to be considered cautiously as it may comprise widely differing methods and levels of surveyor effort/skill.

"Can give a good indication of what was there, but need to be aware if the methodology/effort differed from standard".

In relation to quality of data (collected in the past or present) "Appropriate survey conducted at the appropriate time by suitably qualified staff".

The need for appropriate expertise and clearly defined objectives remained key in consideration of the impact that environmental change may have on the continued robustness of methods. Additionally, participants felt that the methods and their use would have to change in parallel to the environment believing that there would be a need to reflect on past use/data and "to calibrate methods as they evolve and respond to change" such as species behaviour becoming "less predictable" or the windows for using certain methods or equipment may decrease or close altogether. Figure A3 below illustrates how the questionnaire results were updated and refined during the workshop discussions.

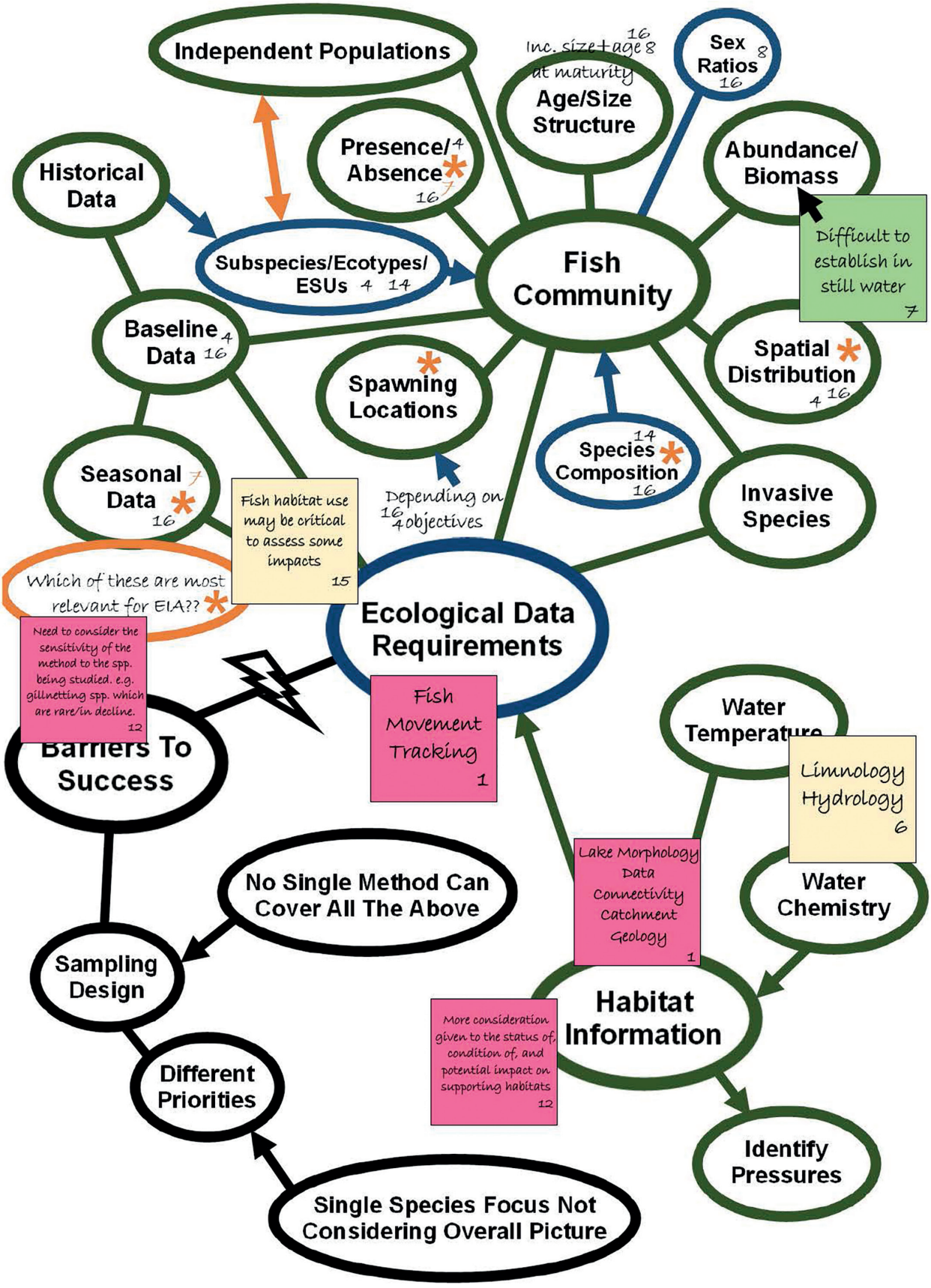

Figure A3: A visualisation of workshop outputs for ecological data requirements.

Suitability of Survey Methods

The responses to the questionnaire were less weighted to one particular facet of this subject. They showed more balance between the components that drove and those that acted as barriers to successful implementation (Figure A4).

The responses pointed to considering which methods could be used in isolation or to complement each other and whether the data provided by the methods would have the statistical power (e.g. sufficient sample size) to support a decision-making/management framework.

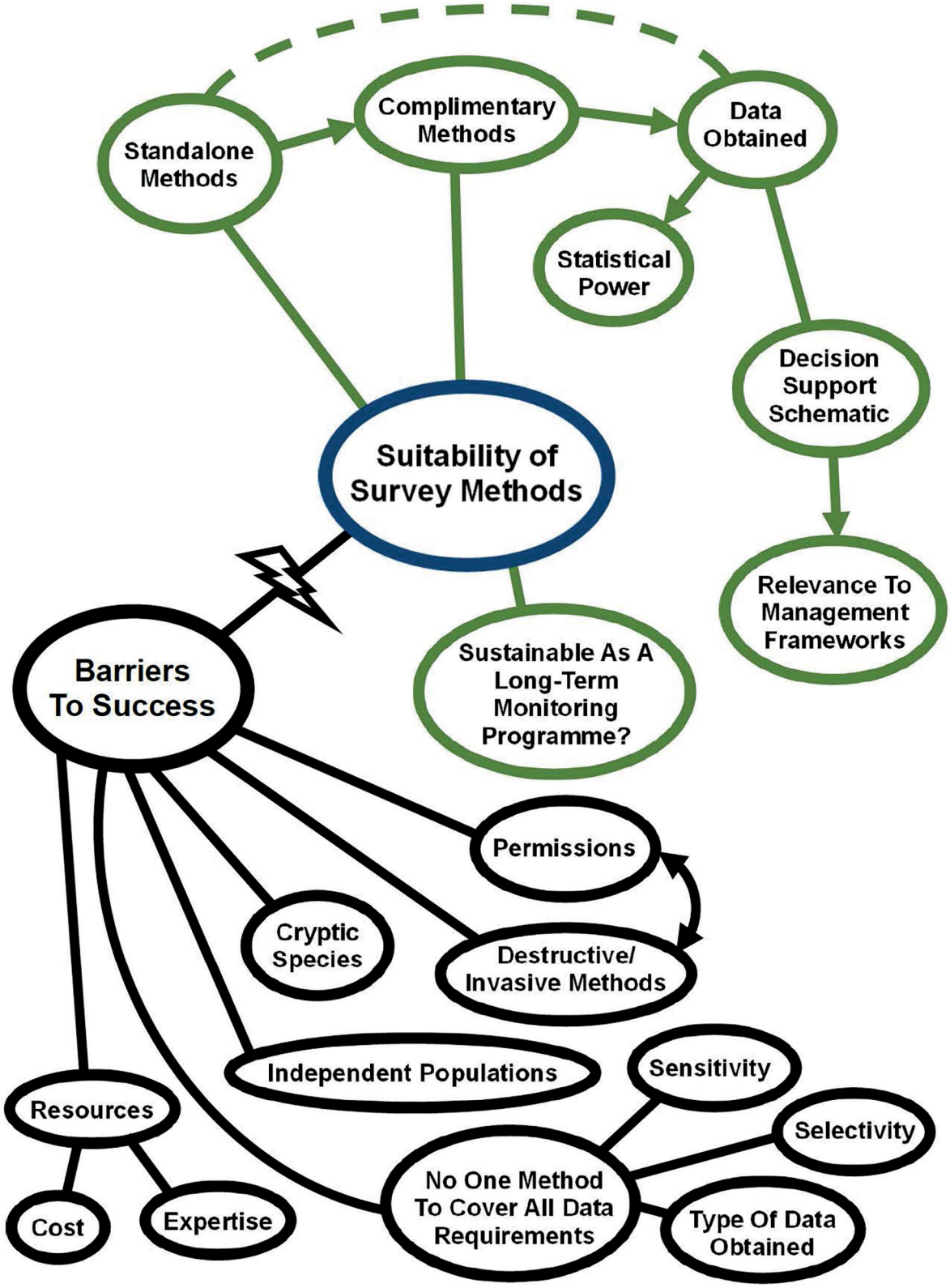

Figure A4: A visualisation of questionnaire responses/priorities based on thematic analysis for suitability of survey methods.

"Currently, it seems that a single approach – e.g. netting, hydroacoustics – can likely provide only fragmentary information for even a single species".

The barriers identified included the cost and expertise required to enact surveys and the selective nature and lack of sensitivity of current methods (Figure A4).

"Barriers are lack of comprehensive technical approach, requirement for diverse skills and high running costs including staff-time".

Workshop participants discussed the importance of selecting methods that are the most suitable for answering the specific questions being asked as part of a survey while acknowledging that the constraints of a given location may impose compromise.

"Method needs to be matched to the question posed and data requirement".

The methods chosen should be capable of producing consistent data across time and avoid targeting priority species or exemplar habitats for baseline assessments, as such practices can skew survey findings and mask issues until mitigation becomes costly or impossible. Instead, it was felt that targeted surveys should be retained for species known to be overlooked by less targeted methods.

It was felt that surveys should initially seek to use the least destructive/most passive methods to answer questions before moving to more destructive/invasive methods. Desk-based methods such as Geographic Information Systems (GIS), remote sensing, and literature reviews were posited as potential low-impact methods.

"Default position should be non-lethal sampling methods unless cannot address the requirement for information".

Gillnetting was generally considered sufficiently destructive to warrant repeated suggestions that it be discontinued and replaced with an alternative, or combinations of alternatives (e.g. Environmental DNA (eDNA), hydroacoustic methods, seine netting, electrofishing) that were equally acceptable to regulatory bodies. It was suggested that species (such as freshwater pearl mussels) known to utilise lentic freshwater bodies and to have life cycles closely linked to those of fish should be included in surveys for their intrinsic value and as indirect indicators of the presence of specific fish species and of the overall biodiversity of a water body.

One group of workshop participants attempted to provide some guidance regarding which methods could be used to capture which ecological data (Table A1).

Table A1: Ecological data requirements associated with the method(s) most likely to capture that data.

(This table was produced during discussion at the workshop)

Data requirement	Applicable method(s)
Age/size distribution	Gill or seine netting
Dependent species	e.g. Glochidia surveys
Population size	Gill or seine netting Hydroacoustic surveys Mark/recapture surveys
Spatial distribution	eDNA Gill or seine netting Hydroacoustic surveys
Spawning locations	eDNA Other?
Species present	eDNA Gill or seine netting
Sub-specific ecotypes	Existing data Gill or seine netting Population genetics analyses

All the methods in Table A1 were considered to be complementary. Participants felt that they could be applied in overlapping ways to provide the fullest possible data regarding the functioning of a water body. However, it was widely felt that any survey would be improved by choosing the method(s) best suited to achieving the objectives of a survey and the inclusion of habitat data. It was suggested that the complementarity of methods could be improved by having a set of common standards, by using methods that provide different but overlapping data and give the best trade-off between the data gathered and damage caused in the collection, by regularly calibrating equipment, and by selecting timings, locations, and depths that are as similar as practicable between surveys (Figure A5).

"How to combine different sampling methods, in order to reduce the number of fish killed, and still getting high quality data".

The implementation of regular reflection/feedback regarding the success and/or failure of methods and the inclusion of the statistical confidence for all data collected would permit constant improvement of methods and their use. This data would permit the prioritisation of methods that produce the most valuable data and to ultimately discontinue the use of methods that provide data of little value, especially if they are also destructive to the water bodies being surveyed.

Finally, it was considered important that any method(s) used contain a temporal component. This would allow for ongoing monitoring to be undertaken, environmental changes to be detected, and methods modified in response. A lack of skilled individuals was identified as a possible barrier to long-term monitoring as well as the cost and feasibility of applying methods in given contexts. Improved training options was the principal suggestion made for improving the available pool of skilled technicians which would also serve to improve user confidence in the data generated by surveyors. It was also posited that planning officers would benefit from improved training in the understanding and use of the ecological data and the methods used to gather them. Figure A5 below illustrates how the questionnaire results were updated and refined during the workshop discussions.

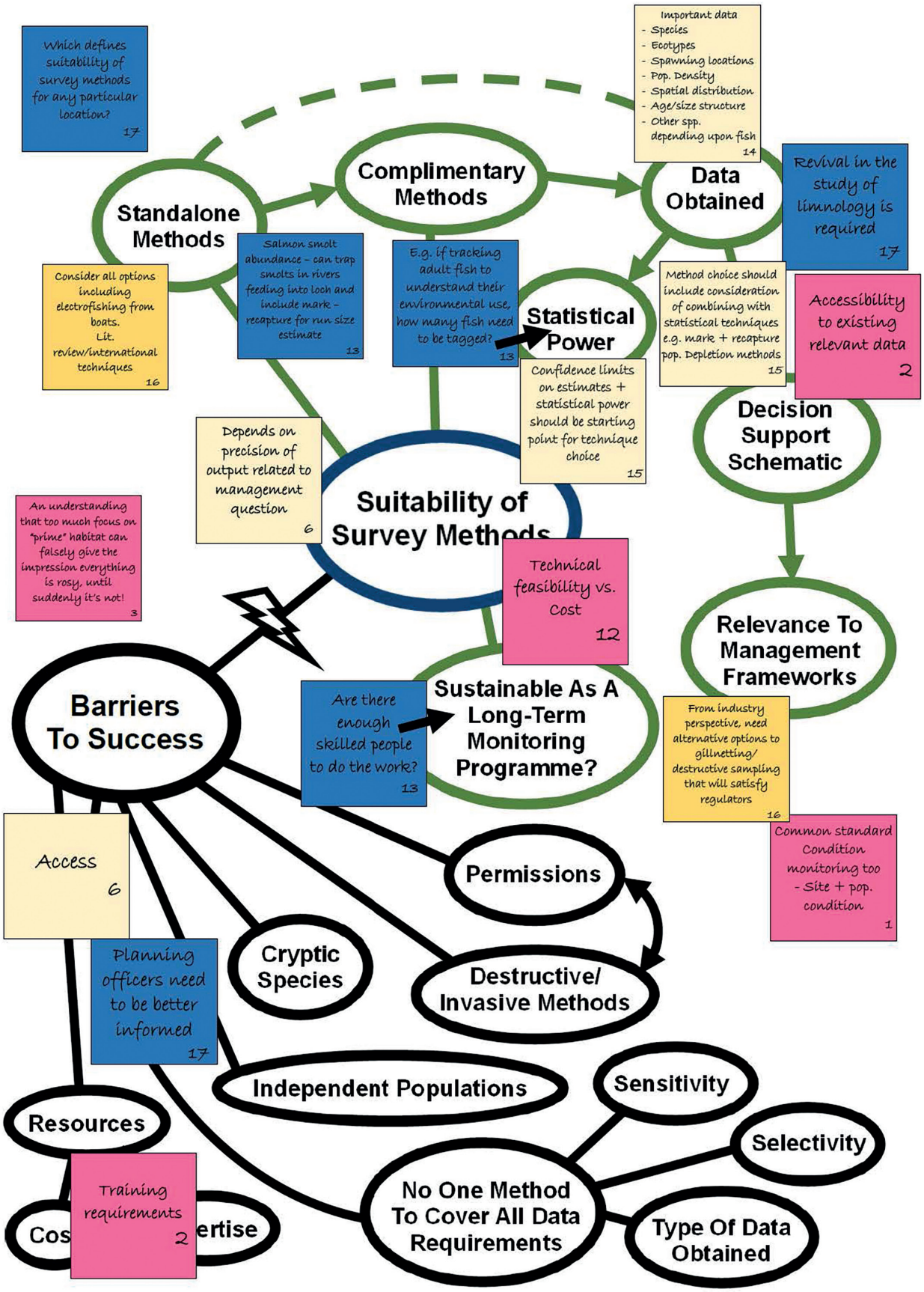

Figure A5: A visualisation of workshop outputs for suitability of survey methods.

Site Specificity

Following analysis of the questionnaires, the main focus of this theme covered: 1) priority species; 2) spawning habitats; 3) existing pressures; 4) size of waterbody; and 5) sampling effort required. The barriers to success that were investigated included: 1) lack of historic/baseline data for some sites; 2) access issues for remote sites; 3) technical issues of sampling very large waterbodies; 4) lack of compatibility; 5) different methods suited to different habitats/sites; and 6) permissions (Figure A6).

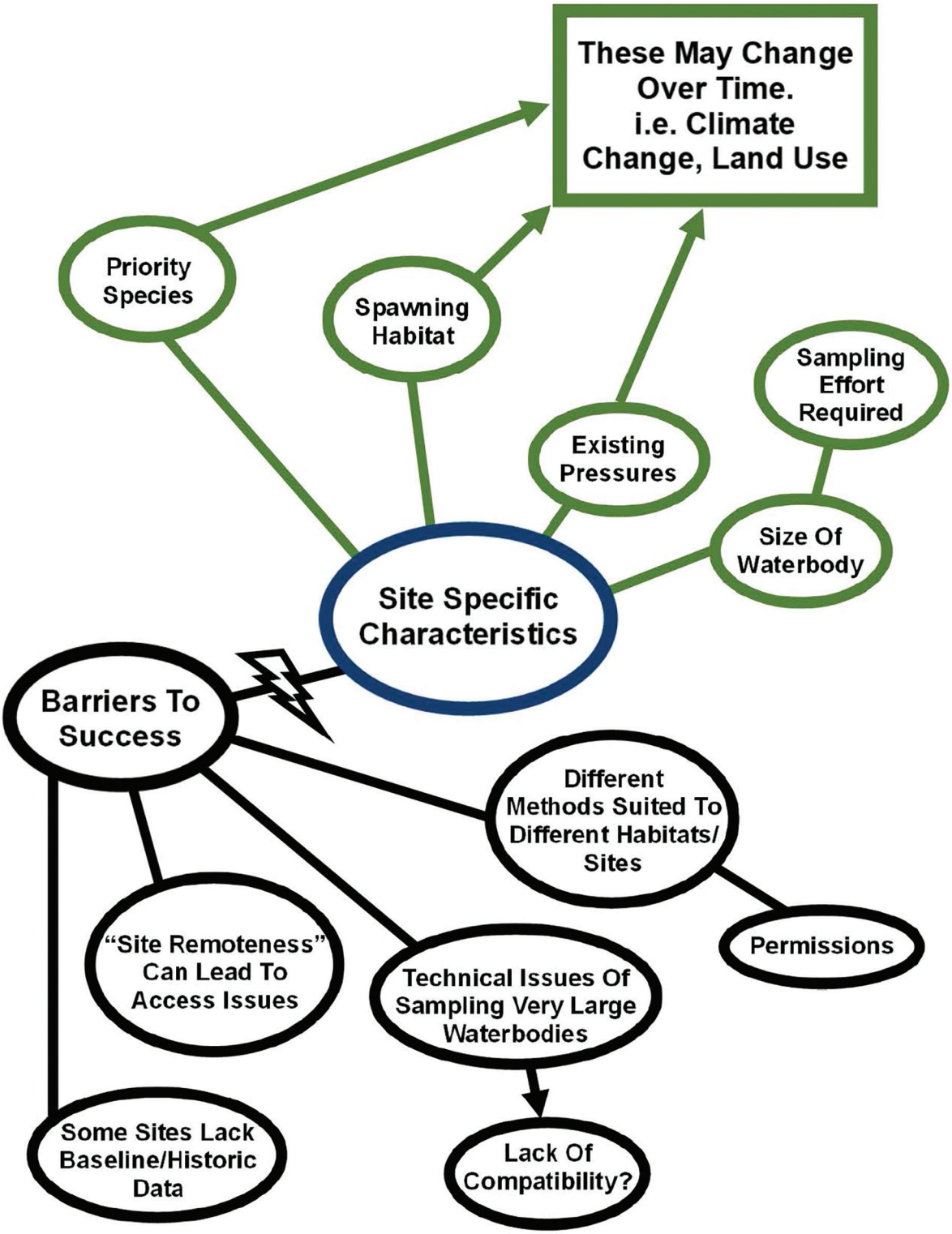

Figure A6: A visualisation of questionnaire responses/priorities based on thematic analysis for site specificity.

The following questions were discussed in the workshop:

Which site-specific elements must be considered to ensure that quality data is collected?

All sectors contributed to this question, with the DSFB/Rivers and Fisheries Trusts particularly engaging with this.

The themes that were discussed were habitat and species characteristics – such as '*Size; depth; clarity/macrophyte; target species + species comp + currents'* and '*habitat diversity e.g. loch with very deep and very shallow areas', 'method chosen must reflect site characteristics. So deep lakes may require the deployment of gillnets (e.g. littoral and deep profundal areas)'*. Also: *'seasonal, spatial and interannual variability needs to be assessed'.*

Considerations around land-use and land management were discussed e.g. *'Land use and other potential sources of pollution. Likelihood of future land-use change',* with *'knowledge of other pressures within the catchment'* was also highlighted as important to consider.

Data, definitions, and impact were also considered relevant for this question e.g. '*cumulative effects of multiple developments'; 'needs to be more focus on scoping stage – better definition of monitoring'.* Also, a need to *'consider historical data + local knowledge'.* Where to monitor*: 'should the river at the outflow at the loch be monitored, not just the loch itself?'* On impact: *'need to consider cumulative impact', 'hydrology, and how the development would impact this'*.

How do methods need to be adapted to specific site conditions?

All sectors engaged with this question and discussion focussed around a number of areas especially adaptability of methodology: *'needs to be more focus on limnology as this influences all aspects of lakes/lochs', 'eDNA sampling; sampling locations and effort need to be season specific', 'any method and monitoring plan needs to be tailored to the site being studied – must also consider* ***diel and seasonal*** *impacts on data collection'*. Also, '*flexibility of approaches to achieve similar results while avoiding other issues like weather, access, season', 'adapt gears to specific known target species'* and *'adapt methodology to site characteristics. Consider appropriate multi-method monitoring'*, another comment was that *'temporal change not always picked up'*.

Decisions around monitoring were also considered: '*decision-tree on methods and site-specific characteristics to guide selection of appropriate methods', and 'who decides what methods are suitable for that site?'*

Other water users need to be taken into consideration: *'awareness of other water body users – recreation; tourist boating; motorised vehicles; fishing, etc'* and '*need to consider other water users e.g. can't deploy gill net in area with lots of boats'.*

There were other considerations as well such as including data such as *'do current conditions represent true historical environment? Danger of preserving something created by previous human impact'* and a query over funding in Scotland: '*There has been a switch from government funded monitoring to private funded. Does this work for Scotland?'*

How do site conditions impact data quality?

Themes that emerged under this question were site characteristics such as '*depth, turbidity, substrate type, algal growth, impact of weather – large, exposed loch may be increasingly hard to survey as weather deteriorates',* '*comparability of spatial elements – big loch – little shallow loch', 'large water bodies reduce chance of finding rare species'*, '*extremes – very large; very deep; very shallow; macrophyte growth; very high; very exposed; etc',* and to consider *'variability needs to be understood and methods chosen and sampling programme implemented to accommodate', 'need to understand INNS situation'*, and '*important to consider microclimates .i.e what happens upstream affects downstream'.* Species characteristics are also important: '*species behaviour – specific traits'*.

Other conditions that might impact data quality: *'weather conditions reduce catch efficiency'*, '*seasonality, also measuring during a drought how to show a baseline*', *'need to account for seasonal variability',* should also be taken into consideration.

There are future considerations – *'how will the physical changes brought about by the actual development impact on future monitoring techniques and capabilities'*, and '*what are the long-term impacts on fish species? Conditions are changing (e.g. temp, rainfall, demand for water). And their prey? – impacts on ecosystem functioning'.*

And also comments around: '*depends on source of data and investment in monitoring'*, '*some/many techniques are very spp specific – many spp can be ignored,'* and '*scalability of study design will be affected by habitat extremes mostly in an unknown way'*.

There was also a lot of engagement with the bubble chart as detailed over (Figure A7).

Trends/outcomes/themes

In summary, participants agreed that water body considerations should extend beyond size to include other factors. There was a recognition of the influence of seasonality, time of the day, depth, clarity, size, morphology, current, hydrology, and species composition within the waterbody. The planning aspect was also explored and that there was a complex interaction between factors.

Baseline data needs to be defined, lack of clarity and consensus was identified as a key barrier. It was felt that EIA results could be shared beyond consultants/developers to wider stakeholders. Links arose between this overall theme and the next theme relating to long-term outlook, which emphasises the need for follow-up and to improve scalability of surveys.

Policy objective was also felt to be key, with a wider focus to include ecosystem such as availability of food, connectivity, and physical features. The need to consider existing and possible future pressures was recognised. Variability of funding and resources were an issue, leading to disparities in capability, which was seen as a barrier. Training, guidance, and standards that could be applied to categories and types of water bodies and could be scientifically accurate but general enough for wider application would mitigate this.

Figure A7: A visualisation of workshop outputs for site specificity.

Long-term outlook – scalability/reproducibility

Following analysis of the questionnaires, the workshop discussions focussed on: 1) whether methods could be standardised/produce consistent data; 2) whether long-term resources are available/accessible and; 3) the calibration of monitoring frameworks. From the questionnaires barriers to success identified the following: poor planning; resources (cost/time/expertise); permissions changing; reproducibility of methods which required a need for consistent approaches/ frameworks. This is laid out in the diagram below:

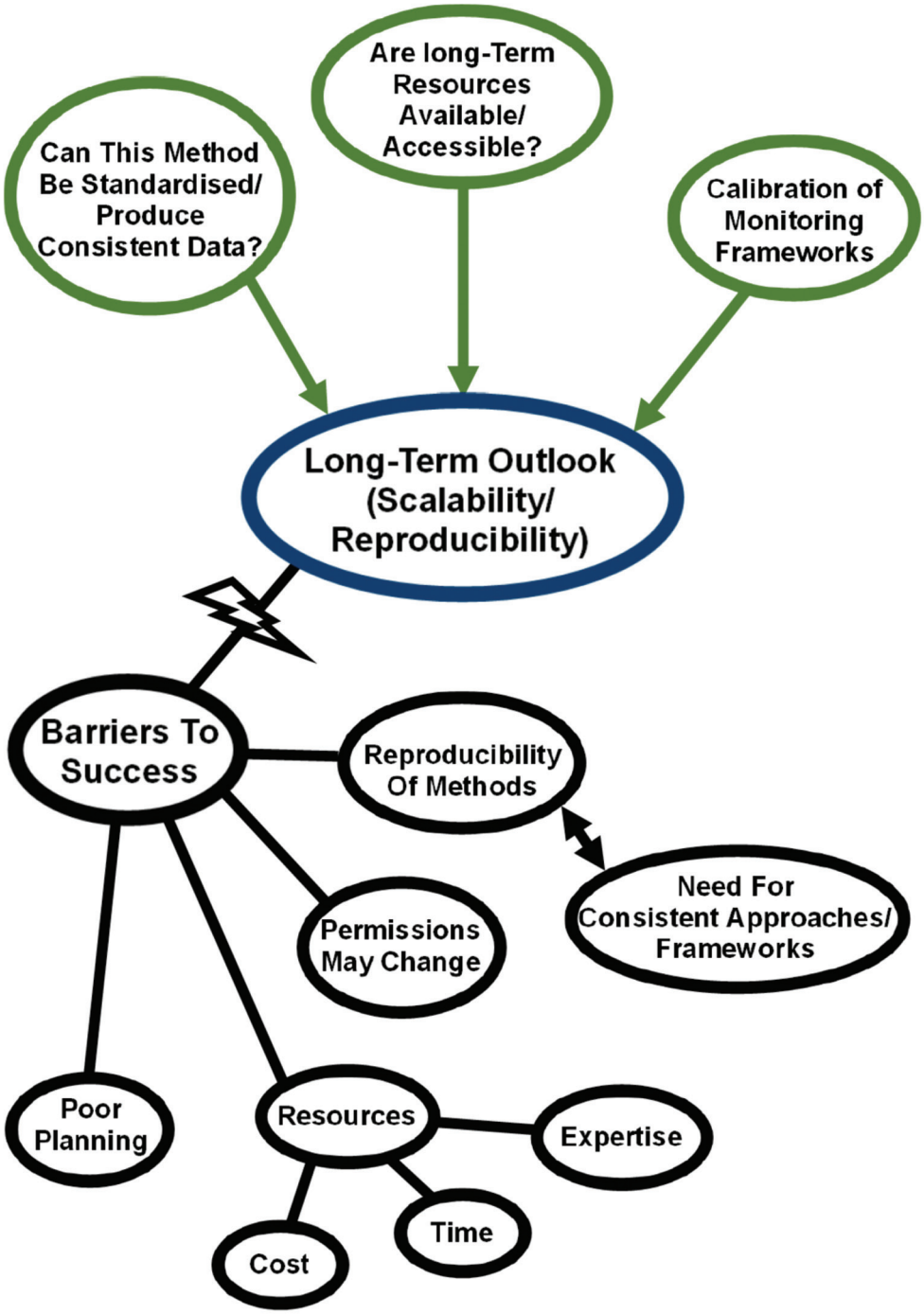

Figure A8: A visualisation of questionnaire responses/priorities based on thematic analysis for long-term outlook.

The key questions asked in the workshop were:

Will discussed methods still be suitable in 10- or 20-years' time?

Every sector responded to this question (academic, industry, NGO's and Rivers Trusts, DSFBs and Government/Government agencies), with most answers from the government and academic groups. Responses to this question could be grouped around resources, with the most prevalent resource concern being around loss of expertise or training (75% of the responses directly relating to this were about training). It was felt that a loss of expertise called for a *'need to build expertise and skills going forward (minimise skills gap)*'. One response queried *'who pays for long-term monitoring'* answering their own question with the response *'the developer surely'.*

A shift away from methods that were seen as intrusive or lethal and how to move to new methods drew the most prevalent response. These centred around a *'moral shift away from intrusive/ lethal methods'*, and that for example gill netting may become less acceptable in the perception of the public. And that there may be a *'legislative shift [towards] improved animal welfare'*. There was comment around evolving or novel methods – that advances in eDNA may look at genetic diversity and that Remotely Operated Vehicles could be developed for fish sampling.

Three responses pointed out the relationship between older and newer methods and the need for a pragmatic approach, as one participant said, '*Danger of constant substitution of 'better' methods – require novel methods when they 1) generate necessary insights that aren't available with older methods or 2) produce equiv data to old methods in less invasive/cheaper/easier way'* and another pointed out the need to *'Consider new emerging technologies and advances in existing methods'* and the *'need to use calibration as methods evolve'.*

Baseline data in future monitoring was mentioned here as well as in relation to some of the other questions (see below): *'Baselines need to be more robust and comprehensive to capture variability and inform future monitoring'.*

One quote is useful in summarising the response to this question of methods being suitable in 10 or 20 years' time: '*Broadly yes. If a method is suitable now it should still produce the same quality of data in 20 years' time'.*

Can discussed methods adapt as the environment changes?

All sectors responded to the question with government having as much as all the other groups together to say around this. Grouping responses to this question it was clear that there are already multiple methods, and a multiple method approach should be used. Comments included: *'Consider different methods for different habitats'. '[…] using multiple methods (i.e. nothing fits all situation) different methods for diff stages in planning process […]'*. '*Data, site method driven. Numerous methods can give similar data. Need to assess each and relate to question'*. On that topic of asking the right questions: *'Fish of conservation importance and fish that may be common but of cultural / economic importance may require different questions'.*

A theme that emerged was that there would be development of methods, these should be recognised, and this shouldn't be constrained – and in fact multiple methods can be used as long as the data are comparable. And that it was necessary to *'review process on methods'*.

There was concern about interpreting data – which comes back to resourcing training – especially as those interpreting data *'will not be scientists'* and that we should *'Put EIA and other lake fish data into the public domain to allow future comparison.'*

Should biological protection be a higher priority in the planning process?

Again, all sectors responded to this question with Rivers/Fisheries Trust/DSFB having the highest response rate and across all sectors the clear answer was that yes, biological protection should be given a higher priority in the planning process.

Responses can be collated as follows: developers need to be given information about what was required '[…] *But developers need to be told what is required […]'* and *'[…] this to be properly communicated to developers'*. It was suggested that this information should come from Government/ Government agencies.

Comments about protections called for clear guidance on what should be protected. This could include habitat protection and one respondent noted a lack of protections and therefore '*difficulty dealing with those species not protected via Scot Freshwater Fisheries Act'.*

It was felt that long-term monitoring was essential: '*many impacts in lochs will be long term – need proper monitoring programmes'* and that

monitoring needs to be suitable: *'avoid "tokenism" in monitoring plans – make them fit for biology of the fish'*.

Another key theme was that the data should be fully utilised i.e. there was a *'responsibility to collate/act upon data collected'*, including proper follow-up on reapplications with little change.

And finally, relating back to the resource issue, that industry could be taxed *'to fund the skills gap for loch monitoring'.*

The final question was:

What is needed to improve planning decisions?

Of all the questions this led to the most engagement from all sectors except the academic sector, with most responses from government. Comments can be collated as follows.

The most important theme to emerge was around long-term planning and monitoring and baseline data and this included monitoring before and after any construction – even on a long-term basis. Planning of projects was seen as important *'[…] to ensure methodology is suited to collecting the data that is required',* and also that *'statistical planning incorporated into methodology'*. And *'forward planning to get good baseline for long term comparison'*. In terms of monitoring, it *'needs to include base of food chain not focussed at the top'*.

Some practical suggestions around this were: *'List of survey/data requirements and options for methods accepted by regulator. E.g. what are 3 acceptable methods to identify spawning habitat'.* Also to consider the *'lifespan of datasets* and *that 'govs, agencies developers need to define objective of study. What level of precision is needed'*. It was pointed out that guidelines need to be adhered to and in relation to this '*no point in long-term monitoring if no legislation to force impact mitigation'*. A visualisation is presented in Figure A9.

Trends/outcomes/themes

Trends and themes that emerged strongly were around **data** – which overlapped with some of the other groups. These included **data gathering**: the need for a suite of methodologies tailored to the question – referring to **planning**. **Data integrity**: consistency and availability – which tied in with **data ownership** and **data access** – including access to historical data – having a comprehensive **baseline** so that ongoing ecological monitoring could be carried out and could see real environmental changes even as technology changes. Additionally, it was suggested that methodology changes over time should not be constrained but driven by data.

Another theme that emerged strongly was resource which was closely related to skills training. It was suggested that cost be with the developer, that there was an issue with staff expertise and loss of expertise due to staff turnover, requiring a need for training, including training in the interpretation of data outputs.

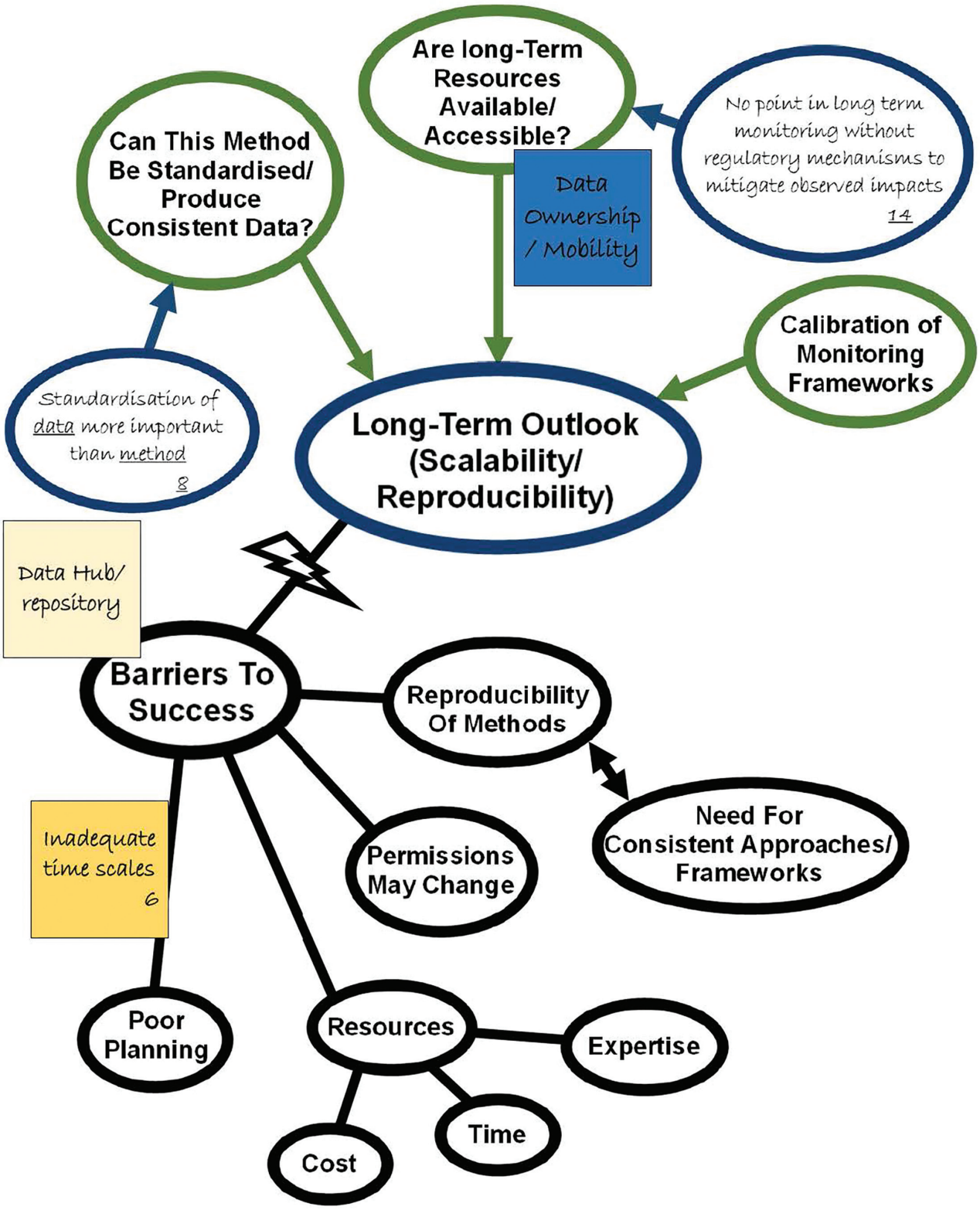

Figure A9: A visualisation of workshop outputs for long-term outlook.

Appendix C: Pre-Project questions

As part of the CREW project on methodologies for sampling fish populations in Scottish freshwater lochs, it is important we can gather information from experts regarding the key themes surrounding this.

As a stakeholder in the management of freshwaters, we really appreciate your input.

In completing the evaluation, we would ask you to:

- Please be as honest and open as possible with your responses (there are no 'right' or 'wrong' answers to the questions posed)

In return, we will:

- Ensure all data is anonymised upon request.
- Ensure your input is represented in the project planning and outputs.

Many thanks in advance for all your help and assistance.

Yours faithfully,

UHI Inverness/CREW

Pre-Project Questionnaire – February 2024

Personal Details	
Name:	
Job Title:	
Institution:	
Department:	

1. When considering the assessment of fish populations in standing freshwaters, what do you consider the key data requirements?

2. What do you consider the main barrier to obtaining high quality data when monitoring fish populations in standing freshwaters?

3. As a stakeholder relevant to the management of standing freshwaters, what do you identify as the main ecological pressure on these systems?

4. How would you rate the following criteria in terms of importance for fish monitoring techniques? Please also rank these in order of priority, from 1 (highest) to 5 (lowest)						
	Irrelevant	Not important	Indifferent	Desirable	Essential	Ranking (1 – 5)
Cost efficiency						
Processing time						
Data quality						
Replicability						
Ease of application / use						

5. Are there any specific themes which you think should be investigated in further detail with regards to fish monitoring and regulatory requirements in standing freshwaters?

Any further comments:

Many thanks for your time and thoughts

Appendix D: PARTICIPANT INFORMATION SHEET (Questionnaire)

Evaluation of methodologies for sampling fish populations in Scottish freshwater

What is the project about?

The main purpose of the project is to explore and evaluate the presently available methodologies for assessing fish populations in Scottish freshwater lochs and how these can be best implemented to carry out baseline and Environmental Impact Assessment (EIA) surveys in Scottish freshwater lochs.

We would like to invite you to take part in this study.

What will you do in the project?

We have a short questionnaire to draw on existing knowledge and relevant expertise to inform the overall research project and an expert led workshop, where these issues will be explored in more detail. The questionnaire is based around the following questions:

When considering the assessment of fish populations in standing freshwaters, what do you consider the key data requirements?

What do you consider the main barrier to obtaining high quality data when monitoring fish populations in standing freshwaters?

As a stakeholder relevant to the management of standing freshwaters, what do you identify as the main ecological pressure on these systems?

How would you rate the following criteria in terms of importance for fish monitoring techniques? [Please see the questionnaire for the full list of criteria]

Are there any specific themes which you think should be discussed in further detail in the workshop with regards to fish monitoring and regulatory requirements in standing freshwaters?

You have been invited to fill in a questionnaire having been identified through a stakeholder mapping process following a consultation with the project steering group to ensure key stakeholders are included.

Please read through this participation information sheet with you and contact one of our researchers by e-mailing Nathan.Griffiths.ic@uhi.ac.uk if you have any questions. Please return the attached consent form with the completed questionnaire.

What is going to happen with the information you share?

The UHI research team will collate the information obtained during a literature review, questionnaire, expert interviews and the expert led stakeholder workshop to form a detailed report highlighting the findings and considerations regarding assessment methods. These will be placed into the context of regulatory requirements to provide specific guidance and considerations on the methods which can be adopted by developers. A one-page summary and website summary will also be provided and disseminated in line with the communication strategy of the steering group. We will seek your specific permission to use non-anonymised, or if you would prefer, anonymised quotes from you in the report and summary.

What are benefits of participating?

This research aims to collate and draw on expert knowledge of current fish sampling and assessment methodologies and explore how these can be best implemented to carry out baseline and EIA surveys in Scottish freshwater lochs. You will have the opportunity to provide expert input on current monitoring techniques, which will inform methodological guidelines.

Are there any risks in taking part?

You are under no obligation to share any information or take part in any activity which you are not comfortable with. You are free to change your mind and opt out at any point.

Further Supporting Information

Your participation is voluntary and you have the right to withdraw your consent at any time up to the analysis of the data which will be 11th March 2024 by emailing Nathan.Griffiths.ic@uhi.ac.uk or IBFC Director Bernd.Haenfling.ic@uhi.ac.uk.

Quotes and excerpts of questionnaire responses might be used in academic publications and reports. Participants' data will be anonymised unless there is specific agreement for parts of the data to be attributable. This will be clearly requested and documented.

All personal data will be processed in accordance with the provisions of the EU General Data Protection Regulation and the Data Protection Act (DPA) and will be handled in line with the Data Protection Policy of the University of the Highlands and Islands. All data relating to the project will be deleted after 10 years.

The study is being organized by The Institute of Biodiversity and Freshwater Conservation (IBFC) at UHI Inverness and the main researchers are Nathan Griffiths and Bernd Hänfling. Vicky Johnson, Centre of Living Sustainability (CLS) is leading a social science team to facilitate the workshop. If you have any questions/ concerns, during or after the research project please contact project lead Nathan.Griffiths.ic@uhi.ac.uk or IBFC Director Bernd.Haenfling.ic@uhi.ac.uk or social science lead: Vicky Johnson vicky.johnson.ic@uhi.ac.uk.

This project is funded by Centre of Expertise for Waters (CREW) and undertaken by the University of the Highlands and Islands. This project was granted ethical approval by the University of the Highlands and Islands Research Ethics Committee, January 2024.

Thank you for taking the time to read this. If you decide to take part, you will be able to keep a copy of this information sheet and you will be asked to sign a Consent Form confirming your participation.

Version 1 – 30 January 2024

Appendix E: PARTICIPANT INFORMATION SHEET (Workshop)

Evaluation of methodologies for sampling fish populations in Scottish freshwater

What is the project about?

The main purpose of the project is to explore and evaluate the presently available methodologies for assessing fish populations in Scottish freshwater lochs and how these can be best implemented to carry out baseline and Environmental Impact Assessment (EIA) surveys in Scottish freshwater lochs.

We would like to invite you to take part in this study.

What will you do in the project?

We are planning to draw on existing knowledge and networks to attract the most relevant expertise for an expert led workshop to address the following key questions:

1. **What are the available fish sampling techniques in freshwater lochs?**

2. **What are the limitations posed by each individual method?**

3. **What monitoring techniques are most reliable and cost effective for detecting different fish species in Scottish lochs?**

4. **What method(s) is optimum under a given set of conditions?**

5. **What techniques are least invasive on fish populations?**

6. **What techniques provide good quality data that can be used on a range of spatial and temporal scales?**

You have been invited to the workshop after being identified through a stakeholder mapping process following a consultation with the project steering group to ensure key stakeholders are included. At the workshop our researchers will go through this participation information sheet with you and answer questions you may have. You will then be asked to fill in a consent form with specific areas of consent around the data you are happy for us to gather and our subsequent use of that.

During the workshop experts will be split into thematic groups to present experiences and work on pre-identified priorities. These may be, for example: addressing the regulatory requirements; discussing the ecological inference provided by each method; understanding the pros and cons of each method; to discuss whether any single approach can suit all scenarios.

The groups will be facilitated to contribute their experiences, with write-up of the discussions within the groups. We may use voice recorders to ensure we capture details of the workshop. We will also take pictures for use in reporting afterwards. Your specific consent will be sought for voice recordings and photographs. However, you can at any point request not to be photographed or to have voice recording devices switched off.

What is going to happen with the information you share?

The UHI research team will collate the information obtained during a literature review, expert consultations and the expert led stakeholder workshop to form a detailed report highlighting the findings and considerations regarding assessment methods. These will be placed into the context of regulatory requirements to provide specific guidance and considerations on the methods which can be adopted by developers. A one-page summary and website summary will also be provided and disseminated in line with the communication strategy of the steering group. We will seek your specific permission to use non-anonymised, or if you would prefer, anonymised quotes from you in the report and summary.

What are benefits of participating?

This research aims to collate and draw on expert knowledge of current fish sampling and assessment methodologies and explore how these can be best implemented to carry out baseline and EIA surveys in Scottish freshwater lochs. You will have the opportunity to provide expert input on current monitoring techniques, which will inform methodological guidelines.

Are there any risks in taking part?

You are under no obligation to share any information or take part in any activity which you are not comfortable with. You are free to change your mind and opt out at any point.

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Quotes and excerpts of discussions might be used in academic publications and reports. Participants' data will be anonymised unless there is specific agreement for parts of the data to be attributable. This will be clearly requested and documented. Any audio or visual data that is not agreed will be destroyed on completion of this project.

All personal data will be processed in accordance with the provisions of the EU General Data Protection Regulation and the Data Protection Act (DPA) and will be handled in line with the Data Protection Policy of the University of the Highlands and Islands. All data relating to the project will be deleted after 10 years.

The study is being organized by The Institute of Biodiversity and Freshwater Conservation (IBFC) at UHI Inverness and the main researchers are Nathan Griffiths and Bernd Hänfling. Vicky Johnson, Centre of Living Sustainability (CLS) is leading a social science team to facilitate the workshop. If you have any questions/ concerns, during or after the research project please contact project lead Nathan.Griffiths.ic@uhi.ac.uk or IBFC Director Bernd.Haenfling.ic@uhi.ac.uk or social science lead: Vicky Johnson vicky.johnson.ic@uhi.ac.uk.

This project is funded by Centre of Expertise for Waters (CREW) and undertaken by the University of the Highlands and Islands. This project was granted ethical approval by the University of the Highlands and Islands Research Ethics Committee, January 2024.

Thank you for taking the time to read this. If you decide to take part, you will be able to keep a copy of this information sheet and you will be asked to sign a Consent Form confirming your participation.

Version 2 – 30 January 2024

Appendix F: PARTICIPANT CONSENT FORM (Questionnaire)

Questionnaire: Evaluation of methodologies for sampling fish populations in Scottish freshwater

1. I confirm that I have read the Participant Information Sheet dated 07/02/2024 for the above study. I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily. ☐

2. I understand that my participation is voluntary and that I am free to withdraw participation and the data and information gathered about me at any time without giving any reason until the results are being analysed. ☐

3. I consent to my data including selected identifiable textualized quotes and excerpts being used (**non-anonymized**). ☐

4. I consent to my data including non-identifiable textualized quotes and excerpts being used in **anonymized form**. ☐

5. I waive any rights to intellectual property over the data generated through my participation and understand that I will not benefit commercially or financially. ☐

I agree to take part in the above study.

Name of Participant	Date	Signature

Information Rights

- You have the right to request a copy of the personal data that the University and/or Academic Partner holds and processes about you.
- You have the right to withdraw your consent to the processing of your data at any time by containing the data controller (see details below)
- You have the right to restrict the processing of your personal data

If you have any queries during related to the use of your information during the project, please contact the following individuals:

Nathan Griffiths: Nathan.griffiths.ic@uhi.ac.uk or Bernd Haenfling: Bernd.Haenfling.ic@uhi.ac.uk

Appendix G: PARTICIPANT CONSENT FORM (Workshop)

Workshop: Evaluation of methodologies for sampling fish populations in Scottish freshwater

1. I confirm that I have read the Participant Information Sheet dated 30/01/2024 for the above study. I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily. ☐
2. I understand that my participation is voluntary and that I am free to withdraw participation and the data and information gathered about me at any time without giving any reason until the results are being analysed from 11th March. ☐
3. I agree to optional voice recordings during the workshop for the purpose of data analysis. ☐
4. I consent to my data including selected identifiable textualized quotes and excerpts being used (non-anonymized). ☐
5. I consent to my data including non-identifiable textualized quotes and excerpts being used in anonymized form. ☐
6. I consent to pictures being taken during the workshop and understand that I will have the option to remove myself, or the researchers will ensure I am unidentifiable on request. ☐
7. There may be certain selected photos that we would like to use in the production of openly available reports or digital outputs at the end of the project. I consent to photos, where I am identifiable being used in this way. ☐
8. I waive any rights to intellectual property over the data generated through my participation and understand that I will not benefit commercially or financially. ☐

I agree to take part in the above study.

Name of Participant	Date	Signature

Information Rights

- You have the right to request a copy of the personal data that the University and/or Academic Partner holds and processes about you.
- You have the right to withdraw your consent to the processing of your data at any time by containing the data controller (see details below)
- You have the right to restrict the processing of your personal data

If you have any queries during related to the use of your information during the project, please contact the following individuals:

Nathan Griffiths: Nathan.griffiths.ic@uhi.ac.uk or Bernd Haenfling: Bernd.Haenfling.ic@uhi.ac.uk

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