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SCIENCE ADVICE ON OPERATIONAL GUIDANCE ON FUNCTIONAL MONITORING: SURROGATE METRICS OF FISH PRODUCTIVITY TO ASSESS THE EFFECTIVENESS OF MITIGATION AND OFFSETTING MEASURES

Figure 1. Measuring water velocity on the Magpie River, ON. Photo credit: DFO.

Figure 2. Measuring habitat area on the Batchawana River, ON. Photo credit: DFO.

Context:

In December 2011, DFO held a science advisory process to examine the feasibility of designing a standardized monitoring approach to determine the effectiveness of habitat compensation (or offsetting) activities. Three hierarchical levels of monitoring were briefly described (compliance, functional, and effectiveness monitoring) but the focus of the 2012 SAR that resulted from the meeting was on effectiveness monitoring, applicable to projects with offsetting measures that warrant detailed monitoring. The technical report (Smokorowski et al. 2015) produced following the 2012 SAR focused on developing the design and metrics for comprehensive effectiveness monitoring.

In the 2012 SAR, functional monitoring was briefly described as a scaled-down assessment of habitat compensation effectiveness, using quantitative techniques but relying on surrogate information to assess changes in productive capacity (e.g., change in macrophyte density, velocity, or amount of a substrate type, Figures 1 and 2). It was recognized that further science guidance was needed on its application.

The objectives of this science advisory process and science advisory report were to provide DFO's Fisheries Protection Program (FPP) with advice on standardized monitoring design and metrics appropriate for undertaking functional monitoring. More specifically, metrics that represent surrogate(s) of fish productivity in marine and freshwater environments and could be used to assess the effectiveness of mitigation, offsetting and restoration measures.

This Science Advisory Report is from the February 26-28, 2018 "Science advice on operational guidance on functional monitoring: Surrogate metrics of fish productivity to assess the effectiveness of mitigation and offsetting measures."

August 2019

Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

SUMMARY

- Success of any monitoring program relies on the development of a clear purpose and objective, informed by well-defined, scientifically based questions articulated at the outset. Three hierarchical levels for monitoring of mitigation, offsetting or restoration measures (hereinafter referred to as management measures) have been previously described, which range along a continuum from a simple assessment of compliance with standards, through to an assessment of function, culminating with the establishment of effectiveness at achieving quantitative fish productivity goals.
- For the purposes of this document, functional monitoring is defined as a science-based, scaled-down version of effectiveness monitoring that relies on surrogate metrics of fish productivity to assess whether management measures provide expected conditions suitable for fish to carry out their life processes.
- The purpose of functional monitoring is to provide a relatively rapid and objective science-based assessment of the performance of the management measure, beyond simple compliance with design/construction standards, but where implementing a full and more costly effectiveness monitoring program may not be required or feasible.
- Functional monitoring is most appropriate for situations where there is some understanding of the performance of management measures and the chosen surrogate metrics in the given ecological context.
- Functional monitoring may also be applied after effectiveness monitoring to provide longer term confirmation of function.
- A synthesis of multiple functional monitoring assessments of similarly applied management measures across a range of sites can increase understanding of the effectiveness of such measures, potentially improving both the site evaluation and program evaluation.
- A recommended framework (Figure 4) is presented to establish the steps used when planning functional monitoring at a given site or type of project. These steps are:
  1. Determine specific objective of functional monitoring program.
  2. Select appropriate indicators/metrics.
  3. Choose appropriate sampling design.
  4. Collect and analyze data using the appropriate standardized approach.
  5. Assess whether management measures meet objectives based on functional monitoring data.
  6. Record data and outcomes in database for future program learning.
- The first step in the functional monitoring framework is to establish objectives (i.e., site and/or program evaluation) of the monitoring program. Pathways of Effects diagrams are conceptual models of how in-water activities could lead to ecosystem changes and could be used to help identify functional monitoring objectives; these objectives should be quantitative and linked to fish productivity.
- The sampling design of the functional monitoring program can take a range of forms; six types of sampling designs were discussed and attributes describing when each may be most appropriate are provided (Table 1). Variability, heterogeneity, replication, minimum information requirements, and other practical limitations must be considered.
- All sampling designs require a comparator; different designs have different comparators (see body of document for details). The collection of “pre-project” data is recommended.

- The most appropriate indicators vary as a function of the specific project and sampling design; Table 2 provides examples of indicators potentially suitable for functional monitoring. Selection of indicators should consider the following criteria;
  - Whether indicators are related to the expected outcome (e.g., macrophyte cover related to creation of a marshland/wetland) and quantitatively linked to fish productivity.
  - Whether indicators are correlated and if so, consider whether measurement of additional indicators provides unique information (e.g., nutrients and chlorophyll *a* are often positivity correlated but nutrients provide information on the availability of nutrients for primary production whereas chlorophyll *a* provides information on how the nutrients are used through photosynthetic rates).
  - How variable the indicators are over time and space (e.g., water depth in rivers can vary daily and is influenced by weather).
  - How reliably the indicators can be measured (e.g., visually assessing sediment composition can have high bias).
  - Whether thresholds for success in a relevant context exist (e.g., minimum thresholds for eel-grass density or oxygen concentrations).
- Functional monitoring sampling designs should follow well-established protocols where they exist. Recommendations on specific sampling designs and protocols for a given metric are not provided as these are widely available (e.g., AFS Standard Methods, see Appendix 2).
- Analyses of resulting data are design dependent and should be considered at the design stage to ensure appropriate spatial and temporal replication and interpretation. Setting decision criteria for determining whether the results of a functional monitoring program indicate success should be established *a priori*. These decision criteria should be regionally relevant and could be developed following a longer term effectiveness monitoring program.
- While a single checklist for all types of projects is not possible, a common checklist style approach is considered feasible to use to gather functional monitoring data if the same type of impact/management measure and sampling design is used across projects.
- A tiered checklist approach is recommended to provide some degree of national standardized data collection while remaining flexible. Tier 1 would provide the most national commonality across projects; tier 2 would provide project-specific commonality; tier 3 would allow for regional specificity, for example:
  1. Basic information (e.g., information often gathered for compliance monitoring including georeferenced location, area of habitat altered by activity, type of habitat, type of management measure, etc.),
  2. Information for all functional monitoring of a given type of management measure (e.g., culverts), and
  3. Site/project/region/habitat specific information, to be elaborated with FPP & Science at the regional scale.
- While functional monitoring will in most cases provide site specific information about a given management measure, when taken together, results from multiple functional monitoring projects could be used to inform the evidence basis for future FPP advice and program development. Some degree of standard data collection and reporting will facilitate future collation and comparison of functional monitoring data.
- As results of functional monitoring on a particular type of management measure accumulate, power analyses can be conducted to identify the number of additional projects and the degree of precision and accuracy needed to address the overarching question of consistency of success in future meta analyses. Cautions should be employed when

conducting meta analysis across designs since effect sizes will vary depending on design and may not be directly comparable.

- Effectiveness monitoring and functional monitoring can work together:
  - Effectiveness monitoring can help establish decision criteria (e.g., for success) to evaluate the performance of functional monitoring metrics.
  - Functional monitoring can extend time series of effectiveness monitoring as less onerous sampling programs may be sustained for longer time scales.
  - Functional monitoring could identify the need for effectiveness monitoring in the future if results strongly deviate from expected.

BACKGROUND

In December 2011, DFO held a science advisory process to examine the feasibility of designing a standardized monitoring approach to determine the effectiveness of habitat compensation (or offsetting) activities in achieving 'No Net Loss of the productive capacity of fish habitat' as was the policy at that time. The Science Advisory Report (SAR) produced from this workshop is available online (henceforth referred to as the 2012 SAR). Three hierarchical levels of monitoring were briefly described (compliance, functional, and effectiveness monitoring) but the focus of the 2012 SAR was on effectiveness monitoring, applicable to projects with offsetting measures that warrant detailed monitoring (e.g., complex projects expected to have a large impact on fish and fish habitat). The technical report (Smokorowski et al. 2015) produced following the 2012 SAR focused on developing the design and metrics for comprehensive effectiveness monitoring.

In contrast, proponents of some projects that require a *Fisheries Ac*t authorization for small or simple projects, or proponents that receive a letter for project-specific advice, may not be required to undertake long term, detailed effectiveness monitoring. DFO's Fisheries Protection Program (FPP), however, remains interested in understanding the outcomes of these projects, and requires an approach to improve monitoring beyond compliance to achieve such understanding. Functional monitoring is of particular interest for FPP due the valuable information that can be collected at a moderate intensity of effort. While FPP recognizes that some projects require high intensity effort for monitoring, opportunities where moderate effort intensity are appropriate and scientifically defensible may allow for the monitoring of additional projects. DFO is committed to improving monitoring and will endeavor to design, test and implement a functional monitoring approach at as many projects as possible, based on risk and capacity and recognizing that this will not be possible for all projects. In addition, when monitoring is a required component of an authorization, proponents will be also expected to provide functional monitoring data, based on the recommended methods (e.g., rapid assessment techniques/use of surrogates or indicators) and process (e.g., functional monitoring checklist) given the conditions outlined herein. In the 2012 SAR, functional monitoring was briefly described as a scaled-down assessment of habitat compensation effectiveness, using quantitative techniques but relying on surrogate information to assess changes in productive capacity (e.g., change in macrophyte density or amount of a substrate type). However, it was recognized that further science guidance was needed on the design and application of functional monitoring.

The objectives of this science advisory process and science advisory report were to provide FPP with advice on standardized monitoring design and metrics appropriate for undertaking functional monitoring, which could use surrogate(s) of fish productivity in marine and freshwater environments, and for analyzing data to assess the effectiveness of mitigation, offsetting, and restoration measures.

The use of standardized functional monitoring techniques could have several potential benefits. The first would be to provide a relatively rapid and objective science-based assessment of the performance of the management measure. A well-planned, implemented, and consistently tracked functional monitoring project would provide valuable information towards the understanding the performance of a greater proportion of projects that currently may only be assessed for compliance with design/construction requirements. Subsequently, as results from monitoring commonly applied management measures accumulate from a range of sites, analyses of these results should facilitate the provision of improved evidence-based advice and requirements from FPP to proponents related to these mitigation and offsetting measures. Such analyses would be expected to provide improved project level direction for proponents, as well as improved program level decisions.

ASSESSMENT OF FUNCTIONAL MONITORING REQUIREMENTS

Monitoring can be categorized as a hierarchy of three general types that can be used to assess mitigation, offsetting, or restoration activities in Canada: compliance, functional, and effectiveness monitoring. Each type of monitoring is defined in the glossary, but additional information on effectiveness monitoring can be found in DFO (2012) and Smokorowski et al. (2015). Success of any monitoring program relies on the development of clear purpose and objectives, informed by well-defined scientifically based (i.e., hypothesis driven) questions articulated at the outset. This advisory document specifically focuses on functional monitoring, which was defined for the purposes of this document as a science-based, scaled-down version of effectiveness monitoring that relies on surrogate metrics to assess whether management measures provide expected conditions suitable for fish to carry out their life processes.

Functional monitoring is most suitably applied where there is some understanding of the performance of the habitat management measure (i.e., mitigation/offsetting/restoration measures), and that the surrogate metrics are understood well enough that they can be quantitatively linked to fish productivity in the given ecological context. Functional monitoring should not be applied when more novel techniques are being used and/or there is a high uncertainty in the habitat-fish linkage or the impacts of the management measure are not well understood (e.g., ecosystem transformation as an offset), as these situations are more appropriate for effectiveness monitoring.

Functional monitoring may also be useful following effectiveness monitoring to provide longer-term confirmation of function. This approach would help develop and/or validate functional surrogates for productivity, strengthening the linkages and assumptions that function can be assessed without specifically measuring metrics of fish productivity. A synthesis of functional monitoring results from commonly applied measures can increase understanding of the effectiveness of measures for a broader evaluation at the site or program level. Both functional and effectiveness monitoring should be viewed as a continuum and not as discrete approaches.

The Terms of Reference for this process had four main objectives that were discussed sequentially:

i. What are the recommended monitoring designs and methods (e.g., rapid assessment techniques/use of surrogates or indicators) to assess mitigation, offsetting and restoration measures that could be done using functional monitoring approaches (i.e., without a comprehensive effectiveness monitoring program)?

ii. What data and analyses are needed to support a science-based functional assessment of mitigation, offsetting, and restoration measures?

iii. Is it feasible to gather functional monitoring data using a checklist style approach that can be applied consistently among project types and stages of construction (i.e., for each project type, a checklist of specific information to collect with proponent led monitoring, a site visit during construction monitoring, and post construction monitoring that can be applied in a consistent manner by FPP biologists)?

iv. If a checklist style approach is considered feasible for various project types and stages of construction, what are the fields required?

Level of effort and program framework

Effort

There are many monitoring programs where little valuable information is gained despite the collection of large amounts of data, due to, for example, poor sampling design, improperly chosen indicators/metrics, or incomplete descriptions of data.

To gain a science-based understanding of the results of decisions on the functionality of habitat, there is a minimum level of effort that must be expended before the value of information gained exceeds the minimum cost of acquiring any information (Figure 3). This threshold is partly dependent on understanding the strength of the connection between habitat and biota that are the target of management measures (fish in this case). If this linkage is not well understood then functional monitoring may be an inefficient use of effort because the data collected will not reliably inform us of the impact of the management measure on fish productivity. In such cases, effectiveness monitoring may be required.

Any functional monitoring program should not be viewed with an eye towards minimizing costs, but instead to optimizing the value of information gained, while remaining logistically simpler and more cost-effective than effectiveness monitoring.

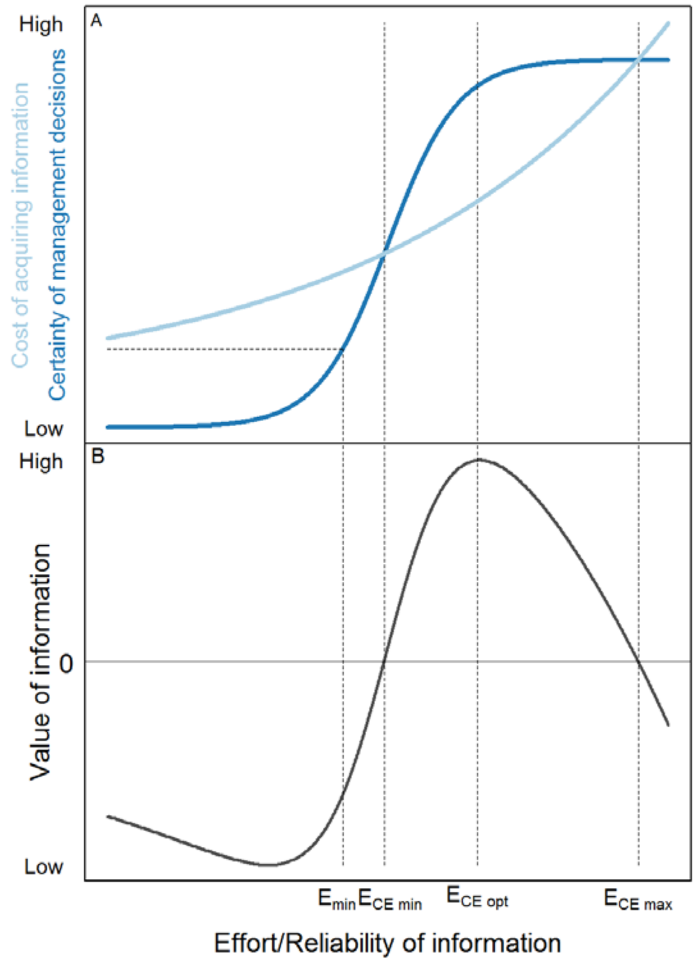

Figure 3. A) The relationships between effort and the cost of acquiring information (light blue line), and the effectiveness of using the information (certainty of management decisions) (dark blue line). B) The relationship between effort and the value of information. The difference between the cost and effectiveness represents the value of information, which is the $E_{CE\ min}$, $E_{CE\ opt}$, $E_{CE\ max}$ and represents the minimum, optimal, and maximum cost-effective monitoring effort, respectively. E_{min} is the minimum effort required to make a management decision. When monitoring effort is too low (Effort < E_{min} & $E_{CE\ min}$), there is no value of the information gathered. As effort increases past the optimal point, eventually there are diminishing returns on the value of information (Effort > $E_{CE\ opt}$) to the point where the gain in effectiveness is no longer justified by the costs. Between these bounds is a window of cost-effective monitoring effort. Theoretical representations of the effort-information trade-off such as this need to be placed in the appropriate context of how inference will be drawn about impacts on habitat or how the information will be used to make decisions. (see Braun et al. 2018 for more information).

Framework

A recommended framework was created outlining the steps used when planning and assessing a functional monitoring program (Figure 4).

The first step in the framework (Step 1) is to establish objectives (i.e., site and/or program evaluation) of the monitoring program. Pathways of Effects (POE) diagrams could be used to help identify relevant questions and monitoring objectives; these objectives should be quantitative, measurable, and linked to fish productivity. For example, this may include setting targets for the appropriate substrate size(s), depth, velocity, oxygen, and/or temperature to be achieved on a created rock spawning shoal for fish, with these targets meeting the criteria for the most restrictive or sensitive species potentially using that spawning habitat. The assessment of whether or not the objective was achieved will be based on a quantitative measurement of the selected metric(s) specific to the indicator(s) tied to the POE endpoints. The sampling design must be decided *a priori* to ensure adequate spatial and temporal coverage to support the data analysis. Consistent indicators should be measured at the impact site and selected comparator (e.g., before impact, control site), and standardized approaches to data collection should be used to increase comparability across sites/projects/region/habitat, when possible. The results should demonstrate that functionality is well established given the monitoring objectives. Recording of the data and outcomes in a standardized database could facilitate program level assessments and future program adaptation. More detail on aspects of this framework can be found below.

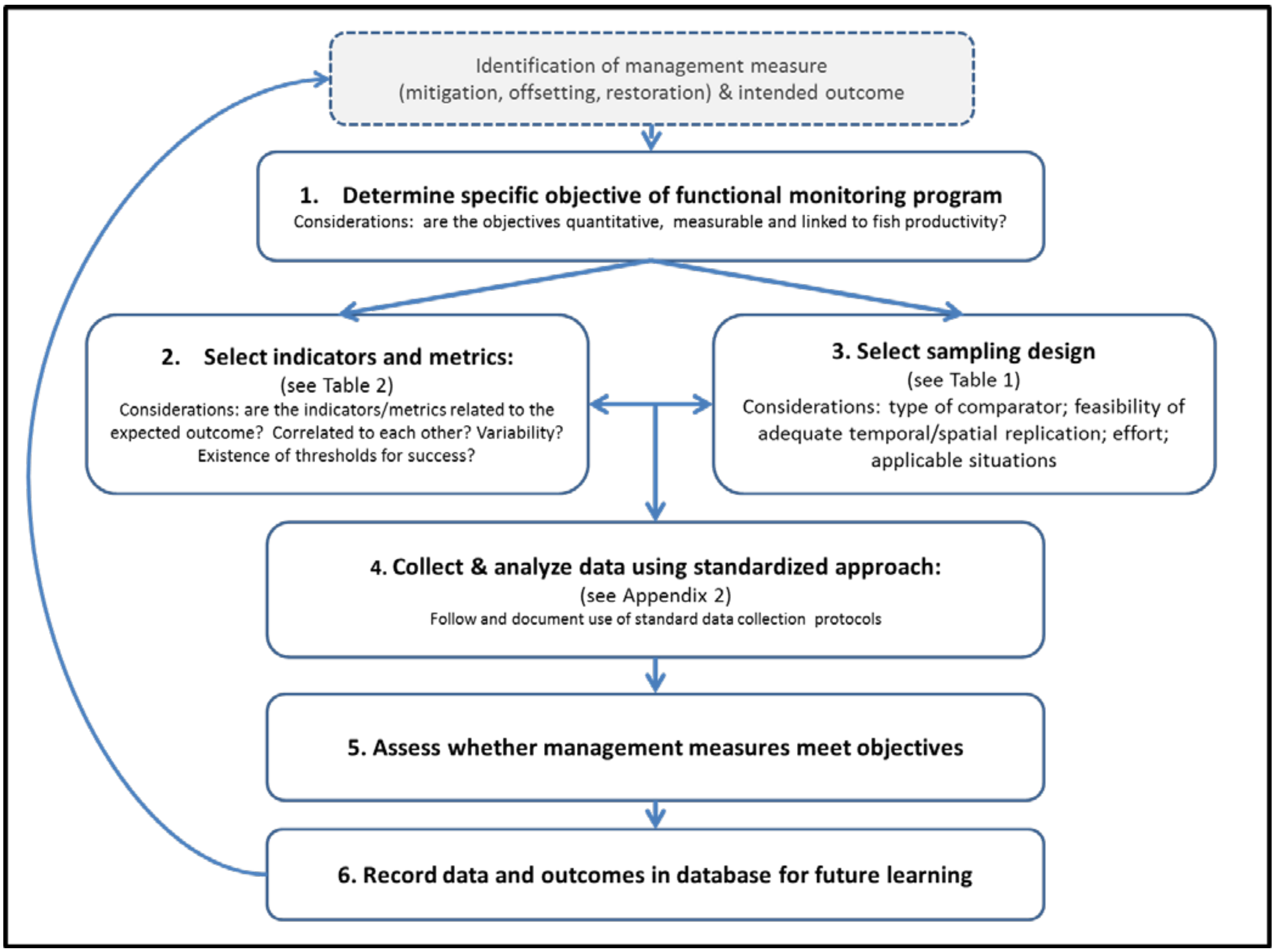

Figure 4. Conceptual framework for developing a functional monitoring program. This framework begins with the assumption that a management measure has been chosen and that the functional monitoring program is being designed to assess whether, as a result of that measure, the habitat is providing its intended function for fish. Although this framework is shown as a step-wise process for illustrative purposes, in practice several of these steps will need to be considered either concurrently or iteratively (e.g., choice of indicators and sampling design will be contingent on each other to some degree).

Terms of Reference Objective 1 – Recommended monitoring design and methods.

No single sampling design is appropriate for all functional monitoring programs due to site or project specific issues (e.g., data availability, uniqueness of sites). A total of six possible designs were discussed and attributes describing when each may be most appropriate are provided (Table 1). One critical element of all designs is that some form of comparator is necessary, whether it be in the form of pre-project data (recommended), paired control site data, reference conditions established from a suite of comparable unaffected sites, time series analyses across a gradient of impact, or from scientifically established regional benchmarks or 'normal ranges'. Without a comparator, there is no way of establishing if the observed functional response was actually the result of the mitigation, offsetting, or restoration activity. Of the six designs the BACI is presented as ideal, however, with proper implementation any of the designs could be appropriate for functional monitoring and would yield valuable information about the management measure.

The Before-After-Control-Impact (BACI) design is considered the optimal design as it provides some control against the risk that a significant change at the impact site may be observed that is not related to the management measure (a risk in the Before-After design), or that the impact site was not affected by the intervention (a risk in the Control-Impact design). While multiple controls are ideal, a single control site may be adequate if it is carefully selected with high confidence to be comparable to the impact site (e.g., upstream control with similar habitat features on the same river). The BACI design requires planning and knowledge of when the impact will occur and pre-project sampling is required. While the BACI is more resource intensive than the more-simple variants (the Before-After or Control-Impact designs), it is not necessarily less cost-effective than some of the other designs presented (e.g., Reference Condition Approach or Trend-by-Time).

The Control-Impact design is a variant of the BACI design that can be used in functional monitoring when pre-project (before) information is not available. This design assumes that the impact site and control site were similar prior to the impact. To reduce the uncertainty around this assumption, several nearby control (3-5) sites may be used to provide some level of variance for the state or metric being monitored. An example where this design could be used would be bank stabilization in rivers (especially those conducted due to extreme events, therefore no before data). Metrics could include sediment downstream of the site or channel morphometry within the site that could then be compared to upstream or nearby controls.

The other variant of the BACI is the Before-After design, which is logistically simpler using only temporal controls as the comparator. Data are collected before and after the change in habitat, ideally over multiple sampling years to quantify variance. The advantages of the Before-After design are that it requires less effort than a full BACI design and it can be applied where appropriate controls sites are unavailable or limited (e.g., unique environments such as very large rivers, large inland deltas). It would not be applicable for projects that are under stringent timelines for which the before data collection is unfeasible (e.g., emergency situations), or in instances where FPP cannot request before data (e.g., with issuance of a Letter of Advice) but still wishes to monitor the results of their advice (i.e., results of recommended mitigation measures).

While assessment of individual results are site-specific, both BACI variants (Before-After or Control-Impact) can contribute to program learning and modification to improve advice, based on empirical evidence on effective mitigation, offsetting, or restoration measures, with adequate standardization and sample size. Risks are inherent in these designs, however, since they incorporate different types of natural variation. Before-After controls for spatial variation by monitoring the same site, but is forced to incorporate natural temporal variation that may not be related to the impact (e.g., a severe weather event occurred at the same time as the implementation of the management measure, confounding interpretation of results). Whereas the Control-Impact design controls for temporal variation by measuring 2 sites concurrently (i.e., a weather event affects both sites, improving reliability that a change at the impact site not observed at the control site resulted from the management measure), but incorporates spatial variation because no 2 sites will be exactly the same.

The Reference Condition Approach (RCA) compares metrics from a site of interest to metric values for many reference sites that are not exposed to the stressor or management action. The most common application uses community composition of benthic invertebrates as the metric, but it could also be applied to other taxa, including fish, provided that dispersal or access do not limit species distribution. The method requires samples from the affected site and samples from multiple reference sites. In some locations reference site data may be available from previous sampling programs. Habitat or other site attribute data are often used to help control for variation in the data. RCA with invertebrates is best suited for evaluating ecosystem health at fairly large spatial scales. In Canada, the Canadian Aquatic Biomonitoring Network (CABIN) is an aquatic bio-monitoring program for assessing the health of fresh water ecosystems. Field sampling is not onerous and often multiple samples can be taken in one day. However, taxonomic analysis of samples requires a specialized skill set and can be lengthy and expensive. Under the CABIN protocol data management and analytical tools are available, but statistical outputs from the models are not readily interpretable as they are often reported using multivariate methods that are difficult to visualize. In addition, the analytical methods preclude the calculation of an effect size and therefore the inclusion of the RCA in a traditional meta analysis is not possible, although alternative aggregate analyses may be possible (e.g., proportion within reference condition). Invertebrate communities are affected by both local conditions at the sampling sites and large-scale watershed conditions. Invertebrate communities are sensitive to changes in water quality and can provide information on lower trophic levels in food webs (e.g., fish food), but may not be a surrogate for other habitat conditions that fish need to complete their life cycle. For example, RCA is probably not the best approach to monitor fish passage, or the availability of structure and cover. Furthermore, the level of effort and expertise required to implement an RCA means that in most cases it is probably not the most suitable design for a functional monitoring program, but there may be cases where its application is appropriate, particularly if a reference database already exists. For example, the RCA is currently used to monitor the effects of placer gold mining in Yukon. This may be an appropriate application as mining occurs at a watershed scale (the affected areas are relatively large) and the primary stressor is the release of suspended sediment. A CSAS review of the first decade of results was recently published and assesses the suitability by highlighting the strengths and limitations of this application of the RCA (DFO 2019).

A variant of the RCA involves using a normal range of conditions or identified benchmarks rather than continued sampling of reference sites. To accomplish this, an expected value or range of values needs to be scientifically established from (i) sampling of appropriate reference sites, (ii) laboratory or field studies that can be used to identify optimal values, or (iii) theoretical or modelled values based on described relationships from the literature. The advantage to this approach is that once the investment has been made to establish the normal range of conditions or benchmarks, project-specific monitoring need only sample the impact site to determine if its conditions meet or fall outside the range of expected values. The disadvantage is that establishing the normal range of conditions or benchmarks can be data-intensive, region or ecosystem specific, and must be completed before the monitoring design can be applied. Caution also needs to be employed when establishing a ‘normal range’ or benchmark as there is potential these could change over time at some sites, due to, for example, climate change.

Although the initial investment may be greater than other monitoring designs, this approach will likely be more cost-effective over the long-term. In addition to project-specific monitoring, a comparison to normal ranges or benchmarks could be used to track how well mitigations or offsets perform relative to expected outcomes at the program level.

Trend-by-Time analyses are well suited for situations where there is an immediate monitoring need that does not allow for the collection of baseline data. Through repeated sampling of sites exposed to a gradient of treatments (Trend-by-Time) or within control and treatment sites (Level-by-Time) they are assumed to incorporate background changes in a metric that are unrelated to the treatment. This assumption must be tested for any metrics of interest and control sites need to be in close proximity (and all sampling sites kept constant) in order to reduce potential confounding variables and violations of this assumption. The major drawback to these approaches for functional monitoring is that they require repeated sampling over a timeframe relevant to the metric of interest (likely measured over multiple years). Also, because these types of analyses are often used in situations where sites are not randomly selected, results can be challenging to apply elsewhere. Given the extended temporal monitoring requirements (and associated additional costs), these techniques are likely not suitable in a functional monitoring context, rather they may be of interest in the assessment of impact/recovery following an occurrence.

Table 1. Monitoring designs commonly used in the assessments of habitat alteration (e.g., impacts, habitat mitigation, restoration and offsetting.)

Design	Temporal Replication	Spatial Scope	Benefits	Challenges	Effort	Most Applicable	Least Applicable	Key Considerations
BACI	Often multiple years of data collected before (temporal control) and after habitat alteration	Often multiple control sites assessed - recommend 3-5 sites	Controls for variation in both the control and altered site	Requires adequate temporal replication	Highest effort design at the time of assessment; no further costs once assessment is complete	Most applicable when appropriate spatial and temporal replicates are available	Least applicable when alteration and response are tightly linked and/or response's temporal distribution is uniform	Must sample impact site prior to impact – preplanning necessary; appropriate temporal, spatial replication, and control sites
Before-After	Often multiple years of data collected before (temporal control) and after habitat alteration	No spatial controls	Can be used to assess a site where appropriate controls sites are limited	Requires pre-impact data; Length of time for pre/post data collection Cannot control for temporal variation not attributable to the impact	Less effort than a full BACI design; no further costs once assessment is complete	Most applicable for projects performed in unique environments (e.g., very large rivers, large inland deltas) for which controls sites are limited	Least applicable for projects that are under stringent timelines for which the before data collection is unfeasible	Must sample impact site prior to impact – preplanning necessary
Control-Impact	No data collected before the habitat alteration, data only collected after the habitat alteration	Often multiple control sites assessed - recommend 3-5 sites	Can be used to assess a site with no baseline data	Doesn't control for temporal variation not attributable to the impact	Less effort than a full BACI design; no further costs once assessment is complete	Most applicable when there is an immediate monitoring that doesn't allow for the collection of baseline data and high spatial replication is possible	Least applicable when systems are highly variable or sites are unique	Appropriate control necessary – can be difficult for more unique sites
Reference Condition Approach	Often no temporal replication but temporal replication possible	Multiple control sites required, recommend 10 reference sites per reference group	Can be used to assess a site with no baseline data	Doesn't capture the baseline conditions of the impacted site; can be difficult to adequately represent reference condition	Lowest effort design at the time of assessment; additional costs of monitoring reference sites may be substantial	Most applicable for evaluating ecosystem health at large spatial scales	Least applicable for assessing local habitat changes (e.g., fish passage, availability of structure and cover)	Appropriate number and type of reference sites; costs may be alleviated by using existing information to develop indicator benchmarks

Design	Temporal Replication	Spatial Scope	Benefits	Challenges	Effort	Most Applicable	Least Applicable	Key Considerations
Normal Range Approach	No data collected before the habitat alteration, data only collected after the habitat alteration	Data may be used from multiple sites	No baseline data required	High data needs (e.g., long time series) to identify normal ranges or benchmarks. Normal ranges may be affected by shifting baselines.	High effort to establish normal ranges or benchmarks unless models or data exist in the literature; lower effort needed for each project.	Most applicable where there is a strong linkage between response and habitat alteration, and benchmarks and normal ranges can be defined using laboratory or field data, experiments, or models	Least applicable when there is little information about the system and relationships with the response	Transfer of information on normal ranges or benchmarks among projects/ systems/species
Trend-by-Time Analysis	No data collected before the habitat alteration, data only collected after the habitat alteration, multiple years required	Data may be used from multiple sites	No baseline data required	Long time series required, assumes dynamic equilibrium	High effort to establish time series.	Most applicable when there is an immediate monitoring need that does not allow for the collection of baseline data	Least applicable when systems are highly variable or where long-term data collection is not feasible	Evaluates relationship between metric and impact (continuous)

Terms of Reference Objective 2 – Data and analyses required to support a functional monitoring program.

As the first step of functional monitoring is to establish quantitative objectives that are tied to the Pathways of Effects (POE) endpoints, these objectives will inform the indicators (e.g., more general quantities, such as temperature, used to evaluate changes in fish productivity) and metrics (e.g., the specific representation or quantification of an indicator, such as maximum temperature) to be measured to achieve the objectives (discussed further in Braun et al. 2018). The most appropriate indicators will vary as a function of the specific project and sampling design, however, selection of indicators should consider the following criteria:

- Whether indicators are related to the expected outcome (e.g., macrophyte cover related to creation of a marshland/wetland). Ideally all indicators will have a strong and established quantitative linkage to fish productivity, but some linkages may have weaker empirical evidence from scientific studies, and thus additional evidence should be pursued.
- Whether indicators are correlated and if so, consider whether measurement of additional indicators provides unique information (e.g., nutrients and chlorophyll *a* are often positivity correlated but nutrients provide information on the availability of nutrients for primary production whereas chlorophyll *a* provides information on how the nutrients are used through photosynthetic rates), or if some redundancy is desirable to increase confidence in results.
- How variable the indicators are over time and space (e.g., water depth in rivers can vary daily and is influenced by weather).
- How reliably the indicators can be measured (e.g., visually assessing sediment composition can have high bias),
- Whether thresholds for success in a relevant context exist (e.g., minimum thresholds for eel-grass density or oxygen concentrations).

Table 2 provides examples of indicators that could be used to represent changes in the 11 POE endpoints relevant to functional monitoring that were compiled from all in-water POEs (DFO 2018a). Most of the indicators listed represent physical or chemical properties of the site since these are relatively easy to measure and can have less variability than biological indicators, both desirable attributes for an efficient and effective functional monitoring program. However, there may be situations where using biota as an additional indicator is appropriate, for example, using the presence/absence of fish when gauging the success of improving access to habitat as an offset, or to document use of a newly created habitat by fish. Generally using indicators of fish productivity (e.g., abundance, biomass) requires a high level of effort conducted over a longer timeframe and is more appropriate for effectiveness monitoring. However, using the presence/absence of fish as a metric for functional monitoring may be appropriate because whether fish are using an area is the ultimate measure of whether or not an area functions as fish habitat. However, since the presence of fish alone may be insufficient for demonstrating functionality, both biotic and abiotic indicators may be needed, but the decision on the inclusion of both should be made on a case-by-case basis.

Using macroinvertebrates was also considered to involve a higher level of effort than would normally be anticipated for functional monitoring. However there may be specific situations where macroinvertebrates would be an appropriate indicator, for example, where existing monitoring programs provide a reference condition (e.g., CABIN) as a comparator thus reducing sampling requirements, and where this group of taxa may be particularly responsive to restoration actions, for example, restoring a site impacted by mining. These specific situations may still be more appropriately assessed by effectiveness monitoring and need to be decided on a case by case basis. In all cases, the most appropriate indicator(s) must be clearly tied to quantitative monitoring objectives that are set during the planning stages of a project.

Braun et al. (2018) provides additional information suggesting specific metrics appropriate for each indicator listed in Table 2. While the list provided is not exhaustive, it provides clear examples of metrics known to be linked to the indicator and POE endpoint of interest. The number of metrics selected for measurement in a functional monitoring program depends on a number of factors, but potentially only one could be used if it is very strongly linked to the objectives, can be reliably measured, and has low spatial and temporal variability. However, measuring a range of metrics will help better understand the mechanism behind functionality observed (or not), and will provide more confidence in the achievement of objectives.

Table 2. Checklist of standardized indicators for in-water activities and Pathways of Effects endpoints (DFO 2018a) that could be used for functional monitoring. Xs indicate if the indicator may potentially be useful for assessing a given in-water activity potential effect endpoint. Project POEs would be identified and for each POE endpoint ecosystem specific suites of indicators would be assigned to a monitoring protocol. Indicators that are used for marine assessments are denoted by M, and those that are used for freshwater assessments are denoted by F. It is assumed that compliance monitoring will be conducted at all projects. Variability in indicators is an important consideration in choosing an appropriate sampling design and data collection methodology.

Indicator	Ecosystem	∆ in Food Supply	∆ in Habitat Structure and Cover	∆ in Sediment Concentrations	∆ in Nutrient Concentrations	∆ in Contaminant Concentrations	∆ in Access to Habitats	∆ in Salinity	∆ in Total Gas Pressure	∆ in Thermal Cues or Temperature Barriers	∆ in Water Temp	∆ in Dissolved O_2
Nutrients	M,F	X			X							
Substrate	M,F	X	X	X								
Water depth	F		X				X				X	
Water velocity	F		X				X				X	
Fish assemblage	F						X					
In-water cover	M,F	X	X								X	
Riparian cover	M,F	X	X	X	X						X	
Sediment concentration	M,F			X							X	

Indicator	Ecosystem	Δ in Food Supply	Δ in Habitat Structure and Cover	Δ in Sediment Concentrations	Δ in Nutrient Concentrations	Δ in Contaminant Concentrations	Δ in Access to Habitats	Δ in Salinity	Δ in Total Gas Pressure	Δ in Thermal Cues or Temperature Barriers	Δ in Water Temp	Δ in Dissolved O_2
Contaminant concentration	M,F					X						
Gradient	F						X					
Fish assemblage	F						X					
Salinity	M,F							X				
Dissolved Gas Pressure	M,F								X			
Temperature	M,F									X	X	
Dissolved O_2 concentration	M,F								X			X

Once the indicators and resulting specific metrics are selected for measurement, all attempts should be made to use standard, published sampling methods to collect the data. While it is not within the scope of this SAR to outline specific methods, a number of appropriate resources are provided in Appendix 2. Following well established protocols will increase the quality of the data collected, increase the potential ability to conduct program-level assessment at the individual metric level due to increased comparability, and ensure greater inclusion of projects within future meta-analyses due to high quality information. Some sampling techniques may be appropriate to use, for example, digital image assessments and/or remote sensing, but established standard methods for their employment may not exist. In these cases, following methods described in a primary peer-reviewed scientific publication or other appropriate published sources should be adequate, provided methods used are well described and cited so that they may be repeatable by others. If novel and unpublished protocols are developed during the monitoring program, these should be reviewed by a team of experts prior to their implementation, and must be documented to a level of detail that ensures repeatability by a qualified biologist unfamiliar with the technique. However, for a functional monitoring program, well established and standardized methods should always be considered first, and novel methods only considered in exceptional circumstances.

The appropriate statistical analyses of data arising from a functional monitoring program are dependent on the design selected. Considerations must be made at the design stage to ensure adequate spatial and temporal replication to accommodate the analysis. Factors such as independence of replicates and consistent, adequate and appropriate temporal replication (e.g., sampling at the same time in a season and over multiple years) must be considered to ensure the appropriate analyses can be completed once data are available. More detail on suitable analytical methods for potential designs considered appropriate for functional monitoring can be found in Braun et al. (2018).

Setting decision criteria for determining whether the results of a functional monitoring program indicate success should be established *a priori*, and whenever possible should be quantitative (e.g., achievement of a particular density of macrophytes relative to a control). These decision criteria should be regionally relevant and could be developed following an effectiveness monitoring program that was able to link habitat function to a desired level of fish productivity, whereby the level of habitat function becomes the success criteria for a longer term functional monitoring program. Other success criteria may be gleaned from the literature, for example, known species-specific oxygen requirements for successful egg incubation within the substrate of created spawning habitat.

As results of functional monitoring on a particular type of management measure accumulate, power analyses can be conducted to identify the number of additional projects and the degree of precision and accuracy needed to address broad questions subject to future meta analyses. For example, meta analyses can answer if a particular management measure in a given type of environment consistently achieves success, and strong evidence to this effect may indicate monitoring beyond compliance is no longer necessary.

Cautions should be employed when conducting meta analysis using effect sizes from more than one monitoring design since effect sizes will vary among designs and may not be directly comparable. For example, a positive high threshold may be set *a priori* for indicating success in a before-after design, but an equivalency threshold for indicating success may be appropriate in a control-impact design where the control site has high quality habitat and fish productivity. Similarly, a normal range approach where the management measure is designed to achieve equivalency with this ‘norm’ would be expected to have a small mean difference between the intervention and normal range, and thus would have a small effect size if successful. For correct interpretation, designs being compared need to be consistent in terms of the expected effect, otherwise must be analyzed separately.

Terms of Reference Objectives 3 and 4 – Feasibility and content of a checklist style approach.

The use of a checklist style approach for monitoring has several advantages including providing a simple way to ensure all relevant data are collected and that these data are captured in a consistent way, facilitating consistent reporting and archiving and thus longer-term, national program level analyses. It is feasible to develop checklists for functional monitoring using the same or very similar format for similar activities and monitoring designs. Such checklists would need modification depending on the project type and monitoring design used, and potentially incorporating regional differences. A number of comprehensive examples of checklists exist within FPP regionally and are currently in use. Examples should be found to build upon for developing nationally consistent checklists. It is recommended that national level checklists be pursued whenever practical.

A tiered checklist approach is recommended because it can incorporate multiple levels of standardized information (site/project/region/habitat), while allowing for greater flexibility as the level of detail in data collection increases. The first tier would be standard across all projects at the national level, and include the collection of basic information such as georeferenced location, affected habitat area, type of habitat and other content typically collected at the compliance level of monitoring. The second tier would be standard across particular project types (e.g., culverts) and would remain relatively consistent at a national scale. The third tier would be specific to a particular site/project/region/habitat and provide the most flexibility in terms of the data collected. Functional monitoring indicator fields used in tier 2 and 3 in checklists could be identified from Table 2. Braun et al. (2018) provides additional information suggesting metrics appropriate for each indicator listed in Table 2. To ensure a high level of quality control and standardization, it is recommended that checklists for tiers 1 and 2 be developed at the national level by FPP, with DFO science input as appropriate. Similarly, it is recommended that checklists for tier 3 (project specific information) be developed as a collaboration between DFO Science and FPP at a project or regional level.

Sources of Uncertainty

Functional monitoring may best apply in situations where there is a clear link between fish productivity and habitat function. Many of these linkages are theoretical and not well supported by empirical data, and in these situations, uncertainty will be greater. There are two levels of uncertainty related to linkages: 1) the strength of evidence linking the habitat management measures (i.e., mitigation/offset/restoration) to fish productivity, and 2) the strength of the linkage between the indicators selected as part of the functional monitoring program and fish productivity.

The degree of uncertainty in the management measure will determine if functional or effectiveness monitoring should be employed; when this uncertainty is high, effectiveness monitoring may help establish the linkage supporting the future use of the offset/restoration technique. The degree of uncertainty in the indicator-fish productivity relationship may influence the number of metrics that should be included in a functional monitoring program; measuring multiple metrics may help reduce this uncertainty.

In addition, the six potential designs recommended here carry with them inherent challenges, assumptions and uncertainties, all of which are reviewed briefly above and in-depth in Braun et al. (2018), and should be carefully considered both when selecting a design and interpreting results from a functional monitoring program.

CONCLUSIONS AND ADVICE

The purpose of functional monitoring is to provide a relatively rapid and objective science-based assessment of the performance of the management measure that goes beyond a simple assessment of compliance with design/construction standards. Functional monitoring should only be implemented when there is low uncertainty of both the expected performance of the management measure, and the strength of the linkage between the surrogate metric(s) measured and the desired fish outcome. If these uncertainties are low, functional monitoring could be conducted by DFO practitioners (when no proponent monitoring is required) and/or proponents (when monitoring is required, but effectiveness monitoring is not considered necessary) at individual projects. Where uncertainties are high, effectiveness monitoring should be implemented. Conducting functional monitoring at multiple similar management measures across a range of sites can increase understanding of effectiveness of such measures, potentially improving both the site evaluation and program evaluation.

Terms of Reference Objective 1: recommended monitoring design and methods

- Six different sampling designs (Before-After Control Impact; Before After; Control Impact; Reference Condition Approach; normal range/benchmarks; trend-by-time or level-by-time) were reviewed for use in Functional Monitoring. The choice of design depends largely on the project context.

- Considerations for choosing the appropriate sampling design were provided for each design (Table 1) and references to standard methods were provided (Appendix 2).

Terms of Reference Objective 2: data and analyses to support functional monitoring

- Considerations for the selection of specific indicators were provided; these include the relation between the indicator and the expected outcome, the correlation between indicators, the temporal and spatial variability of indicators, the reliability in measuring indicators and the availability of clear thresholds.
- Examples of appropriate indicators are provided relative to POE endpoints in marine and freshwater ecosystems (Table 2) and references to standard methods are provided (Appendix 2).

Terms of Reference Objectives 3 and 4: feasibility and content of checklists

- Checklists were considered a feasible means to confirm the collection of relevant data for functional monitoring.
- A tiered checklist was recommended to retain some standardization across functional monitoring programs while allowing for project and regional specific data collection. The first tier would contain standard fields across all projects, the second tier would contain standard fields across particular project types (e.g., culverts), and the third tier would be site/project/region/habitat specific. Functional monitoring indicator fields for the checklists could be informed from indicators provided in Table 2.

OTHER CONSIDERATIONS

The following critical key knowledge gaps should be addressed to facilitate the implementation of a successful functional monitoring program:

- Working towards establishing evidence-based metrics for indicators of fish productivity to expand the applicability of functional monitoring;
- Establish normal ranges/benchmarks for high priority project types or ecosystem types;
- More detailed guidance on key fields to be incorporated into functional monitoring for specific project/ecosystem types (i.e., tier 2 and tier 3 of the checklist).

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SOURCES OF INFORMATION

This Science Advisory Report is from the February 26-28, 2018 on Science advice on operational guidance on functional monitoring: Surrogate metrics of fish productivity to assess the effectiveness of mitigation and offsetting measures. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

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APPENDICES

Appendix 1. Glossary

Glossary

Term	Description	Reference
BA	Before-After - A commonly used monitoring design that compares data collected before and after a development activity.	Underwood 1991
BACI	Before-After-Control-Impact - A commonly used monitoring design where the control and impact sites are sampled before and after the development occurs.	Underwood 1991
CI	Control-Impact - A commonly used monitoring design that compares data between control and impact sites.	Underwood 1991
Effectiveness Monitoring	A science-based activity, requiring a standardized, transferable design. The metrics or indicators must measure productive capacity or fish based surrogates of productive capacity.	Smokorowski et al. 2015
Fish Productivity	A survival parameter specific to a population of fish (e.g., maximum growth rate of a population at low density). Productivity may also be characterized by other population traits such as growth, fecundity and age-at-maturity.	Randall 2003
Fisheries Productivity	The sustained yield of all component populations and species, and their habitat, which support and contribute to a fishery in a specified area.	Randall et al. 2013
Functional Monitoring	A science-based, scaled-down version of effectiveness monitoring that relies on surrogate metrics to assess whether management measures provide expected conditions suitable for fish to carry out their life processes.	DFO 2012
Habitat	Spawning grounds and other areas, including nursery, rearing, food supply, and migration areas, on which fish depend directly or indirectly in order to carry out their life processes.	DFO 2018b
Indicator	Some quantity that describes, and is hypothesized to be related to, changes in fish productivity. Indicators may be comprised of one or more quantitative metrics, or may be qualitative in nature (cf. “change in LWD”, “loss of structure”).	Bradford et al. 2014

Term	Description	Reference
Letters of Advice	Guidance provided to a proponent by FPP when a Fisheries Act Authorization is not required but there is potential to avoid or mitigate any effects of the project impact on fisheries productivity.	DFO 2018c
***Fisheries Act* Authorizations**	Guidance for a project proponent from FPP outlining how to avoid or mitigate for impacts where possible and requirements for restoration and offsetting where impacts are unavoidable and cannot be mitigated.	DFO 2018c
Management Monitoring Objectives	Monitoring objectives of the Fisheries Protection Program related to project monitoring are: 1) to ensure conformity with advice, construction/design standards and compliance with the *Fisheries Act* and *Species at Risk Act* (compliance monitoring program); and 2) to evaluate the effectiveness of management measures aimed at reducing the impacts of projects on fish and fish habitat (functional and effectiveness monitoring programs).	Braun et al. 2018
Measurements	Measurements are taken in the field and describe the current state of the ecosystem or its biota. Examples include fish abundance or discharge.	Bradford et al. 2014
Meta-analyses	A powerful analytical method that can be used to determine how effective different management measures are at achieving sustainable fish productivity by evaluating the overall effect of a given management measure for multiple projects.	Arnqvist and Wooster 1995
Metric	The specific representation or quantification of an indicator. Metrics are used to evaluate change or the relationship between the altered site and control(s) or relevant comparator(s). A metric can be derived from before-after field measurements (e.g., change in fish abundance), or can be estimated from baseline measurements and a predicted or modelled effect.	Bradford et al. 2014
Mitigation	Is a measure to reduce the spatial scale, duration, or intensity of serious harm to fish that cannot be completely avoided. Mitigation measures include the implementation of best management practices during the construction, maintenance, operation and decommissioning of a project.	DFO 2013
Offsetting	A measure that counterbalances unavoidable serious harm to fish resulting from a project with the goal of maintaining or improving fish productivity.	DFO 2013

Term	Description	Reference
Productive Capacity	Sum of production of all co-habiting fish species for a defined time period.	Randall 2003
Quantitative	Collecting both physical and biological measures, metrics and indicators through varying degrees of measurement.	Smokorowski et al. 2015
Rapid Assessment	An assessment protocol that can be conducted in a short amount of time (e.g., < 1 day for 2 people to collect the data, manage the data, analyze the data, and complete reporting).	Sutula et al. 2006
RCA	Reference Condition Approach - An approach that compares a test site to a set of conditions defined by multiple reference sites that represent some desirable state (e.g., undisturbed, pristine or not-impaired)	Stoddard et al. 2006
Restoration	The creation or restoring of a previously degraded habitat known to have served this function in the past.	Smokorowski et al. 2015
Standardized Monitoring	Are monitoring programs that use consistent data collection, analysis, and reporting protocols.	Braun et al 2018.
System Type	Lake, river, stream, estuary marine coastal or other major category of waterbody.	Braun et al. 2018.

Appendix 2. Standard Methods Resources

American Fisheries Society: Fisheries Techniques

American Fisheries Society: Standard Methods for Sampling North American Freshwater Fishes

Standard methods also has a companion website:

American Fisheries Society: Analysis and Interpretation of Freshwater Fisheries Data

All the examples from this book have been converted into R and can be found here:

American Fisheries Society: Monitoring Stream and Watershed Restoration

American Fisheries Society: A Guide to Sampling Freshwater Mussel Populations

American Fisheries Society: Biological Indicators of Aquatic Ecosystem Stress

American Fisheries Society: Aquatic Habitat Assessment

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Example provincial monitoring program guides:

British Columbia

Government of British Columbia inventory of monitoring protocols:

Alberta

Government of Alberta Fish Habitat Manual:

Ontario

Broadscale Monitoring Program:

Broadscale Monitoring Program Fish Community Monitoring Guidelines:

Manitoba

Manitoba/Manitoba Hydro Coordinated Aquatic Monitoring Program:

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