ASSESSING THE EFFECTIVENESS OF FISH HABITAT COMPENSATION ACTIVITIES IN CANADA: MONITORING DESIGN AND METRICS

Figure 1: Department of Fisheries and Oceans' (DFO) six administrative regions.

Context :

In Canada, the principal tools for the management of fisheries and fish habitat are the Fisheries Act and its associated habitat management policies. Compensation for loss of fish habitat is defined by the Department of Fisheries and Oceans' (DFO) Habitat Management Program as 'replacement of natural habitat, increase in productivity of existing habitat, or maintenance of fish production by artificial means' (DFO 1986). Compensation is considered as a management option only if proposed activities affecting habitat cannot be avoided by redesign, relocation, or by mitigating potential impacts. The main goal of any compensation program is to offset the loss of 'productive capacity' described in the 'no net loss' guiding principle outlined in the DFO Policy for the Management of Fish Habitat in Canada. Monitoring to determine the effectiveness of compensation actions is a priority of the DFO Habitat Management (HM) program. Science-based monitoring to assess effectiveness of compensation requires clear data collection standards, which in turn requires guidance on appropriate metrics and survey design.

To report on the effectiveness of habitat compensation projects, DFO's Habitat Management program has requested scientific advice regarding monitoring metrics and design. In addition, the HM program also seeks advice on appropriate indicators of ecosystem health in systems with significant human activity. These indicators could contribute toward future reporting on the state/condition of fish habitat in Canada. This report is from DFO's Canadian Science Advisory Secretariat (CSAS) national peer review process held December 6 to 8, 2011 in Ottawa to address this request and management program needs.

Canada

SUMMARY

- To report on their operational activities, DFO Habitat managers must evaluate the adequacy of fish habitat compensation projects in accomplishing the intended management goals. To assess the success of these habitat compensation works or activities in achieving the expected result, three broad categories of monitoring tools are available; '*effectiveness'* monitoring; '*functional*' monitoring, and '*compliance*' monitoring.

- Due to demanding data collection methods and scientifically-defensible analyses, *effectiveness monitoring* for habitat compensation projects is essentially a science-based activity, requiring a standardized, transferable design. The metrics (or indicators) for effectiveness monitoring must measure productive capacity[1] or fish based surrogates of productive capacity. Effectiveness monitoring is particularly important for complex projects expected to have a large impact on fish and fish habitat.

- *Functional monitoring* is a scaled-down assessment of habitat compensation effectiveness. It is quantitative, but relies on surrogate information to assess changes in productive capacity (e.g., change in macrophyte density or amount of a substrate type). At a minimum, data collected for functional monitoring must be able to account for net habitat loss or gain (i.e., by unit area of a particular habitat).

- At a lower intensity of effort, a well-designed functional monitoring program can yield valuable information that feeds into the assessment of the Habitat Management program as a whole. A higher intensity of effort of functional monitoring will produce a diminishing rate of return on investment. In contrast, at a lower intensity of effort (i.e., poorly designed, shorter-term, surrogate metrics), an effectiveness monitoring program will yield little value. For an effectiveness monitoring program to achieve its goals, a high intensity of effort will often be required.

- *Compliance monitoring* is an operational activity conducted by either DFO Habitat Management or Compliance and Enforcement staff. It is used to determine whether the terms and conditions prescribed under a *Fisheries Act* authorization have been implemented. As such, compliance monitoring is not a focus of this report.

- The systematic effectiveness monitoring of these habitat compensation activities can be broadly based on the types of fish habitat as defined in the *Fisheries Act* (i.e. "spawning grounds and nursery, rearing, food supply and migration areas on which fish depend directly or indirectly in order to carry out their life processes").

- Regional benchmarks of habitat productivity (at the fish population or community level) for specific habitat types should be scientifically established. Such a system of Regional benchmarks could be used as a tool to help set appropriate management goals and thereby to evaluate the effectiveness of compensation activities.

- Evaluating the effectiveness of habitat compensation via a Before-After/Control-Impact (BACI) study is among the most statistically robust monitoring techniques. Temporal and spatial controls (i.e., before data and data from other comparable sites, namely the BACI design) are often but not always advisable when designing a monitoring plan. Controls, when properly chosen and utilized, tend to improve the precision of the estimate of change, and reduce the likelihood of incorrectly attributing natural environmental patterns in time or space to the compensation action. Determining the appropriate design type and

[1] See "Appendix 1 - Productive Capacity Definitions".

level of replication to provide a statistically robust study is non-trivial in all but the simplest cases. Expert statistical and biological assistance will therefore almost always be advisable.

- In addition, various habitat modeling techniques are also available to predict the potential environmental effects of habitat compensation (at the watershed or ecosystem scale). They may be used to test scenarios of site suitability, predict limiting factors, or to direct compensation monitoring strategies and provide information within a decision-making framework. However, models come with assumptions and can make it more difficult to assess the validity of the results. Complex models should be avoided unless there are sufficient resources to thoroughly evaluate the approach and assumptions.
- Effective monitoring also requires well-designed and proactive data management methods in order to summarize habitat quantity and quality. Data management and geomatics tools (i.e., geospatial decision-support tools) can provide support for effectiveness monitoring by storing and integrating data over various scales (spatial and temporal).
- Currently in Canada, habitat compensation activities are assessed and implemented at the site scale. Use of standardized data collection, assessment and reporting methods are required to examine cumulative effects from anthropogenic influences at the appropriate scale where habitat impacts have the potential to cause broad-scale, ecosystem-level changes. Within DFO, the consideration of cumulative effects is both a science and management function, and compensation monitoring conducted with appropriate guidelines would provide valuable data to inform both these roles.
- Similarly understanding the average effect of different compensation types would well inform managers as to the value of various activities. For example, expressing the average amount of productive capacity produced per unit lost (or dollar spent, or unit gained, etc.) by habitat type would allow science and management to assess the mean and variability of the effectiveness of different approaches (in different conditions), greatly improving the knowledge to feed into future compensation decisions.
- A framework for a scientifically defensible effectiveness monitoring program is presented as advice to Habitat Managers (see Appendices for 'Table of Contents' for each of the five habitat types / life history stages as defined in the *Fisheries Act*.) The steps listed in the Appendices will require an accompanying DFO Technical Report (i.e. *Canadian Technical Report of Fisheries and Aquatic Sciences*) with further details on methodologies and supporting information.

INTRODUCTION

Significant resources have been expended on fish habitat compensation activities relating to the implementation of the habitat protection provisions of the *Fisheries Act* in Canada. Monitoring the effectiveness of habitat compensation activities (including creation, restoration and enhancement) is critical to validate the success of these work(s). To confirm that these specific habitat compensation actions have achieved the management goal of 'no net loss' of the productive capacity of fish habitat, effectiveness monitoring is required.

To adequately assess the effectiveness of a specific compensation project, monitoring must determine if the approved compensation effectively replaces lost habitat productive capacity. Thus, a defensible examination of the effectiveness of compensation activities must also address other important temporal and spatial considerations (e.g., watershed or coastal ecosystem effects, climate change, etc.) within the dynamic range of the ecosystem.

This DFO Science advisory process examined the feasibility of designing a standardized monitoring approach (and associated metrics) to determine the effectiveness of habitat compensation activities in achieving the objectives of DFO's Policy for the Management of Fish Habitat (1986). Outcomes of this process include this Science Advisory Report, a Proceedings document, research documents and a DFO Series Technical Report providing the details of the standardized Effectiveness Monitoring outlined here.

ASSESSMENT OF FISH HABITAT COMPENSATION ACTIVITIES

Types of Compensation Monitoring:

Monitoring can be categorized into three general types that can be used to assess compensation activities in Canada: *Compliance*, *Functional* and *Effectiveness* monitoring (Table 1). *Compliance* monitoring is conducted by Habitat Managers and/or Compliance and Enforcement staff in order to determine if the proponent has complied with conditions set out in an authorization under the *Fisheries Act*. Part of the compliance determination includes the assessment of implementation of the compensation activities (i.e., 'has the project been constructed or implemented as approved'). However, the suite of operational activities involved in the determination of compliance is beyond the scope of this science report and will not be discussed further. This report will focus only on two types of monitoring: Functional and Effectiveness monitoring. Both types of monitoring form an important part of the HM program, however the intensity of effort required for each is commensurate with the scale and potential impact of the proposed development activity. Both types of monitoring require standardized data collection methods, standardized analysis and reporting formats to ensure that the maximum value can be extracted from all monitoring efforts.

Table 1: Description of the general types of fish habitat monitoring programs. (Courtesy of M. Bradford, 2011)

Type	Metric	Design	Goal
Compliance	Area, physical works	Site visit soon after construction	Compliance with authorization
Functional	Area, visual assessment of function, some biotic measures	Spatial: site visit, treatment-control comparison. Trend: Repeat sampling over time	Suitability and stability of constructed works. Expert assessment of function.
Effectiveness	Physical, vegetation, invertebrates, fish	Before-After Spatial Multi-year sampling	Does the project create functioning fish habitat? "No net loss" (NNL).

'*Functional*' monitoring here is defined as a sub-component of effectiveness monitoring that is quantitative, but relies on surrogate information to assess changes in habitat (as opposed to a direct measure of fish production or index thereof). Functional monitoring can be used to provide quick appraisal of habitat function and can provide feedback on the design of compensation works (relative to other similar habitats at a regional level). In itself, functional monitoring is generally not scientifically defensible as an independent means of assessing the effectiveness of compensation activities. However, data and information collected from functional monitoring can be used to assess cumulative habitat loss within a given area (e.g., watershed or marine spatial unit) to support assessing the effectiveness of the Habitat Management Program as whole. In addition, in cases when a number of *functional* monitoring efforts are conducted in a standardized manner on a similar habitat type, and yield similar results, a case may be built for correlational evidence in support of the efficacy of that habitat type. Functional monitoring would be employed where the potential impact of the development activity is small and the type of compensation habitat employed is relatively well understood

Effectiveness monitoring is here defined as a scientifically defensible monitoring program that directly assesses the key metric (or indicator) of interest, and which must include the assessment of productive capacity (or surrogate) of the habitat compensation. Key metrics will vary by type of habitat (as defined in the *Fisheries Act*: “spawning grounds and nursery, rearing, food supply and migration areas on which fish depend directly or indirectly in order to carry out their life processes”) and are further discussed in Appendices 2-6. Some examples of such metrics include changes in fish abundance (population), species richness, or fish community composition, productivity and biomass. The objective of effectiveness monitoring is to demonstrate by field measurement that the compensation activity achieved the ecological milestones as set out in the terms of the authorization, which in many cases will be that there has been ‘no net loss’ of the productive capacity of fish habitat. Effectiveness monitoring can determine if the approved compensation measures were adequate or effective as a replacement for the loss of habitat or productive capacity incurred. Statistically defensible compensation monitoring is a longer-term undertaking with demanding data collection methods and scientifically-defensible analyses, and requires a standardized, transferable monitoring design.

Effectiveness monitoring is particularly important to employ in complex projects expected to have a large impact on fish and fish habitat, and/or where the risk and uncertainty regarding the efficacy of the compensation habitat is great. Once the validation of the effectiveness of a compensation habitat type (for a particular species/life stage) has been done, one would require only ‘*functional*’ monitoring at similar habitat types in similar environments (i.e., a measurement of key parameters that demonstrate its effectiveness).

Projects for which the size and/or uncertainty of the expected impact is large should be more intensively monitored. Conversely if through monitoring of a representative group of projects of a particular type uncertainty in the outcome of that project type is decreased, less effort should be expended monitoring that project type.

Effective habitat compensation should be ecologically relevant and lead to restoration preferably within the ecosystem where the habitat damage occurred (although this may not be possible in all cases). In this respect, habitat compensation should aim to achieve the success criteria (biological targets) as set out in the terms of the authorization, and ultimately determine if the compensation is ecologically stable and self-sustaining.

The ‘effectiveness’ of a habitat compensation project is usually determined by comparing metrics from the compensated habitats to those measured at one or more reference sites and/or to values from areas before being negatively impacted (i.e., pre-impact conditions). Thus, the monitoring criteria of effectiveness are pre-determined, and usually involve these metrics falling within the natural range of variability of the reference sites, within a specific time period. As such, defensible effectiveness monitoring of compensation projects more closely resembles a scientific research project or program, but could also be achieved by a proponent-driven monitoring program that is both well-designed and appropriately resourced. However, it should be noted that appropriate reference sites are not always available. In such cases, a before-after design would be most appropriate, and should include an examination of the rates and times required to reach full functionality of the measured parameters.

Figure 2 visually describes the difference between functional and effectiveness monitoring. At the lowest intensity of effort, neither type of monitoring will yield information of any value. At a moderate intensity of effort, a well designed functional monitoring program can yield valuable information that feeds into the assessment of the Habitat Management program as a whole. A higher intensity of effort of functional monitoring will produce a diminishing rate of return on investment. However, at a lower intensity of effort (i.e., poorly designed, shorter-term, surrogate metrics), an effectiveness monitoring program will yield little value. Thus, for an effectiveness monitoring program to achieve its goals, a high intensity of effort is required (Figure 2).

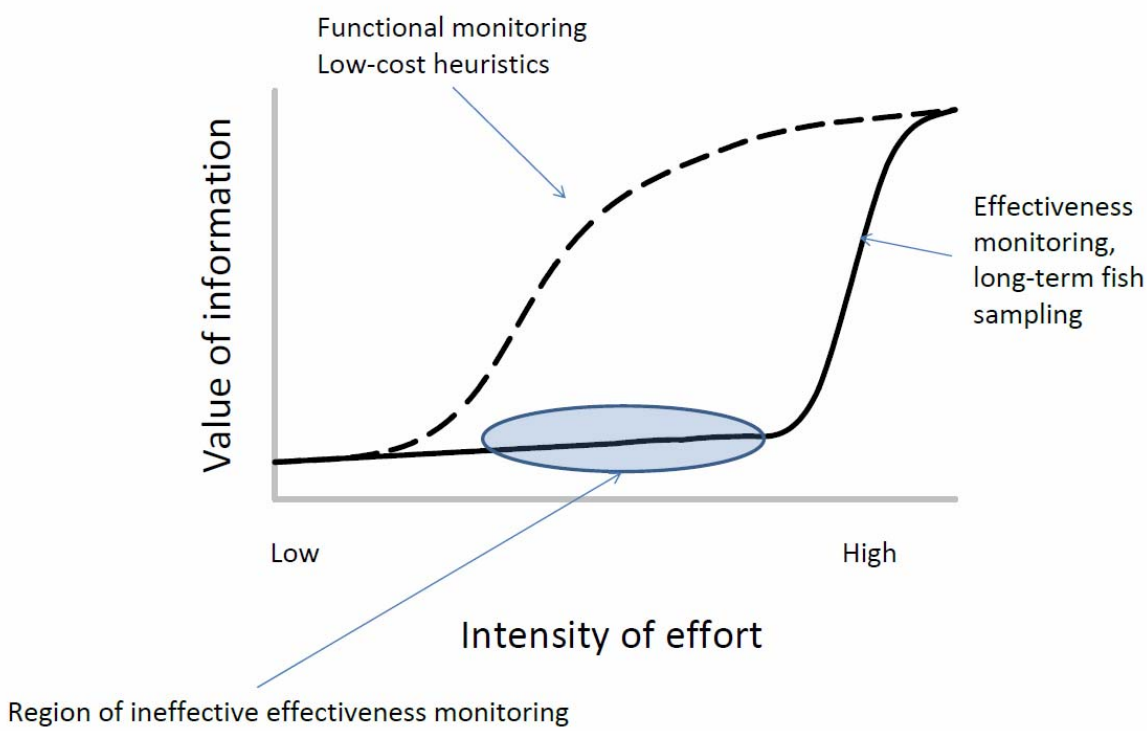

Figure 2: Conceptual schematic illustrating how assessing the 'effectiveness' of compensation activities will often require a scientifically designed and supported monitoring program. (Courtesy of M. Bradford, 2011).

Region Specific Benchmarks:

Basic fish and habitat monitoring data, collected over time, can be used to determine region-specific benchmarks for measuring compensation effectiveness (guiding principle of 'no net loss'). The data would include estimates of survey area, site characteristics that could affect productive capacity (e.g., channel type, elevation, drainage area, riparian characteristics), habitat type, fish abundance, fish weight by species, and total biomass. Area-biomass relationships would be used to determine regional estimates of productive capacity. These data could be obtained from existing datasets (e.g., DFO or provincial fish population assessment data) or from science-based monitoring programs. The development of regional benchmarks is a science function. Regional benchmarks exist for some areas (or could easily be developed), but not for other areas.

In this context, a “region” can be defined broadly as a geographic area with similar fish assemblages, climate and water nutrients (e.g., a watershed, a collection of adjacent watersheds, or a coastal management area). Measurement of productive capacity on a regional basis rather than at a site level to assess compensation effectiveness is consistent with an area-based and ecosystem approach for resource management. Regional benchmarks would be particularly useful where pre-treatment data are limited or unavailable.

Scale considerations for compensation monitoring (temporal and spatial):

Monitoring of habitat compensation must be undertaken for a period of time that is long enough to allow (i) biological or physical changes to be reflected in the data collected, and (ii) any adjustments to the monitoring design necessary to efficiently estimate changes in fish habitat productive capacity.

Duration of the monitoring program in relation to the time required for a restored habitat to reach full ecological functionality (i.e., supporting fish reproduction, growth, and survival) should be adjusted according to the habitat type and the life span of the biota. There is usually a lag time, ranging from months to years, before compensation habitat becomes ecologically functional. Thus, to be effective, the design of compensation monitoring must adequately address timescale.

An additional level of monitoring can occur at the ecosystem-level, and examines the baseline habitat conditions, variability, and trajectory in habitat supply and productive capacity given the geographic and regional location of the habitat and other stressor impacts on the ecosystem. Ecosystem-level monitoring (and associated ecosystem-level indicators) can further be used to comprehensively assess the cumulative impacts to habitat and the overall ecosystem resulting from development activities.

Challenges for Practitioners:

A ‘Before-After-Control-Impact’ (BACI) design is a statistically powerful experimental design for effectiveness monitoring. If the timing and location of the impact are known and adequate pre-project data are collected, the BACI design will help isolate the effect of the development from natural variability. However, there is a need for caution in the application of the BACI design. Interpretation of the data and conclusions of ‘statistically significant’ can vary depending on the number of years included in the analysis (thus duration of monitoring), the model used to analyze the data, and the level of amalgamation of data. Using any one individual metric (e.g., invertebrate versus fish, or abundance versus diversity) could give an incomplete picture of ecosystem response to environmental change. The interpretation of ‘significant impact’ needs to be tempered by an examination of the annual data plots to ensure the interpretation of BACI results is not misleading. Potential confounding factors that may influence a response metric (e.g., climate, hydrology, bathymetry) must also be examined. Including data collected from ‘Before’ years and a Control site can provide highly useful information for interpretation of results observed on the ‘Impact’ site. Multiple control sites are often desired to account for variability within the ecosystem in question; however, such a design might not always be practical.

BACI design can therefore be highly useful in monitoring effectiveness of compensation, but caution needs to be employed in terms of the design of analyses and interpretation. BACI design should only be employed if scientific guidance (government or external) is sought prior to initiating the monitoring project, during the monitoring project, and particularly during the analysis stage of the monitoring project. Thus BACI assessments, while desirable in some cases, are usually problematic in proponent-driven monitoring programs, and may only be possible in association with the largest (and most well-funded) development projects.

Habitat restoration practitioners have several methods available for assessing the success of habitat compensation projects which were intended for the creation, rehabilitation, or restoration of aquatic habitat. However, many of the methods may be labour intensive or require large amounts of data to be statistically defensible, thus potentially limiting implementation and ultimate program effectiveness. The real challenge for practitioners is in integrating information obtained on the effects of habitat compensation over a geographic area and which may be of limited relevance to population success, with other measures (e.g., egg production, larval or juvenile recruitment and adult production) that may be spatially and temporally removed from the compensation habitat.

For many habitat compensation projects, there are little or no baseline data or information (i.e. pre-project), and this is particularly evident in northern environments. Such data-deficient situations make it extremely difficult to quantify *a priori* site conditions, or to identify reference habitats with which to compare the compensation habitats. Additionally, confounding of environmental factors impinging on reference habitats may limit the assessment and evaluation of compensatory habitat.

Recommended Monitoring Framework

The focus of the remainder of this Science Advisory Report (SAR) will be to characterize the critical components of an effectiveness monitoring program. Details of such a standardized program will follow in a DFO Technical Report to be written by DFO science staff in the near future. However, since we reached consensus on the framework at the workshop, the steps to be included in the monitoring (in the format of a Table of Contents of the Technical Report) will be included here.

The Terms of Reference for this Science advisory process were clearly focused on assessing the effectiveness of habitat compensation. It is assumed that the initial steps involved prior to authorizing habitat compensation would have already been completed (i.e., steps 1-11 below in the Table of Contents are part of the Environmental Assessment and/or *Fisheries Act* authorization). While these initial steps are not the focus of this SAR or the resulting Technical Report, it is important to identify all the steps of the process to put the compensation monitoring into perspective.

The *Fisheries Act* (Section 34) defines fish habitat as “spawning grounds and nursery, rearing, food supply and migration areas on which fish depend directly or indirectly in order to carry out their life processes”. This definition can be used to provide a framework for the design of effectiveness monitoring programs based on habitat type. Note that the intent of this type of compensation monitoring is to compare standardized data between two sites (e.g., quantification of a “harmful alteration, disruption or destruction (HADD) of fish habitat” (per S.35 *Fisheries Act*) as compared to the related compensation activity).

For steps 11-17 listed below, the monitoring plan should be a component of a broader adaptive management plan. Monitoring details can be found in Appendices 2-6 of this report (as specific to the various *Fisheries Act* life history requirements on which fish depend directly or indirectly in order to carry out their life processes - spawning grounds and nursery, rearing, food supply and migration areas). It is worth reiterating that monitoring programs should be designed to assess effectiveness of compensation at meeting success criteria (biological targets), and ultimately to determine if the compensation is ecologically stable and self-sustaining. Another important objective for monitoring is to learn what compensation works and what doesn't. These overarching goals should be kept in the forefront of the monitoring program design.

Recommended Table of Contents for Standardized Effectiveness Monitoring (Technical Report):

Description of impacted habitat:

1. Characterization of baseline habitat condition (including physical, chemical and biotic components). Site description should include similar metrics to what is listed below in monitoring program description.
   * Collection of baseline data may involve use of surrogates in instances of rapid proposed development (time and information availability).
2. Define temporal and spatial scale of potential impact, standardized, *a priori* (of proposed alteration). Based on number of ecological functions (spawning, nursery, rearing, food supply and migration areas) potentially impacted. An assessment of the limiting factors at the landscape/watershed/ecosystem-level should be conducted at this stage.
3. Define ecological type/unit and function (including an assessment of the sensitivity of the particular habitat to the proposed alteration).

Habitat Impact Decision:

4. Quantify the current habitat condition, both at site being impacted and appropriate control (i.e., collection of baseline data, including spatial/GIS data).
5. Determine the extent to which impacts (direct and indirect) to fish habitat extend beyond the local site.
6. Define the ecosystem functions which are important at the scale of impact.
7. Assess if the project will likely affect the structure and function of the ecosystem.
8. Define confidence in the predicted impact (uncertainty in both predicted impact and management decision).
9. Determine if the compensation objective will be (i) habitat replacement or (ii) other appropriate compensation for habitat lost.
10. Establish compensation goals and success criteria (management role).

Implement effectiveness monitoring plan or program (also refer to Appendices):

11. Establish goals of monitoring:
    a) at site-scale (is it performing as intended, have quantitative targets been achieved or are results trending in the right direction).
    b) by monitoring type/category (see Appendices).

12. Establish science-based, quantitative targets to evaluate achievement of compensation goals. For example, as based on regional benchmarks for productive capacity, or based on pre-treatment data collected at the site of impact and/or a reference site.
13. Determine likelihood of success of compensation (based on documented success):
    - Where uncertainty of compensation success is high, use a higher frequency/intensity of monitoring; more compensation.
    - Where uncertainty of compensation success is low, use a lower frequency/intensity of monitoring.
14. Define metrics / indicators for monitoring (direct and indirect, linked to scale). Metrics should be the same as per the characterization of the baseline habitat (see Step #1 above).
15. Monitoring design decision (reference site, control, sampling intensity, sample size, etc.).
16. Determine appropriate duration for monitoring (both pre- and post-compensation activity).
17. Proponent reporting (in a standardized format which can be incorporated into a common, shared database).

Post-effectiveness monitoring of compensation works:

18. Review monitoring data to determine if monitoring timeframe was adequate, and/or if the timeframe should be extended.
19. Periodic scientific meta-analysis conducted by DFO science. Analyze and report at program level.

CONCLUSIONS AND ADVICE

(Not in any order of priority)

- A framework for a scientifically defensible effectiveness monitoring program is presented as advice to Habitat Managers (see Appendices for 'Table of Contents' for each of the five habitat types / life history stages as defined in the *Fisheries Act*.) The steps listed in the Appendices will require an accompanying DFO Technical Report (i.e. *Canadian Technical Report of Fisheries and Aquatic Sciences*) with further details on methodologies and supporting information.
- At the lowest intensity of effort, neither functional or effectiveness types of monitoring will yield information of any value. At a moderate intensity of effort, a well designed functional monitoring program can yield valuable information that feeds into the assessment of the Habitat Management program as a whole. A higher intensity of effort of functional monitoring will produce a diminishing rate of return on investment. However, at a lower intensity of effort (i.e., poorly designed, shorter-term, surrogate metrics), an effectiveness monitoring program will yield little value. Thus, for an effectiveness monitoring program to achieve its goals, a high intensity of effort is required (Figure 2).
- A standardized approach to data collection, storage, use of standardized indicators, and standardized reporting will allow for the results to be combined to assess cumulative changes, and average changes for specific project types. This is essential for effective compensation planning.
- Research is required to further develop and refine robust monitoring (sampling) designs for determining the effectiveness of fish habitat compensation activities. This should

include identification of effective monitoring designs for areas where there are potential population or ecosystem-level effects. Particular attention should be paid to establishment of “baseline” or reference conditions (possibly using regional benchmarks), cost-benefit of monitoring programs and suitability of various indices in terms of predictive capability, ease of calculation, sources of error, and data requirements.

- The design of compensation monitoring should be based on the intended outcomes of the compensation projects, and include an assessment of the limiting factors at the landscape/watershed/ecosystem-level. It is recommended that these intended outcomes be formalized within ‘habitat management objectives’ and/or ‘fisheries management objectives’, and contained within area-based fisheries and/or fish habitat management plans (where such plans exist).
- Scientific advice and guidance is needed regarding:
  a) monitoring methodologies which evaluate the linkages between habitat impacts and their resultant effects on populations / communities / ecosystems.
  b) various habitat classification systems and/or available frameworks which could serve as the basis for compensation monitoring program(s).
  c) testing and validation of habitat models (e.g., food web models) across a range of environmental conditions. This will better define potential application(s), and provide confidence in their predictive capability.
- Assessment of site-scale metrics of compensation effectiveness may not adequately reflect potential broader, ecosystem-scale impacts. Additional work is required on cumulative effects (and pressures of multiple stressors) on productive capacity in the various regions and ecosystems in Canada, including the identification of indicators reflective of significant changes in fish habitat at the ecosystem-scale. A framework (standard units, reporting, database) is needed to support the collection and integration of monitoring results to allow the ecosystem-scale assessment of impacts and compensation effectiveness to inform the report on the ‘state of fish habitat’.
- Regional benchmarks of habitat productivity (measured at the fish population or community level) for specific habitat types should be established by science, in collaboration with managers and clients. Proponent baseline data, collected using science-based protocols, could feed into the development of regional benchmarks. Such a system of Regional benchmarks could be used to set management goals for assessing compensation success.
- A geographic information system (GIS) is a useful tool for storing and integrating important data and layers of information on physical-chemical-biological features of the habitat. A geospatial decision-support system should be implemented such that both monitoring data and subsequent analyses are available to habitat managers, proponents, and the public. This tool could also be used for gap analyses, estimation of cumulative effects, and regional-level reporting.

APPENDIX 1 - PRODUCTIVE CAPACITY DEFINITIONS

The maximum natural capability of habitats to produce healthy fish, safe for human consumption, or to support or produce aquatic organisms upon which fish depend. (DFO 1986)

The sum of the maximum production of all co-habiting species; the capability of habitat to support a fish community; the sum of all production accrued by all stock during the time they spend any part of their life history in that area (Randall 2003)

The maximum natural ability of a habitat to support healthy fish or grow aquatic organisms upon which fish depend. (Gordon et al. undated)

APPENDIX 2 – SPAWNING GROUNDS

Technical guidance for monitoring design to assess effectiveness of habitat compensation in/to fish spawning grounds.

* Refer to Recommended Tables of Contents above for entire series of steps, within which these #12-18 steps would be included.

12. Establish the success criteria of habitat compensation in spawning ground areas:
    a) at site-scale (is it performing as spawning habitat as intended, what level of spawning success has been achieved against quantitative targets?)
    b) by monitoring type/category.

13. Establish science-based indicators and targets (biological endpoints) to demonstrate biological success. For example, as based on regional benchmarks for productive capacity.

    - Standardized guidance for spawning habitats (general).
    - Determine if it is realistic to take a quantitative approach.
    - Will necessarily be regionally and species specific.
    - Number of larvae or juvenile fish produced by that area.
    - Juvenile recruitment from that ecological area.
    - Establish Regional reference condition (i.e. potentially via Regional benchmarks, or deviation from a reference condition, non-parametric, interquartile)
    - Determine deviation from (variable) reference condition (which should be a range/function of the variability in the reference condition.
    - Range (suggested use interquartile, non-parametric).
    - Reference can be a control site
    - This category may be less applicable for marine environments if spawning areas are not geographically specific areas (esp. pelagic spp.)

14. Incorporate determination of likelihood of successful of compensation into design (based on other documented success).

    - uncertain = higher frequency/intensity of monitoring; more compensation
    - more certain = lower frequency/intensity of monitoring
    - Certainty – should be based on habitat types.
    - Well studied for salmonids. Less well understood for other species.
    - Dependant on type of compensation practiced.
    - Certainty of metrics is high for some species.
    - Difficult to assess a priori for species where compensation success is previously unknown.
    - Project success can be assessed by habitat biologists.

15. Define metrics / indicators for monitoring (direct and indirect, linked to scale).
    Data that should always be collected:

    - ultimately the production of emergent/hatched fish(es) (master variable); Young-of-the-Year (YOY)
    - measure of spawning area, geospatially referenced (m2)

- characterize suitable substrate (particle size, substrate stability, embeddedness etc.), including vegetation.
- physical metrics appropriate to the habitat type.
- If the biological endpoints have been met (e.g., emergent/hatched fish), the collection of metrics has been satisfied; if not, then proceed with collection of mechanistic information ("why did the compensation plan fail").
- temperature (for range of functional site requirements of species)
- dissolved oxygen (at site for locations or ecosystems with known low oxygen concerns)
- based on % of larval or juvenile fish emergence or hatch rate (low/med/high)
- define timescale for assessment/data collection (consider cyclic EC model).

  Additional work for DFO Science required in defining the set of physical metrics as appropriate to habitat/ecosystem (based on respective areas of expertise). To include defining appropriate timescale for assessment/data collection.

16. Monitoring design decision (reference site, control, sampling intensity, sample size, duration, etc.).

    - Baseline data to support monitoring should be collected using metrics similar to those that will be used for monitoring.
    - Establish reference condition and control site(s) as appropriate.
    - This could be established via:
      a) "before" data, and/or
      b) regional standard/benchmark and/or
      c) historic information and/or
      d) control site and/or
      e) modelling.

17. Establish appropriate durations (timescale) for monitoring.

18. Proponent reporting.

APPENDIX 3 – NURSERY AREAS

Technical guidance for monitoring design to assess effectiveness of compensation in fish nursery areas (emergence through first growing season).

* Refer to *Recommended Tables of Contents* above for entire series of steps, within which these #12-15 steps would be included.

12. Establish the success criteria of habitat compensation in nursery areas:

    - at site-scale (is it functioning as nursery habitat as intended)
    - by monitoring type/category.

13. Establish science-based targets to evaluate achievement of compensation goals. For example, based on regional benchmarks for productive capacity.

    - standardized guidance for nursery habitats (general)
    - it is realistic to be quantitative
    - will be regionally and species specific
    - survival/growth of juvenile fish to subsequent life-stage
    - juvenile recruitment from that ecological area
    - establish Regional reference condition (i.e. potentially via Regional benchmarks, or deviation from a reference condition, non-parametric, interquartile)
    - deviation from (variable) reference condition
    - this should be a range/function of the variability in the reference condition.
    - Range (suggested use interquartile, non-parametric).
    - Reference can be a control site
    - Determine likelihood of success of compensation (based on documented success).
    - uncertain = higher frequency/intensity of monitoring; more compensation
    - certain = lower frequency/intensity of monitoring
    - Certainty – should be based on habitat types.
    - Dependant on type of compensation practiced.
    - Certainty of metrics is high for some species
    - Can be assessed by habitat management biologist

15. Define metrics / indicators for monitoring (direct and indirect, linked to scale).

    Data that should always be collected:

    - ultimately the production of juvenile fish from the habitat area (master variable)

- measure of habitat area, geospatially referenced (m^2)
- characterize physical aspects of the habitat – including substrate, vegetation, and complexity.
- If you can demonstrate that the biological endpoints have been met (e.g. recruited fish), collection of metrics has been satisfied.
- If not, then proceed with collection of mechanistic information ("why did it fail").
- temperature (for range of functional site requirements of spp.)
- dissolved oxygen (at habitat location, for sites/ecosystems with known low oxygen)
- based on % of baseline growth/survival (low/med/high)
- define timescale for assessment/data collection (consider cyclic EC model).

16. Monitoring design decision (reference site, control, sampling intensity, sample size, etc.).

17. Determine appropriate duration for monitoring (both pre- and post-compensation activity).

18. Proponent reporting.

APPENDIX 4 – REARING AREAS

Technical guidance for monitoring design to assess effectiveness of habitat compensation in fish rearing areas (defined as habitat area that supports fish residency, growth and survival from the end of the nursery to adult stage).

* Refer to Recommended Tables of Contents above for entire series of steps, within which these #12-18 steps would be included.

Technical guidance for monitoring design to assess effectiveness of compensation in rearing areas:

12. Establish the success criteria of habitat compensation in rearing areas, including:
    - Confirmation at the site-scale that the compensation rearing habitat is functioning as intended, for residence, growth and survival of fishes
    - Attain empirical evidence of successful rearing at compensation habitat
    - Attain empirical evidence of functional rearing habitat

13. Science-based targets to evaluate achievement of compensation goals. For example, as based on regional benchmarks for productive capacity
    - rearing habitats are defined by broad mesohabitat categories: for streams: riffles/runs, pools; for rivers: slow and fast flow areas; for lakes: littoral, benthic and pelagic; for estuaries: tide channels, river discharge, riparian vegetation, seagrass, and marshes; for open marine and coastal: seabed variety and bathymetric diversity. Regional benchmarks of habitat capacity will likely include composites of these habitat categories
    - regional and species-specific or community quantitative targets, in densities of juvenile and adult fishes (and inferred production)
    - Regional reference condition (benchmarks) need to be established and agreed upon, including quantification of the normal deviation from the reference condition (e.g., interquartile range)
    - This approach may be less applicable for pelagic species
    - Reference can be a control site in close proximity to compensation site

14. Likelihood of success of rearing habitat compensation
    - for rearing habitat, certainty of success of compensation depends on the ecosystem and species. Assuming access to habitat is unimpeded (free movement of fishes) and that source populations are abundant, likelihood of success is high for streams and lake littoral, and medium for estuarine or marine.

15. Metrics / indicators for monitoring rearing habitat
    - quantitative data need to be collected on habitat and fish metrics
    - fishes:
        - -ultimately the abundance and/or biomass of juvenile and adult fish(es), for a known compensation area, are the master variables
        - -units: number of fish per m2; biomass (g wet weight) per m2 (i.e., abundance and/or biomass density)
    - density determination and sampling effort are measured as defined by protocol (pending)

- if it has been demonstrated that the biological endpoints have been met (abundance or biomass of fish within target range) sampling can be terminated or continued periodically according to an agreed-upon temporal scheme.
- if not, then proceed with collection of mechanistic information to determine why fish are not using the area
- partial barriers to access
- non-habitat factors affecting fish abundance (e.g., exploitation)
- temperature (for range of functional site requirements of spp.)
- dissolved oxygen (for sites/ecosystems with known low oxygen)
- other abiotic factors limiting abundance
- habitat surrogates:
- measure of rearing area, by habitat type, geospatially referenced, with units of m2, including areas both directly (footprint) and indirectly impacted
- physical metrics appropriate to the habitat type (substrate, depth, cover, water velocity for fluvial)
- physical metrics as defined by protocol (pending)

16. Monitoring design decision (reference site, control, sampling intensity, sample size, duration, etc.).
    - Benchmark data to support monitoring should be collected using the same metrics that will be used for monitoring.
        - establish reference condition and/or control site(s) as appropriate using:
        - “before” data
        - regional benchmarks
        - historic information, and/or
        - control site (s)
    - Certainty of success for rearing habitat compensation is high for well-studied species (i.e. if habitat suitability requirements are known, e.g., salmonids)

17. Establish appropriate durations (timescale) for monitoring.
    - if using a regional benchmark: 3 yrs post-impact (approx.)
    - if using a control site (s), 3 yrs pre- and 3 yrs post-impact (approx.)
    - seasonal data collection, to cover growth period (3 sampling dates: early, mid and late growth period within a year).

18. Proponent reporting.

APPENDIX 5 – FOOD SUPPLY AREAS

Technical guidance for monitoring to assess the effectiveness of habitat compensation measures regarding food supply areas.

* Refer to *Recommended Tables of Contents* above for entire series of steps.

Ecosystem components that contribute to the production of food for fish are considered fish habitat by the *Fisheries Act*. Development activities can impact food supply via a variety of pathways including, but not limited to:

- Removal of riparian vegetation
- Destruction of aquatic macrophytes from estuary or coastal habitats
- Degradation of substrate by the introduction of sediment or other substances
- Changes to habitat structure such as large woody debris (LWD) or other features
- Changes in water quality including transparency, and nutrient concentrations

Consequently compensation is usually required when the habitats that contribute to food supply are impacted. The primary food organisms of most larval and juvenile fishes and many adults are invertebrate species including zooplankton, and benthic and terrestrial taxa. There is a large body of knowledge about how these species are affected, in a general way, by alterations to habitat listed above. Invertebrate productivity may also be a useful indicator of food web function as it integrates various energy sources for fish.

Unfortunately the direct monitoring of invertebrate abundance or diversity to evaluate changes in food supply caused by project development, or due to compensation or mitigation measures can be extremely demanding. Invertebrate communities are inherently diverse and variable and extensive sampling and taxonomic efforts are required for a monitoring program to be able to detect changes in abundance or community structure. Further, the taxonomic expertise required for these studies is becoming scarcer. Broader-based analyses focused on the production and biomass of trophic levels may alleviate some of the need for detailed taxonomic work that is usually required in invertebrate diversity or abundance approaches.

Consequently, monitoring programs for food supply often rely on proxies for that are informed by knowledge of linkages between those proxies and invertebrate production. Examples include:

- Riparian vegetation or aquatic macrophyte density, structure and diversity
- Large woody debris (LWD) or other structural components that provide substrate for invertebrates
- Substrate composition metrics such as D90 or imbeddedness
- Primary production models that use water clarity and nutrient concentrations as predictors.

All of these measures have relatively low levels of natural and sampling variability and are therefore amenable to use in Treatment-Control or Before-After designs.

Some types of compensation or restoration actions designed to increase food supply can take many years to fully mature. Streambeds and intertidal mudflats may be fully colonized within a year, however, aquatic macrophytes and riparian vegetation may take 5-20 years to fully develop. Further, the food producing capacity of constructed habitat can deteriorate over time if natural or human factors (e.g., sediment discharges, storms, floods) alter those structures. Sampling programs should include intermittent revisits at 5-10 year intervals to evaluate long-term changes in function of those habitats.

APPENDIX 6 – MIGRATION AREAS

Technical guidance for monitoring design to assess effectiveness of habitat compensation in fish migration areas.

* Refer to *Recommended Tables of Contents* above for entire series of steps, within which these #12-18 steps would be included.

Fish species rely on migration corridors for accessing spawning grounds, nursery, rearing, and food supply areas. Barriers to fish passage includes artificial physical structures (e.g., dams, culverts, river training structures, causeways, some breakwaters), hydraulic (e.g., high velocity or turbulence) and pollution (e.g. effluents).

12. Establish goals of monitoring of compensation in migration areas:

    Overall effectiveness of restoring migration corridors (most commonly associated with freshwater and estuarine corridors):

    a. Compensation projects have the potential of causing harm to fish habitat (e.g., dam decommissioning operations and associated sediment transport in downstream habitats). Compensation measures will be inefficient if providing access to habitats beyond a barrier (e.g., located above a former obstruction) induce habitat loss in an area (below the former obstruction). To determine the overall effectiveness of a compensation measure, a long-term evaluation of the potential impacts resulting from these activities should be conducted concordantly with the evaluation of passage efficiency and potential for re-colonization (broad scale) in the areas beyond the restoration.
    b. Evaluate passage efficiency at the site of the former obstruction (fine scale), consider use of biotelemetry.
    c. Compensation measures will be inefficient if the newly accessible habitats are not re-colonized (production of juvenile fish). Therefore, the ultimate goal of restoring migration corridors should be the production juvenile fish in the newly accessible habitats (broad scale).
    d. Compensation projects for this purpose in the marine environment will be less common and are likely to consist mainly of alterations to causeways obstructing fish passage to semi-enclosed embayments and estuaries.

13. Establish science-based targets to evaluate achievement of compensation goals. For example, as based on regional benchmarks for productive capacity.
    a. Threshold targets of the main parameters susceptible of inducing impacts.
    b. Percent of fish that successfully navigate the migration corridor.
    c. Densities: Multi-species and multi-life stages (adults, young-of-the-year and older juveniles).

14. Determine likelihood of success of compensation (based on documented success).
    a. In recent years, studies on the potential habitat destruction caused by compensation activities are emerging in the literature. However, the impacts on fish habitats are influenced by the selected compensation technique and specific environmental conditions. The potential impacts of the compensation measures are therefore site or region specific and the likelihood of success is frequently unknown.

b. In the past, compensation measures have principally been designed to provide passage for salmonids (strong swimmers). However, several compensation techniques remained untested and it is generally unknown if other species (commercial and non-game species) can successfully navigate the restored migration corridor. Although passage efficiency for some species is relatively well documented, the success of using a multi-species approach is generally unknown for most projects conducted to restore migration corridor.

c. Passage efficiency is generally determined based on the percent of fish that successfully navigate a migration corridor. However, the ultimate measure of success is the colonization rate (production of juvenile fish or young-of-the-year, adult spawning) in the newly accessible habitats. Therefore, the likelihood of success will depend on fish (genitors) passage efficiency but also on habitat quality and availability which influence the production of juvenile fish.

15. Define metrics / indicators for monitoring (direct and indirect, linked to scale).

The effectiveness of measures to restore migration corridors depend on the type of measures used and the environmental conditions. Compensation projects could be classified into categories and the effectiveness could be determined based on a subset of study cases from each category. The indicators that should be considered are:

a. Potential impact parameters:
Indicator: Threshold from the literature and monitoring in the field.

b. Passage efficiency. Multi-species approach but selection of an indicator species:
Indicator: Species with the lowest swimming capacity (fine scale).

c. Fish dispersal above the former obstruction and the production of juvenile fish (multi-species approach; broad scale).
Indicator: Fish densities.

d. Quality and availability of the newly accessible habitats (spawning grounds and nursery, rearing, and food supply areas).
Indicator: Physical parameters that influence fish survival in different habitats (See indicators described in previous sections).

16. Monitoring design decision (reference site, control, sampling intensity, sample size, duration, etc.).

a. Telemetry (preferred) or mark and recapture experiments.
b. Before and after study design.
c. Comparison of habitat quality and availability below and above the former obstruction and regional comparisons.
d. Comparison of fish densities (multi-species and multi-life stages) below and above the former obstruction and regional comparisons.
e. Modelling. Use of physical (habitat) parameters to infer survival of juvenile fishes (e.g., determination of percent of fine in the substrate to predict percent emergence of embryos).

17. Establish appropriate durations (timescale) for monitoring:

a. Passage efficiency,
b. Potential habitat loss and colonization of the newly accessible habitats.

18. Proponent reporting.

SOURCES OF INFORMATION

This Science Advisory Report is from the Fisheries and Oceans Canada, Canadian Science Advisory Secretariat, National Advisory Meeting, December 6-8, 2011, at Ottawa, ON regarding *Monitoring Design and Metrics to Assess the Effectiveness of Habitat Compensation Activities*. Additional publications from this process will be posted as they become available on the DFO Science Advisory Schedule at http://www.dfo-mpo.gc.ca/csas-sccs/index-eng.htm.

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