Assessing the Effectiveness of Habitat Offset Activities in Canada: Monitoring Design and Metrics.

Karen E. Smokorowski[1], Michael J. Bradford[2], Keith D. Clarke[3], Marie Clément[4], Robert S. Gregory[3], Robert G. Randall[5]

[1]Great Lakes Laboratory for Fisheries and Aquatic Sciences, Fisheries and Oceans Canada, Sault Ste. Marie, ON
[2]Fisheries and Oceans Canada and School of Resource and Environmental Management, Simon Fraser University, Burnaby BC
[3]Northwest Atlantic Fisheries Center, Science Branch, Fisheries and Oceans Canada, St. John's, NL
[4] Gulf Fisheries Centre, Fisheries and Oceans Canada, Moncton, NB. Current address: Fisheries and Marine Institute in partnership with the Labrador Institute, Memorial University of Newfoundland, Happy Valley - Goose Bay, NL
[5]Great Lakes Laboratory for Fisheries and Aquatic Sciences, Fisheries and Oceans Canada, Burlington, ON

2015

Canadian Technical Report of Fisheries and Aquatic Sciences 3132

Fisheries and Oceans Canada   Pêches et Océans Canada

Canada

Canadian Technical Report of Fisheries and Aquatic Sciences

Technical reports contain scientific and technical information that contributes to existing knowledge but which is not normally appropriate for primary literature. Technical reports are directed primarily toward a worldwide audience and have an international distribution. No restriction is placed on subject matter and the series reflects the broad interests and policies of Fisheries and Oceans Canada, namely, fisheries and aquatic sciences.

Technical reports may be cited as full publications. The correct citation appears above the abstract of each report. Each report is abstracted in the data base *Aquatic Sciences and Fisheries Abstracts*.

Technical reports are produced regionally but are numbered nationally. Requests for individual reports will be filled by the issuing establishment listed on the front cover and title page.

Numbers 1-456 in this series were issued as Technical Reports of the Fisheries Research Board of Canada. Numbers 457-714 were issued as Department of the Environment, Fisheries and Marine Service, Research and Development Directorate Technical Reports. Numbers 715-924 were issued as Department of Fisheries and Environment, Fisheries and Marine Service Technical Reports. The current series name was changed with report number 925.

Rapport technique canadien des sciences halieutiques et aquatiques

Les rapports techniques contiennent des renseignements scientifiques et techniques qui constituent une contribution aux connaissances actuelles, mais qui ne sont pas normalement appropriés pour la publication dans un journal scientifique. Les rapports techniques sont destinés essentiellement à un public international et ils sont distribués à cet échelon. II n'y a aucune restriction quant au sujet; de fait, la série reflète la vaste gamme des intérêts et des politiques de Pêches et Océans Canada, c'est-à-dire les sciences halieutiques et aquatiques.

Les rapports techniques peuvent être cités comme des publications à part entière. Le titre exact figure au-dessus du résumé de chaque rapport. Les rapports techniques sont résumés dans la base de données *Résumés des sciences aquatiques et halieutiques.*

Les rapports techniques sont produits à l'échelon régional, mais numérotés à l'échelon national. Les demandes de rapports seront satisfaites par l'établissement auteur dont le nom figure sur la couverture et la page du titre.

Les numéros 1 à 456 de cette série ont été publiés à titre de Rapports techniques de l'Office des recherches sur les pêcheries du Canada. Les numéros 457 à 714 sont parus à titre de Rapports techniques de la Direction générale de la recherche et du développement, Service des pêches et de la mer, ministère de l'Environnement. Les numéros 715 à 924 ont été publiés à titre de Rapports techniques du Service des pêches et de la mer, ministère des Pêches et de l'Environnement. Le nom actuel de la série a été établi lors de la parution du numéro 925.

Canadian Technical Report of

Fisheries and Aquatic Sciences 3132

2015

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

by

Karen E. Smokorowski[1], Michael J. Bradford[2], Keith, D. Clarke[3], Marie Clément[4], Robert S. Gregory[3], Robert G. Randall[5]

[1]Great Lakes Laboratory for Fisheries and Aquatic Sciences
Fisheries and Oceans Canada, Sault Ste. Marie, ON

[2]Fisheries and Oceans Canada and School of Resource and Environmental Management, Simon Fraser University, Burnaby BC

[3]Northwest Atlantic Fisheries Center Science Branch
Fisheries and Oceans Canada, St. John’s, NL

[4] Gulf Fisheries Centre, Fisheries and Oceans Canada, Moncton, NB.
Current address: Fisheries and Marine Institute in partnership with the Labrador Institute, Memorial University of Newfoundland, Happy Valley - Goose Bay, NL

[5]Great Lakes Laboratory for Fisheries and Aquatic Sciences
Fisheries and Oceans Canada, Burlington, ON

Cat. No. Fs97-6/3132E-PDF, ISBN 978-0-660-02331-1, ISSN 1488-5379

Correct citation for this publication:

Smokorowski, K.E., Bradford, M.J., Clarke, K.D., Clément, M., Gregory, R.S., Randall, R.G. 2015. Assessing the effectiveness of habitat offset activities in Canada: Monitoring design and metrics. Can. Tech. Rep. Fish. Aquat. Sci. 3132: vi + 48 p.

TABLE OF CONTENTS

ABSTRACT

Smokorowski, K.E., Bradford, M.J., Clarke, K.D., Clément, M., Gregory, R.S., Randall, R.G. 2015. Assessing the effectiveness of habitat offset activities in Canada: Monitoring design and metrics. Can. Tech. Rep. Fish. Aquat. Sci. 3132: vi + 48 p.

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 2012 amendments to the *Fisheries Act* require the focus of this monitoring program for offsetting activities now be adjusted according to the new Fisheries Protection Provisions. The metrics for *effectiveness* monitoring should measure fisheries productivity or an appropriate surrogate of productivity. Three hierarchical levels of monitoring are briefly described (compliance, functional, and *effectiveness* monitoring) but the focus of this report is on *effectiveness* monitoring. The *Fisheries Act* definition of fish habitat (i.e., spawning grounds and any other areas including nursery, rearing, food supply, and migration areas on which fish depend directly or indirectly to carry out their life processes) is used to provide a framework for the design of *effectiveness* monitoring programs based on habitat type. The importance of collecting consistent, comparable data that allow a number of project-level assessments to be statistically assessed and compared, improving our understanding of the effectiveness of the various offsetting strategies, is highlighted. The goal for each section is to be comprehensive enough to provide practitioners and proponents with guidelines for quantitative *effectiveness* monitoring, but will use references as appropriate (e.g., for detailed descriptions of methods) to keep the advice brief. A *monitoring report summary* should be included at the beginning of each monitoring report (a template should be provided by the DFO Fisheries Protection Program) and include key points of information to facilitate digital capture of the data allowing a formal review (meta-analysis) of projects on a cyclical basis (circa every five years by DFO Science). Such analyses could lead to the long-term improvement of offsetting plans and monitoring design for the ultimate benefit of fisheries productivity and sustainable aquatic ecosystems in Canada.

RÉSUMÉ

Smokorowski, K. E., Bradford, M. J., Clarke, K. D., Clément, M., Gregory, R. S. et R. G. Randall. 2015. Évaluation de l'efficacité des activités de compensation de l'habitat du poisson au Canada : conception et paramètres des programmes de surveillance Rapp. tech. can. sci. halieut. aquat. 3132: vi + 48 p.

En décembre 2011, le MPO a tenu un processus d'avis scientifique afin d'examiner la faisabilité de concevoir une approche de surveillance normalisée afin de vérifier l'efficacité des activités de compensation de l'habitat pour faire en sorte « qu'il n'y ait aucune perte nette de la capacité de production de l'habitat du poisson », ce que la politique prescrivait à cette époque. Les modifications apportées à la Loi sur les pêches en 2012 exigent que l'accent mis sur les activités de compensation par ce programme de surveillance soit maintenant ajusté d'après les nouvelles dispositions de protection des pêches. Les paramètres pour surveiller l'*efficacité* devraient mesurer la productivité des pêches ou un autre indicateur de productivité approprié. Trois niveaux de surveillance hiérarchiques sont brièvement décrits (surveillance de la conformité, de la fonctionnalité et de l'*efficacité*), mais le présent avis s'intéresse surtout à la surveillance de l'*efficacité*. La définition de l'habitat du poisson dans la *Loi sur les pêches* (c.-à-d. toute aire dont dépend, directement ou indirectement, la survie du poisson, notamment les frayères, les aires d'alevinage, de croissance ou d'alimentation et les routes migratoires) sert de cadre pour la conception des programmes de surveillance de l'*efficacité* selon le type d'habitat. On souligne l'importance de recueillir des données comparables de manière uniforme qui se prêtent à plusieurs évaluations au niveau des projets et qui peuvent être analysées et comparées pour améliorer notre compréhension de l'efficacité des différentes stratégies de compensation. Le but de chaque section est d'être assez exhaustive pour fournir aux praticiens et aux promoteurs des lignes directrices en vue de la surveillance quantitative de l'*efficacité*, mais des références seront utilisées si cela est approprié (p. ex., pour la description détaillée des méthodes), pour que les avis demeurent brefs. Il faudrait inclure un *sommaire du rapport de surveillance* au début de chaque rapport de surveillance (un modèle devrait être fourni par le Programme de protection des pêches du MPO) et y inclure les éléments d'information clés afin de faciliter la saisie numérique des données pour permettre un examen officiel (méta-analyse) cyclique des projets (environ tous les cinq ans, par le Secteur des sciences du MPO). De telles analyses pourraient mener à une amélioration à long terme des plans de compensation et de la conception de la surveillance, et ce, au profit de la productivité des pêches et de la durabilité des écosystèmes aquatiques au Canada.

1 INTRODUCTION

In December 2011 DFO held a science advisory process to examine the feasibility of designing a standardized monitoring approach (and associated metrics) to determine the effectiveness of habitat compensation activities in achieving the fish habitat conservation goal of DFO's Policy for the Management of Fish Habitat (1986). The Science Advisory Report (SAR) produced from this workshop was published and is available online at http://www.dfo-mpo.gc.ca/csas-sccs/Publications/SAR-AS/2012/2012_060-eng.pdf (henceforth referred to as the SAR, DFO 2012). One of the conclusions of the workshop was that a comprehensive program needed to be developed to help guide practitioners and proponents when monitoring the effectiveness of compensation habitat was required under the terms of a *Fisheries Act* authorization. In the SAR, the intent of the advice proposed for monitoring was to compare standardized data from the impact site (e.g., quantification of a "harmful alteration, disruption or destruction (HADD) of fish habitat", Section 35 of the pre-2012 *Fisheries Act*) as compared to the related compensation activity, with the goal of the monitoring to assess if the project achieved 'No Net Loss of the productive capacity of fish habitat' as was the policy at that time (DFO 1986). As the workshop was held prior to the changes in the *Fisheries Act* (amendments received Royal Assent on June 29, 2012), the advice was couched in the language and process of the old act, some of which is no longer applicable. For example, the term 'compensation', used in documents published prior to June 2012 (including the SAR), is now referred to as 'offsetting', which is used throughout all new science advice to the Fisheries Protection Program, including this report.

Three hierarchical levels of monitoring were described in the SAR: *compliance*, *functional*, and *effectiveness* monitoring. *Compliance monitoring* was described as an operational activity conducted by either DFO Habitat Management or Compliance and Enforcement staff. It was used to determine whether the terms and conditions prescribed under a *Fisheries Act* authorization were implemented. *Functional* monitoring was described as a scaled-down assessment of habitat offsetting effectiveness. It was quantitative, but relied 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).

This report will focus on *effectiveness* monitoring, which was described as the most rigorous, science-based monitoring, requiring a standardized, transferable design. The new *Fisheries Act* requires that the focus of this monitoring program now be adjusted according to the new Fisheries Protection Provisions. The metrics for *effectiveness* monitoring should measure fisheries productivity or an appropriate surrogate of productivity (Bradford et al. 2014). *Effectiveness* monitoring is particularly important for complex projects expected to have a large impact on fisheries productivity.

Amendments to the *Fisheries Act* have sharpened the focus of assessment to protecting the productivity of commercial, recreational, and Aboriginal (CRA) fisheries. The new prohibition (Section 35(1)) reads that “no person shall carry on any work, undertaking or activity that results in serious harm to fish that are part of a commercial, recreational, or Aboriginal fishery, or to fish that support such a fishery” where ‘serious harm to fish’ is defined as “the death of fish or any permanent alteration to, or destruction of, fish habitat” (Table 1). If a proposed project is expected to cause ‘serious harm’ to fish, then the prohibition is triggered and factors under Section 6 need to be applied. Among those factors is 6(c), which stipulates that the Minister shall consider “whether there are measures and standards to avoid, mitigate or offset serious harm to fish that are part of a CRA fishery, or that support such a fishery”. Guidance related to offsetting serious harm under the Fisheries Protection Provisions of the *Fisheries Act* (2012) was reviewed at a CSAS workshop held June 2013 (DFO 2013a, Loughlin and Clarke 2014). Options reviewed include those traditionally considered ‘compensation’ under the 1986 Policy, such as habitat creation (e.g., creation or expansion of artificial stream channels, artificial lakes, side channel habitats, and wetlands) or physical habitat manipulation (e.g., increasing structure through the placement of coarse material or woody debris, increased shoreline complexity, river bank stabilization, and channel complexing or improving access to off-channel habitats, and the removal of natural or anthropogenic barriers to migration). These types of offsetting activities will be the focus of this report.

Throughout this report we refer to the importance of reaching quantitative targets (or endpoints) to establish the effectiveness of the offsetting activity, and these targets are straightforward when ‘in kind’ habitat is created (i.e., like-for-like offset targeting the species and life stage impacted by the development). However, these targets become more complex if an ‘out of kind’ habitat is created, targeting a different species or life stage by creating different habitat than was affected by the development activity. Such measures of success should be identified in the offsetting plan (DFO 2013b) and will direct the development of the monitoring program.

Table 1: Definition of key terms used in the Fisheries Act (2012) and by previous DFO Science advice to the Fisheries Protection Program via the Canadian Science Advisory Secretariat Processes.

Term	Definition	Source
Habitat	Spawning grounds and any 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.	Fisheries Act, 2012.
Serious Harm	The death of fish or any permanent alteration to, or destruction of, fish habitat.	Fisheries Act, 2012.
System type	Lake, river, stream, estuary or other major category of waterbody that affects the nature of the habitat types and measurements that need to be taken to evaluate the habitat.	This report.
Metric	Metrics are used to evaluate change. 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
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.
Indicator	Indicators are more general quantities used to evaluate changes in fisheries productivity. Indicators may be comprised of one or more quantitative metrics, or may be more qualitative in nature (cf. “% change in LWD”, “loss of structure”).	Bradford et al. 2014.
Carrying Capacity	The maximum number of individuals in a population that the resources of a habitat can support.	Ricklefs 1990.
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.
Ongoing Productivity	Ongoing is interpreted as being sustained productivity, as experienced by participants in the fishery at and just before the time of interest.	Randall et al. 2013.

The definition of ‘habitat’ in the amended *Fisheries Act* (Section 34) (Table 1) has not changed substantially from the previous version, and was used to provide a framework for the design of *effectiveness* monitoring programs based on habitat type. The SAR characterized the critical components of an *effectiveness* monitoring program in the format of a Table of Contents (Appendix A, 19 steps total), which was used to guide the development of each chapter by habitat-type, starting with step #11, which is where offsetting monitoring commences. For clarity the seven steps of monitoring (steps #11-17) recommended in the SAR are listed below. However, for the sake of being comprehensive, we outlined the initial steps for evaluating offsetting measures to ensure all steps are identified and to put the monitoring into context (Appendix A). In light of the changes to the *Fisheries Act*, these initial steps should be modified to reflect the new focus on fisheries productivity as opposed to habitat productive capacity, but those modifications will not be addressed in this report. The Fisheries Productivity Investment Policy: A Proponent’s Guide to Offsetting provides a direction to proponents for developing an offsetting plan (DFO 2013b).

The scientific literature contains numerous examples of monitoring plans, but two in particular are relevant to the *effectiveness* monitoring program of DFO’s Fisheries Protection Program and are similar to the approach advocated here. Souchon et al. (2008) proposed a general design template to detect biological responses to flow management decisions over long time periods. They advocate that the use of their template should result in more certainty in decision making, more efficient use of resources, and reduced administrative costs. Essential to the success of the framework is to include a central reporting mechanism, which would improve communication and long-term decision making. Their nine step framework includes:

1. Establish monitoring goals and project objectives; determine the questions of interest;
2. Create specific hypotheses to test linkages between variables;
3. Determine response variables, methods, metrics, and keystone species;
4. Determine appropriate time scales for responses (i.e., appropriate monitoring timescale to detect a response in fish);
5. Consider regulatory requirements and incorporate these into study;
6. Design the study;
7. Implement the study;
8. Analyse data and report results;
9. Allow for adaptive management.

Similarly, in a report produced by the DFO Pacific Region on monitoring for effectiveness of fish habitat compensation projects, Pearson et al. (2005) outlined detailed steps required that would be the equivalent of *compliance* monitoring and *effectiveness* monitoring, as described in the SAR, combined. To illustrate the similarity to the steps recommended in the SAR, an adaptation of Table 5 from Pearson et al. (2005) has been recreated below (Table 2). Table 2 is shown here as an illustration of other advice on monitoring that has been provided within DFO independent of the advice provided in this report. However, since the advice contained in the SAR (that was peer-reviewed in the CSAS workshop) differed in some cases, content of Table 2 will be different from what is recommended in this report. Terms used in Table 2 were also not updated to reflect the amended Fisheries Act since Pearson et al. (2005) was written prior to 2012.

Table 2: Summary of design objectives and methods for *effectiveness* monitoring, adapted from Table 5, Pearson et al. (2005). Content is provided as an example of past advice on monitoring within DFO, prior to the changes in the Fisheries Act, and is not intended to be considered specific recommendations arising from the SAR that spurred the creation of this report.

	Description
Objective 1	***To verify that the project was implemented as designed and approved***
As-Built Survey	Direct comparison with approved design of project configuration, materials, structural integrity, and area (by habitat type), using rigorous topographic survey methods and photography.
Post-project Surveys	Same methods used as in as-built survey. Recommended for years 2, 5 and 10 in post-construction monitoring period
Objective 2	***To quantify the net change in habitat productive capacity***
Approach	Multi-metric approach to assessing habitat productive capacity that includes a broad range of surrogate variables including measures of physical habitat, biological production (e.g. biomass) at a range of trophic levels, and individual measures of fitness (e.g. fish growth and condition)
Experimental design	BACIP (before-after-control-impact-paired) • Surrogate variables for productive capacity measured at project and control sites before and after project implementation
Control sites	• One local control for variables involving fish (to correct for movement effects) • Two distant controls as insurance in case of difficulties with one
Monitoring duration	• Two years of pre-project monitoring (minimum one year) • 10 years of post-project monitoring

Monitoring frequency	• Pulsed in three periods of two years each (1 and 2, 5 and 6, 9 and 10) • Sampled three times per monitoring year for most variables (once per year for riparian vegetation)
Typical variables	Physical • water temperature • water quantity (area, hydrograph) • water quality (dissolved oxygen, BOD, nutrients, contaminants) Biological • primary production (e.g. periphyton density and diversity, eelgrass density) • secondary production (e.g. macroinvertebrate density and diversity) • tertiary production (e.g. fish abundance, density and production by species and life stage, fish growth and condition)
Data analysis	Three Welsh T-tests per variable. Tests compare differences between control and project sites before construction with differences in the immediate (1-2 yr), short (5-6 yr) and medium (9-10 yr) terms.

Both above-noted references provide valuable details on each step of their framework and should be consulted for clarification as required. As stated in the SAR, the monitoring plan should be a component of a broader monitoring framework used by DFO to evaluate program effectiveness. It is worth reiterating that monitoring programs should be designed to assess effectiveness of offsetting at meeting success criteria (biological targets) and ultimately to determine if the offsetting activity is ecologically stable and self-sustaining. The monitoring plan should include clearly articulated measures of success that are linked to the objective of the offsets and that provide benchmarks for measuring progress. Another important objective for monitoring is to learn what offsetting activity works and what doesn't. Thus, monitoring would provide feedback that could be used to modify management actions related to an adaptive management plan. However, this feedback is only useful if it reaches the front-line biologists in the program, requiring a standardized reporting format that will easily allow transfer of essential information into a central database. These overarching goals should be kept in the forefront of the monitoring program design. The seven steps advocated in the SAR as part of a comprehensive *effectiveness* monitoring program are as follows:

1. 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 (spawning, nursery, rearing, food supply, and migration habitats).

2. Establish science-based, quantitative targets to evaluate achievement of offsetting goals. For example, as based on regional benchmarks for productivity or based on pre-impact data collected at the site of impact and/or a reference site.

3. Determine likelihood of success of offsetting (based on documented success):
    a. Where uncertainty of offsetting success is high, use a higher frequency/intensity of monitoring; more offsetting.
    b. Where uncertainty of offsetting success is low, use a lower frequency/intensity of monitoring.

4. Define metrics for monitoring (direct and indirect, linked to scale). Metrics should be the same used in the characterization of the baseline data (see step #1, Appendix A).

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

6. Determine appropriate duration for monitoring (both pre- and post-offsetting activity).

7. Proponent reporting (in a standardized format, which can be incorporated into a common, shared database).

Where Pearson et al. (2005) provide a generic monitoring framework for all habitat types and focused on assessing compensation for lost habitat productive capacity (thus, a more ecosystem level approach), we will be more specific in providing monitoring guidance for different habitats, allowing more targeted recommendations on metrics and design. A common theme among these monitoring guidance publications is the importance of collecting consistent, comparable data that would allow a number of project-level assessments to be statistically assessed and compared, improving understanding of the effectiveness of the various offsetting strategies. Following a standardized approach will improve the Fisheries Protection Program’s ability to both assess success of individual offsetting projects, but will also allow the assessment of program success, should Fisheries and Oceans Canada seek to conduct an assessment. As highlighted above, this report is not the first to provide recommendations on the quantification of effectiveness of management activities, and valuable guidance can be gleaned elsewhere.

This report will follow the seven steps listed above providing practical guidance for *effectiveness* monitoring of offsetting serious harm for DFO's new Fisheries Protection Program on a national scale. Habitat types covered include spawning, nursery, rearing, food supply, and migration areas. If more than one habitat type is created via offsetting activities, recommendations should be complementary enough to combine strategies but include multiple metrics and targets to gauge success. The goal for each section is to be comprehensive enough to provide practitioners and proponents with a methodology for quantitative *effectiveness* monitoring, but will use references as appropriate (e.g., for detailed descriptions of methods) to keep this report brief. The proponent reporting section (step #7) is common to all habitat types and can be found at the end of this report.

2 SPAWNING HABITAT

Spawning habitat is defined as habitat that provides the environmental conditions necessary for successful spawning. While all fish habitat types as defined in the *Fisheries Act* are essential to complete their life processes, spawning habitat is often considered the most critical since many fishes are selective about where and when they spawn (Balon 1975; Præbel et al. 2009) and availability of specific habitat features, at particular times, can be limited. Spawning habitat is well studied, partially because of the reduced mobility of early life stages, and relative ease in observing spawning and early development *in situ* in many freshwater (Fitzsimons 2014) and marine ecosystems (Kornfield et al. 1982). Considering the local and specific nature of spawning habitat for a number of species, it is also one of the more frequently considered habitat types when negotiating restoration or creation of habitat for offsetting simply because it is often smaller in area, may be easier to define and thus create. Whether or not spawning habitat is in fact limited or whether its creation contributed to increased recruitment is rarely assessed (Minns et al. 1996).

Spawning habitat requirements for a number of species are well known and include well defined parameters such as substrate composition, cover, depth, water quality, velocity, salinity/conductivity, oxygen concentration, etc. (e.g., Bjorrn and Reiser 1991, Miller et al. 1991, Lane et al. 1996). Spawning habitat has a direct and obvious link to fisheries productivity since the number of spawners and success of their progeny can depend on the quality and quantity of available spawning habitat. Furthermore, the importance of early life stage survival to population abundance and fisheries has been well documented (Kelso and Rutherford 1996). For a number of well-studied fishery species, mainly salmonids in a variety of regions in Canada, productivity can be directly estimated by achieving target egg deposition levels per area of appropriate habitat (Levy and Slaney 1993; DFO and MNRF 2008).

Successful incubation of embryos and emergence of young-of-the-year depend on habitat characteristics as described above, and on additional factors, including temperature, dissolved oxygen, biological oxygen demand in proximity to the eggs, channel gradient, discharge, velocity, depth, permeability and porosity of substrate (Bjorrn and Reiser 1991). Both selection of the offsetting habitat by adult spawners and successful incubation of embryos to emergence are required for the habitat to be considered effective. Here we provide technical guidance for monitoring design to assess effectiveness of habitat offsetting in/to fish spawning grounds.

2.1 SUCCESS CRITERIA

Success criteria of offsetting for spawning habitat would include both compliance and effectiveness components:

- Compliance aspects include a quantitative evaluation of habitat replacement ratio (i.e., m^2 loss/changed vs. m^2 gained). Ratio must meet negotiated target, which is often greater than 1:1 to allow for the delay in becoming functional habitat and uncertainty that the offset will be successful.
- Compliance must also include evidence that the created habitat is stable and would withstand extreme weather events (storms, water discharge and levels, droughts).
- At the site-scale effectiveness must evaluate if the spawning habitat is performing as intended, what level of spawning success has been achieved against quantitative targets. Habitat offset needs to be self-sustaining.
- Targets to be established prior to monitoring (see below).

2.2 TARGETS

Quantitative targets must be established prior to monitoring and are to be science based, with levels set from historical data from the site (if available), reference data from proximate natural habitats (could be a control site in another system) or from regional benchmarks. Deviation from a reference condition or regional benchmark is likely to be best measured using non-parametric ranges (e.g., interquartile range).

- Presence/absence of eggs or larvae can confirm the use of the habitat (qualitative), but quantitative assessment is necessary to establish effectiveness, assuming the goals of the habitat offset include effectiveness assessment.

Presence of adult spawners in the proximity of the offset spawning habitat does not confirm use of the habitat for spawning.

- Egg incubation is often used to assess the quality of the habitat via determining egg survival in spawning redds (e.g., Merz et al. 2004; Palm et al. 2007) and capelin spawning beaches (e.g., Nakashima and Taggart 2002).
- Juvenile recruitment or year-class strength can also be an appropriate method to assess the effectiveness of the spawning habitat in some instances where they can be associated with specific spawning locations.
- This category may be less applicable for marine environments if spawning areas are not geographically specific areas (especially for pelagic species). In this case, quantitative sampling is possible using active gears (e.g., high speed plankton nets), but using spawning habitat as an offset may be less appropriate.

2.3 LIKELIHOOD OF SUCCESS

Spawning habitat is frequently created for offsetting habitat loss in freshwater ecosystems. Some of the reasons for this high frequency include: 1) its loss may be the cause of the offsetting requirement (loss of spawning habitat is usually considered high risk/serious); 2) it is often perceived to be limiting; 3) more is thought to be known about the spawning habitat requirements for a number of valued fish species; and/or 4) the area required for creating spawning habitat is usually smaller than for other life stages. However, despite the frequency of spawning habitat creation (or rehabilitation), thorough *effectiveness* monitoring is not often conducted and great uncertainty remains about the effectiveness of spawning habitat restoration (Roni et al. 2002). This lack of knowledge was addressed in a 2003 American Fisheries Society Symposium that resulted in the publication of a book highlighting the state of knowledge and deficiencies for riverine salmonid spawning habitat restoration (Sear and DeVries 2008). In marine ecosystems, knowledge of the effects of improvements to spawning habitat is virtually absent.

The likelihood of success of the offsetting must be based on other documented successes. For better studied species such as sturgeon (e.g., Dumont et al. 2011) or salmonids (e.g., House 1996; Fitzsimons 1996, 2014; Merz et al. 2004; Palm et al. 2007), there will likely be greater certainty than for other species. Where offsetting success is previously unknown, the level of uncertainty will be difficult to assess *a priori*. The greater the uncertainty is, the greater the offsetting ratio and intensity of monitoring that is required.

2.4 METRICS AND INDICATORS FOR MONITORING EFFECTIVENESS

For *effectiveness* monitoring, it is essential that quantitative data be collected on both the physical and biological aspects of the spawning habitat. Depending on the goals of monitoring, a hierarchy of metrics should be collected. Table 3 from Pearson et al. (2005) provides a list of useful references that detail sampling methodologies organized by category (physical, chemical, biological) and system type (stream, river, lake, estuarine and marine).

Data collection activities include:

- Measure the area of the spawning habitat, geospatially referenced (m^2), including areas both directly and indirectly impacted.
- Characterize suitable substrate (substrate type including vegetation, particle size, substrate stability, embeddedness, etc.)
- Characterize other relevant physical variables including depth (range based on normal water level fluctuations), water velocity, and cover, exposure (fetch) or other relevant physical descriptors.
- Ultimately, the production of emergent/hatched fish(es) or density of young-of-the-year (YOY) fish(es) should be the biological variable to verify the effectiveness of the offset habitat. Egg density will confirm use of the habitat, but not necessarily its success if the environment is not conducive for survival to emergence.
- Spawning habitat is traditionally assessed in a variety of ways, including measures of egg density (using egg mats, egg traps or other egg-capture substrates), larval emergence (lakes) or larval drift (streams/rivers). Appropriate media (e.g., type of egg mat/trap, type of larval capture net/trap, pumps, etc.) is species and habitat dependent. Kelso and Rutherford (1996) and Bagenal and Nellen (1980) provide a review of egg and larvae sampling techniques for different species under different circumstances. Balon (1975) provides information on fish reproduction, which could help guide collection methods, gear types, and sampling periodicity depending on species expected to use the offset habitat. In some marine demersal spawning species (e.g., capelin – Nakashima and Taggart 2002, herring - Haegele and Schweigert 1985), similar approaches may be suitable.

Data that may need to be collected depending on results of the above data collection:

- If the biological endpoints (quantitative targets) have been met (e.g., emergent/hatched fish), the collection of metrics has been satisfied. Periodic resampling of above metrics will be required according to an agreed-upon temporal scheme; if biological endpoints have not been met, then proceed with collection of mechanistic information ("why did the offsetting plan fail?").

- Temperature can be the reason for recruitment failure (for range of functional site requirements of species).
- Dissolved oxygen can be another reason for low egg survival rates. Both surface and hyporheic (within the substrate) oxygen levels should be measured, for relevant species (e.g., salmonid, and some other freshwater forms).
- Other water quality variables can be collected as appropriate for the site.

2.5 MONITORING DESIGN

The monitoring design for assessing effectiveness of spawning habitat would include the selection of an appropriate reference site or control (or use of regional benchmark if established), sampling intensity, sample size, and duration.

- Baseline data for project and offsetting assessments should be collected using metrics similar to those that will be used for *effectiveness* monitoring.
- Establish reference condition[1] (*sensu* Stoddard et al. 2006) and control site(s) as appropriate using as many of the following options as are practical:

    - "Before" data from the impacted habitat, and/or
    - Regional standard/benchmark (Randall et al. 2013) based on spatial and historical data from the region, and/or
    - Historic data (availability will be site specific), and/or
    - Data from a reference or control site, and/or
    - Modelling.

- A properly implemented Before-After Control-Impact design (BACI) is still considered the best for environmental monitoring and is suitable in projects incorporating 'before' data and data from reference or control site(s) (Underwood 1991; Stewart-Oaten and Bence 2001). If only one of either 'before' or 'reference' data are available, using a Before-After *or* Control-Impact design is also possible, but these designs are suboptimal and will deliver less certainty in the results.
- When using regional benchmark data, sufficient data are required to establish isopleths of productivity for different geographic regions, and could be partitioned among habitat types using science-based suitability indices (Randall et al. 2013).

[1] In this report, reference condition is for productivity. Development of the reference condition approach for offsetting and FPP is ongoing.

- Historic data need to be of adequate duration to establish a range of variability and estimate carrying capacity.

2.6 ESTABLISH APPROPRIATE DURATIONS (TIMESCALE) FOR MONITORING

A review of 345 articles that examined the effectiveness of various habitat rehabilitation techniques found that firm conclusions were elusive due to lack of information, resulting mainly from short term studies of limited scope (Roni et al. 2008). They identified three major needs related to effectiveness monitoring and evaluation: 1) long-term evaluation, 2) watershed or broad-scale monitoring, and 3) consistent metrics. In keeping with these recommendations, we outline a rigorous, long-term monitoring program that is expected to capture variability, consider the life cycle of valued species, and the specific project details. When a project is expected to alter habitat conditions, (e.g., siltation/infilling, flow change, and other local conditions) it may take years or decades before a change in biota is evident (Roni et al. 2008), and a longer term (i.e., >10 years) monitoring program may be required.

The duration of monitoring must capture inter-annual variability or the monitoring program risks not being able to distinguish project effects from natural variability. One year of sampling is not adequate to provide any estimate of variability, two years of sampling are not adequate to generate a mean with valid error, therefore a minimum of three years of sampling are required, regardless of the type of data used (i.e., before data, historical data, benchmarks, control sites, etc.). The period of post-impact sampling should also consider the life cycle of the target fish species. These timelines will be project, region, and ecosystem specific.

For spawning habitat, the seasonal timing of sampling depends on the species and habitat, but should aim to capture the spawning season, incubation time, and emergence, depending on the selected biological metric.

Therefore we recommend:

- Three years before development at the impact site to establish baseline;
- Three years sampling immediately post-change;
- An additional 3 years of sampling at a later time (e.g., four to six years post or some later time); and,
- A revisit ten years after project impact to capture longer-term changes to the site.

3 NURSERY HABITAT

Habitat that provides better than average conditions for larval and young-of-the-year fish to grow and survive to the next life stage is often referred to as nursery habitat (Beck et al. 2001). Nursery habitat and its function in determining potential productivity apply to most ecosystem types. The duration to which a species will utilize nursery habitat is species-specific but generally it is most important during the first year of life (e.g., post-emergence for salmonids, post-settlement for decapod crustaceans and demersal marine groundfish species with pelagic life stages). Nursery habitat has been shown to play a substantive role in the productivity of fish populations in a wide variety of ecosystems (e.g. Jurajda 1999, Seitz et al. 2014). In general, nursery habitat tends to be in highly productive areas within the aquatic landscape such as deltas, wetlands, seagrass beds, marshes, etc. that allow for increased juvenile density and growth due to warm temperatures and high prey concentrations. Nursery habitat is also often structurally complex and provides cover for juveniles from larger aquatic and terrestrial predators and thus increases their chances of survival. Nursery habitat can overlap spatially and, in some cases, temporally with spawning or rearing habitat, depending on the species and its specific life history constraints.

While growth and survival are important, the main role of nursery habitat from a fisheries productivity perspective is to provide a better than average contribution to recruitment to the subsequent life stage. Therefore, connectivity of a nursery habitat to both a source of juveniles and to sub-adult and adult habitat is of utmost importance as it is often essential to fish population survival. Some species have nursery habitat adjacent to spawning habitat (e.g., Pink Salmon, Thedinga et al. 2000), but others spawn pelagic eggs or produce larvae and juveniles, which may be transported to nursery habitat 10's to 100s of kilometers away by natural processes of wind and current (e.g., some Fraser River Chinook Salmon populations, Levings et al. 1995; Bluefish, Juanes and Conover 1995; and Atlantic cod, Bradbury et al. 2008). Offsetting plans involving nursery habitat tend to focus on restoring previously degraded habitat known to have served this function in the past (e.g., restoration of eelgrass habitat, Short et al. 2002).

3.1 SUCCESS CRITERIA

Success criteria of offsetting for nursery habitat may be project and species specific but would include both compliance and effectiveness components:

- Compliance will depend on project-specific details. However, often in nursery habitat offsets there will be a number of different physical works that could be constructed (e.g., substrate placement, flow manipulation, vegetation placement), which may be unique to the project. The stability of these physical works would likely become the main objectives for *compliance* monitoring.

- Compliance must also include evidence that the created habitat is stable and would withstand extreme weather events (e.g., storms, elevated discharge levels and water level surges, water drawdown rates and levels, and droughts).
- At the site-scale, effectiveness must evaluate the degree to which the nursery habitat is performing as intended or anticipated. Effectiveness evaluation should include some indication of the recruitment to the next life stage, which represents the functional aspects of the nursery habitat, not just its unit area. The nursery habitat offset should be self-sustaining and not require maintenance to fulfill its function in the long term.
- Targets should be established prior to monitoring (see below).

3.2 SCIENCE-BASED TARGETS TO EVALUATE EFFECTIVENESS

Quantitative targets must be established prior to monitoring and are to be science-based. Targets can be set from historical data from the site (preferred), if available, reference data from proximate natural habitats (e.g., control sites in other similar ecosystems [watershed, river/stream reach, lake/pond, coastal embayment]) or based upon relevant regional benchmarks.

- Nursery habitat has historically been more difficult to assess than spawning habitat, being more spatially extensive than the latter, which are comparatively better known, in both freshwater and marine systems. Temporally, nursery habitat may be occupied by larval and early juvenile life stages for short periods of time - a few days in pelagic species to periods of several months or years in slow growing, long-lived species. An assessment of post-hatch abundance taken together with measures of survival to subsequent life stages (e.g., juvenile or beyond) will be necessary to evaluate nursery function. Most methodology will be both regional and species-specific.

- Surrogates for nursery habitats could be defined for regionally determined habitat categories. In freshwater, these would include measures of stream riffles and runs, pools for streams; slow and fast flowing reaches for rivers; riparian structure, amount and ratio of benthic and pelagic areas for lakes and large riverine environments. In estuarine and marine coastal ecosystems, surrogates include the amount of tide channel habitat, extent of seagrass and marsh areas, and the complexity of seabed habitat (substrate, exposure, bathymetric diversity).

- Presence/absence of larvae and juveniles can confirm the use of the habitat (qualitative), but quantitative assessment is necessary to establish effectiveness in an offsetting context. Presence of adults in the vicinity does not always indicate use of such areas as nursery habitat. Early life stages often are not found in the same locations as adults of the same species, which are often cannibalistic in the absence of cover for larvae and juveniles.

- Regional and species-specific quantitative targets such as density of juvenile and adult fishes (i.e., inferred production) can be useful surrogates of nursery function.
- Targets based on reference condition, historical information, and regional benchmarks need to be established.
- Juvenile recruitment and cohort strength are appropriate methods to assess the effectiveness of the combined value of nursery and rearing habitat in many cases, where separating the two habitats is not possible or practical.
- Delimiting nursery habitat for pelagic species in the marine environment or large lake systems may often prove impractical. These are to a great extent, "open systems", not easy to delimit or effectively evaluate. In such cases, quantitative sampling is possible using active gears (e.g., high speed plankton nets) or large-mouthed trawls, but the ability to offset habitat loss in this category will be difficult in most instances.

3.3 LIKELIHOOD OF SUCCESS OF OFFSETTING

For nursery habitat, certainty of success of offsetting habitat loss is species and ecosystem dependent. Assuming open access to the habitat by juvenile fishes and the proximity to a source of progeny, likelihood of success is high for freshwater and most estuarine systems, particularly for well-studied species like salmonids and marine demersal species. Offsetting for true pelagic species (e.g., herring) will typically be difficult to attain but may be possible for pelagic species spawning demersal eggs (e.g., Capelin) and for demersal species producing pelagic eggs that will later ‘settle’ into nursery habitats (e.g., Atlantic Cod).

3.4 METRICS AND INDICATORS FOR MONITORING EFFECTIVENESS

For *effectiveness* monitoring, it is essential that quantitative data be collected on both the physical and biological aspects of the nursery habitat. Depending on the goals of monitoring, a hierarchy of metrics should be collected. Table 3 from Pearson et al. (2005) provides a list of useful references that detail sampling methodologies organized by category (physical, chemical, biological) and system type (stream, river, lake, estuarine and marine).

Data collection should include:

- Measure the area of the existing nursery habitat, geospatially referenced, including areas both directly and indirectly impacted (m^2),
- Measure proximity to known spawning and rearing habitats.
- Characterize suitable substrate (particle size, substrate stability) and vegetation in all nursery areas directly and indirectly affected by the project.
- Characterize other relevant physical variables including depth (range based on normal water level fluctuations), water velocity, cover, exposure (fetch) or other relevant physical measures appropriate for each system type (substrate, depth, cover, water velocity for fluvial, etc.)
- Measure physical and chemical variables that are key drivers of productivity (e.g., temperature, wind exposure for lake and marine shorelines, nutrient and oxygen concentrations, pH).
- Quantify nursery habitat lost in order to determine the area and habitat type needed to offset the planned impact, including a measure of uncertainty.
- Ultimately, the production of larval and juvenile fish (as appropriate to the species) should be the primary biological variable (e.g., for salmonids this would be density or abundance of young-of-the-year; for cod it would be the density or abundance of 1-year old individuals) to verify the effectiveness of the offset nursery habitat to fish production.

If the quantitative targets have been met (e.g., abundance or density of larvae or juvenile fish), the collection of metrics has been satisfied. Periodic resampling of above metrics will be required at accepted time-frames and schedules. However, in some circumstances, additional data that may need to be collected on fish metrics are:

- If biological endpoints have not been met, then mechanistic information will be required with the objective of determining why the offsetting plan failed. Why is the intended area not functioning as an effective nursery habitat?
- Abundance and biomass of larvae and juvenile fish per unit of offsetting area may be key variable. Consequently, potential metrics may include:

    - Fish density (number of fish per m^2) or at least catch per unit effort (CPUE).
    - Biomass (kilograms of fish per m^2) or at least biomass per unit effort.
- A verification of connectivity (physical and physiological) between nursery habitat and other required habitat types, especially in freshwater ecosystems.
- Non-habitat associated factors affecting fish abundance (e.g., exploitation of spawners affecting apparent recruitment and use of nursery habitat).
- Abiotic factors (e.g. temperature, dissolved oxygen etc.) potentially limiting abundance, as appropriate to the specific system type and region.

3.5 MONITORING DESIGN

The monitoring design for assessing effectiveness of nursery habitat includes the selection of appropriate controls (or use of a regional benchmark, if established), sampling intensity, sample size, and duration.

- Baseline data for project and offsetting assessments should be collected using metrics similar to those that will be used for *effectiveness* monitoring.
- Establish reference condition[2] (*sensu* Stoddard et al. 2006) and control site(s) as appropriate using as many of the following options as are practical:
    - "Before" data from the impacted habitat, and/or
    - Regional standard/benchmark based on spatial and historical data from the region(Randall et al. 2013), and/or
    - Historic data (availability will be site specific), and/or
    - Data from a reference or control site, and/or
    - Modelling.
- A properly implemented Before-After Control-Impact design (BACI) is still considered the best for environmental monitoring and is suitable in projects incorporating 'before' data and data from a reference or control site (Underwood 1991; Stewart-Oaten and Bence 2001). If only one of either 'before' or 'reference' data are available, using a Before-After *or* Control-Impact design is possible, but

[2] In this report, reference condition is for productivity. Development of the reference condition approach for offsetting and FPP is ongoing.

such designs are suboptimal and will deliver less certainty in the results and may require larger number of sites to achieve an effective outcome.

- When using regional benchmark data, sufficient data are required to establish isopleths of productivity for different geographic regions, and could be partitioned among habitat types using science-based suitability indices (Randall et al. 2013).
- Historic data need to be of adequate duration and quantity to establish a range of variability and estimate carrying capacity.

3.6 ESTABLISH APPROPRIATE DURATIONS (TIMESCALE) FOR MONITORING.

The scientific explanation for the recommended monitoring duration can be found in section 2.6 above. The seasonal timing of sampling nursery habitat depends on the species and habitat, but should aim to capture the season(s) when the area is being used as a nursery by the target species, depending on the metric selected as the biological variable.

Therefore we recommend:

- Three years before development at the impact site to establish baseline;
- Three years sampling immediately post-change;
- An additional 3 years of sampling at a later time (e.g., four to six years post or some later time); and,
- A revisit ten years after project impact to capture longer-term changes to the site.

4 REARING HABITAT

Technical guidance is provided in this section to assess the effectiveness of offsetting the loss or permanent alteration of fish rearing areas. Rearing habitat is defined as the area, and the environmental conditions within the area, that support fish growth, survival, and production during the life history stages from the end of the young-of-the-year or post-larval stage to the adult stage (i.e., usually “juvenile” life stages). Rearing habitat is usually less specialized, in terms of depth and substrate, than spawning or nursery habitat. Depending on the species and life history strategy, the rearing habitat is sometimes separate from nursery or spawning habitat, but these habitat types can also overlap spatially.

Functional links between rearing habitat and fish production include food supply and foraging to support energetics (maintenance), somatic growth, and adult maturation and, simultaneously, the living space and refugia needed for residency and survival during the rearing period. Together, the foraging and refugia functions of rearing habitat contribute to both the growth (G) and biomass ($\bar{B}$) components of fish production, where $P = G_{\Delta t}\bar{B}_{\text{average}}$, (product of growth in fish size and average biomass during the time interval). Units of production rate are kg of fish biomass produced in the rearing habitat (m^2) during the rearing stage stage (Δt), measured annually as total (kg/yr) or relative production (kg/ m^2/yr). Most of the fish population biomass produced and accumulated while using the rearing habitat contributes to sustaining population viability (energy for maturation and spawning) and ultimately to population and fisheries productivity (harvest). The space requirements for rearing habitat of individual fishes increases with body size within and among life stages. The rearing habitat for all age groups, collectively, is vital for the ongoing productivity of CRA fishes and the rearing habitat needed for a population is often extensive. Area of rearing habitat and the food supply available within this area determine the carrying capacity (maximum abundance) of a population.

Production rate *per se* is sometimes measured, but surrogate metrics of productivity (abundance, biomass, and the vital rates of growth and survival) are measured more frequently and are relevant as they are sub-components of the algorithm for calculating production (above equation).

The description of rearing habitat in this section, and the functions of the habitat that determine fisheries productivity, are generic and apply to all ecosystem types: streams, rivers, lake littoral, estuarine and marine coastal. Much of the information on monitoring, study design, methods and assessment guidance for rearing habitat in this section was taken from Pearson et al. (2005). Case studies involving the use of productivity metrics and different monitoring study designs for rearing habitat in a few ecosystem types (wetland, rivers, and an estuary) are cited from the Pearson et al. (2005) report and other literature, with an emphasis on Canadian examples.

4.1 SUCCESS CRITERIA

Success criteria of offsetting for rearing habitat would include both compliance and effectiveness components. *Compliance* monitoring should include evidence that the offset habitat is stable over time.

- Quantitative measure of rearing habitat loss (m^2) and/or rearing habitat quality change (m^2).
- Successful offsetting requires that equal or likely more habitat units are needed to replace or offset this loss. An evaluation of an appropriate offsetting ratio (*sensu* Minns 2006, Clarke and Bradford 2014) is needed.

- Evidence that the habitat is stable and would withstand extreme weather events (storms, water discharge and levels, droughts – e.g., Warren et al. 2010).

- To evaluate effectiveness, confirmation at the project site-scale that the offset rearing habitat is functioning as intended. Empirical evidence of successful rearing at the offset habitat, such as persistent seasonal abundance of fishes (demonstrating residence) and evidence of growth and survival of fishes.

4.2 TARGETS

Targets for assessing effectiveness would be based on information not only from the impacted site, but also historical data from the site (if available), from reference site(s), or from a regional benchmark dataset (Randall et al. 2013).

- Quantitative science-based targets for the offsetting area would be based on historic, reference or agreed-upon regional benchmarks.

- Depending on the offsetting goals, the targets would be qualitative, semi-quantitative or quantitative (Bradford et al. 2013).

- Targets could be based on measuring or inferring productivity from habitat surrogates or by measuring biological metrics.

- Surrogates for rearing habitats could be defined for regionally determined habitat categories. In freshwater, these would include measures of stream riffles and runs, pools for streams; slow and fast flowing reaches for rivers; riparian structure, amount and ratio of benthic and pelagic areas for lakes and large riverine environments. In estuarine and marine coastal ecosystems, surrogates include the amount of tide channel habitat, extent of seagrass and marsh areas, and the complexity of seabed habitat (substrate, exposure, bathymetric diversity).

- Regional benchmarks of habitat productivity will likely include composites of these habitat categories.

- Reference sites would likely be specific habitat categories, comparable and in close proximity to the impacted site.

- Regional and species-specific quantitative targets such as density of juvenile and adult fishes (i.e., inferred production) can be useful surrogates of rearing function.

- Targets based on reference condition, regional benchmarks or historical information need to be established and agreed upon, including quantification of the normal deviation from the reference condition (e.g., interquartile range).

- Juvenile recruitment and cohort strength are appropriate methods to assess the effectiveness of the combined value of nursery and rearing habitat in many cases, where separating the two habitats is not possible or practical.

- Habitat-based surrogates of productivity would be less applicable for pelagic fishes.

4.3 LIKELIHOOD OF SUCCESS

For rearing habitat, certainty of success of offsetting 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, rivers, and lake littoral (particularly for well-studied species such as salmonids) and medium to high for estuarine or marine environments. Several example studies have shown success or lack of success of rearing habitat offsetting in streams, rivers, lakes (littoral), estuaries and coastal marine habitat (Laurel et al 2003; Jones and Tonn 2004; Pearson et al. 2005; Quigley and Harper 2006; Roni et al. 2008; Smokorowski and Pratt 2007; Warren et al 2010; Wong et al. 2011; Cote et al 2013).

4.4 METRICS AND INDICATORS FOR MONITORING EFFECTIVENESS

Quantitative data need to be collected on both habitat and fish (or other biotic) metrics. For both the physical and biological measures, metrics and indicators are listed from simple to more sophisticated measures, which would depend on the offsetting goals:

Habitat metrics:

- Measurement of the area of the existing rearing habitat (m^2).

- Measurement of rearing habitat by broad habitat categories, geospatially referenced, with units of m^2, including areas both directly and indirectly impacted.

- Physical variables appropriate for each habitat category (e.g., substrate, depth, cover, water velocity for fluvial habitat).

- Other physical and chemical variables that are key drivers of productivity (e.g., temperature, wind exposure for lake littoral nutrient concentration, and other variables as determined in the offsetting plan).

- Quantification of habitat lost, by habitat category, would be used to determine the area and habitat needed for offsetting the impacts, including accounting for uncertainty (offsetting ratios; Minns 2006, Clarke and Bradford 2014).

Fish metrics:

- Abundance and/or biomass of juvenile and adult fish(es) for a known offsetting area should be the primary biological variable. Depending on the objectives of the offsetting plan, and in order of effort, potential metrics are:
    - Presence/absence,
    - Fish density [Number of fish per unit of effort or per m^2],
    - Biomass [g wet weight per unit of effort or per m^2],
    - Sampling effort (relative or absolute units of abundance) is determined by the agreed-upon offsetting plan,
    - Examples of each metric are provided in the marine and freshwater literature cited above for Likelihood of Success.

- 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, contaminants),
    - Temperature (for range of functional site requirements of species and life-stage),
    - Dissolved oxygen (for sites/ecosystems with known low oxygen),
    - Other possible abiotic factors limiting abundance.

- Sampling methods, catch efficiencies, and use of many common gears for fishes are described by Portt et al. (2006) for freshwater habitats and Beck et al. (2001), among many others, for marine waters, including their potential use for estimating relative or absolute abundance in different habitats. Other metrics and monitoring guides are given by Pearson et al. (2005).

- Examples of methods for estimating absolute density in using single or multiple pass (removal) electrofishing catches are described by Zippin (1958), Reynolds (1983), Jones and Stockwell (1995) and Reid et al. (2008).

Other metrics:

- Invertebrates, other biota, and individual and fish community metrics can be used as described in Green (1979) Quigley and Harper (2006), Pearson et al. (2005), Minns et al. (2011) and Eleftheriou (2013).

4.5 MONITORING DESIGN

The monitoring design for assessing effectiveness of rearing habitat would include information on the location and size of a reference site or benchmark control, sampling intensity, duration and sample size.

- Reference site or benchmark data used to measure effectiveness of offsetting should be the same metrics as those to be used for monitoring.

- Establish reference condition[3] (*sensu* Stoddard et al. 2006) and control site(s) as appropriate using as many of the following options as are practical:
    - "Before" data from the impacted habitat, and/or
    - Regional standard/benchmark based on spatial and historical data from the region(Randall et al. 2013), and/or
    - Historic data (availability will be site specific), and/or
    - Data from a reference or control site, and/or
    - Modelling.

- A properly implemented Before-After, Control-Impact design (BACI) is still considered the best for environmental monitoring and is suitable in projects

[3] In this report, reference condition is for productivity. Development of the reference condition approach for offsetting and FPP is ongoing.

incorporating ‘before’ data and data from a reference or control site (Underwood 1991; Stewart-Oaten and Bence 2001). If only one of either ‘before’ or ‘reference’ data are available, using a Before-After *or* Control-Impact design is possible, but such designs are suboptimal and will deliver less certainty in the results and may require larger number of sites to achieve an effective outcome.

- When using regional benchmark data, sufficient data are required to establish isopleths of productivity for different geographic regions, and could be partitioned among habitat types using science-based suitability indices (Randall et al. 2013).

- Historic data need to be of adequate duration and quantity to establish a range of variability and estimate carrying capacity.

4.6 ESTABLISH APPROPRIATE DURATIONS (TIMESCALE) FOR MONITORING

The scientific explanation for the recommended monitoring duration can be found in section 2.6 above. The seasonal timing of sampling rearing habitat needs to cover growth period (three sampling dates, early, mid and late growth period within a year). Pearson et al. (2005) note that ‘temporal scales (frequency and duration) of monitoring should be linked to those of habitat development rates and the life cycle of target species’. Pearson et al. (2005) discuss a number of case studies with appropriate timeframes for each.

Therefore we recommend:

- Three years before development at the impact site to establish baseline;
- Three years sampling immediately post-change;
- An additional 3 years of sampling at a later time (e.g., four to six years post or some later time); and,
- A revisit ten years after project impact to capture longer-term changes to the site.

5 FOOD SUPPLY

Ecosystem components that contribute to the production of food for fish are considered fish habitat by the *Fisheries Act*. Development projects 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), seabed fauna, or other features,
- Changes in water quality including transparency and nutrient concentrations,
- Changes in flow, especially flow diversions, withdrawals, and channelization.

The primary food organisms of most larval and juvenile fishes and many adults are invertebrate species including phyto- and zooplankton, and benthic and terrestrial macro-invertebrates and insects. There is a large body of knowledge about how these species are affected, in a general way, by the habitat alterations listed above. Invertebrate productivity may also be a useful metric of food web function as it integrates various energy sources for fish (Wong et al. 2011).

Unfortunately, the direct monitoring of invertebrate productivity, abundance or diversity to evaluate changes in food supply caused by a project, or due to mitigation or offsetting 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 productivity, abundance or diversity (Miller et al. 2010). Further, the taxonomic expertise required for such monitoring programs is becoming scarce.

Consequently, monitoring programs for food supply often rely on surrogates that are informed by knowledge of linkages between those surrogates and invertebrate productivity (Peterson et al. 2008). Examples include:

- Riparian vegetation or aquatic macrophyte density, structure, and diversity,
- LWD or other structural features that provide substrate for invertebrates,
- Substrate composition measures (e.g., % classification by size, $D_{90,}$ embeddedness; Bunte and Abt 2001)
- Primary production models that use water clarity and nutrient concentrations as predictors,
- Hydraulic or geomorphological measures such as wetted width, area of littoral zone or more detailed measures such as Habitat Suitability Indices for food producing organisms such as benthic invertebrates or forage fish.

All of these measures have relatively low levels of natural and sampling variability and are therefore amenable to use in quantitative monitoring programs.

5.1 SUCCESS CRITERIA

The goal of offsetting activities related to food supply is to maintain the production of food resources, primarily invertebrates, for fish populations. The first preference is to provide additional food supply for fish that are potentially affected by the project through offsetting activities implemented in the project vicinity. Off-site activities have the goal of increasing fisheries productivity of other populations. Many activities designed to offset losses to food supply will also benefit other aspects of fisheries productivity and it may be appropriate to identify and assess these gains as well.

5.2 TARGETS

Targets for the monitoring program will depend on the nature of the offsetting and the metrics chosen for evaluation. In most cases, the offsetting activities will be considered successful if the metrics chosen to monitor offsetting are relevant to food supply and result in values equivalent to, or greater than losses caused by the project.

In the case of the addition of structure for the purpose of a substrate for food production, the surface area suitable for production must meet or exceed the potential production lost. In cases where the new habitats are similar to those lost, the area of habitat may be a sufficient metric for evaluation.

For vegetation planting, the target will likely be a density, structure, and composition similar to that lost. Alternative targets include data from reference or control sites nearby. In some cases regional standards may be available (Lewis et al. 2009).

If invertebrates are being sampled directly, targets will usually be based on information from the impacted site, but may also rely on data from reference or control sites (density, biomass, diversity, EPT index, etc.). In some cases existing information on reference conditions may be available (e.g., the Canadian Aquatic Biomonitoring Network (CABIN) database, http://www.ec.gc.ca/rcba-cabin/).

5.3 LIKELIHOOD OF SUCCESS

The likelihood of success of an offsetting activity designed to increase food supply can be used to identify the level of monitoring that will be required. In some cases it may be appropriate to tailor the monitoring to address the aspect of offsetting that is the most risky, either because of uncertainty (lack of knowledge) or because of potential for high rates of failure. For example, the importance of intertidal macrophytes for secondary production is well known, and the monitoring of the density and diversity of invertebrates within a macrophyte bed is likely a low priority compared to assessing the stability and long-term persistence of constructed marsh or eelgrass beds, since there are many aspects of the physical environment that can lead to failures of these offsetting activities.

In general, the efficacy of structures to increase the supply of invertebrates to aquatic communities is relatively well understood and probably do not warrant detailed *effectiveness* monitoring that would include metrics such as invertebrate productivity, diversity, and abundance, fish feeding rates, stomach contents, growth rates or abundance. *Functional* monitoring to determine the stability of structures or the succession of plant communities towards desired endpoints is likely adequate.

Conversely, unproven offsetting actives, or those for which the benefits are difficult to predict with reasonable accuracy are candidates for more detailed *effectiveness* monitoring. An example is the monitoring of fish growth rates in stream or lake fertilization programs (Kiffney et al. 2005).

5.4 METRICS AND INDICATORS FOR MONITORING EFFECTIVENESS

Three classes of metrics or indicators may be useful for evaluating offsetting to increase food supply. These are:

1. *Metrics related to physical structures or vegetation that provides substrate for food production.* These are surrogates for actual food organisms and assume the relation between these metrics and food supply are understood sufficiently that direct monitoring of food organisms is not needed.
2. *Estimates of the abundance and composition of invertebrates.* Measurement of the food supply may be required for other types of offsetting activities, such as manipulations of water quality or quantity if the relation between the activity and the response of food supply organisms is not well understood or is less predictable. Invertebrate monitoring (particularly secondary production) may also be required as a common currency when offsetting is very different in location or nature to the project to ensure the offset is at least equivalent to the project’s impact.
3. *Estimates of the effects of the offsetting activity on the abundance, growth and production of fish.* Some combinations of offsetting activities and recipient ecosystems may be amenable to evaluating the impact on fisheries productivity in a research-level monitoring program.

Extensive guidance is available on the design of monitoring programs, the selection of metrics, and the details of sampling. Examples include Roni (2005) for streams, Lewis (2009) for riparian areas, and Thayer et al. (2005) for the coastal zones. These documents are intended for the monitoring of habitat restoration activities, but the technical issues are very similar for the monitoring of offsetting activities.

5.5 MONITORING DESIGN

The design of the monitoring program should be tied to the goals of the offsetting activity. The program should be able to evaluate whether the offsets are equivalent to the serious harm caused by the project and if those benefits are sustainable over an appropriate time frame. In cases where the offsetting is different in nature to the serious harm the monitoring design should allow for the evaluation of whether offsetting activities have provided the benefits to fisheries production that was expected.

In simple situations the loss of an element of food supply (such as riparian vegetation or underwater structure) caused be the project is assessed during the baseline period and compared (preferably using the same metric) to the gains associated with the offsetting activity. Thus, the design is a Before-After at the project site and a Before-After at the offsetting site. The collection of pre-impact (or baseline) data is critical for the evaluation; without it, a Control-Impact approach has to be used and the power of such designs is often low because of significant natural among-site variation (Cooperman et al. 2007).

The reference condition approach may be appropriate for evaluating the function of created or manipulated habitat elements, particularly in situations where many similar projects or offsetting activities are likely to occur in an environment or ecosystem type. In these cases existing or newly developed reference conditions can be identified that would allow for a simplified monitoring program at the offsetting site (e.g., Short et al. 2000). The challenge of this approach is determining suitable reference sites, particularly when ecosystems are heavily modified and it is unclear what the baseline or undisturbed state should be (Lewis et al. 2009).

In the absence of reference information, control sites will need to be established to provide a point of reference. In cases where new habitats are being created (such as marshes) from dry ground the design will necessarily be a Control-Impact comparison. There is significant value in obtaining multiple control sites to establish the variation in natural conditions. In cases where offsetting activities are being proposed to increase the food supply to existing habitats, baseline data collected at the project site is needed to evaluate conditions prior to the offsetting.

BACI (Before-After Control-Impact; Schmitt and Osenberg [1996]) designs are useful when the chosen metric has the potential to be affected by large-scale environmental or biological factors that are unrelated to the offsetting activity. Such factors can be controlled for by sampling at nearby control sites under the assumption large-scale effects will occur at project and control sites will have similar effects.

5.6 ESTABLISH APPROPRIATE DURATIONS (TIMESCALE) FOR MONITORING

The scientific explanation for the recommended monitoring duration can be found in Section 2.6 above. Some types of offsetting or restoration activities designed to increase food supply can take many years to fully mature. Manipulated streambeds or coastal areas may be fully colonized by primary and secondary producers within a year or two. However, aquatic macrophytes and riparian vegetation may take 5-20 years to fully develop (Lennox et al. 2011). 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 (Dawe et al. 2000, 2011). .
Therefore we recommend:

- In cases where the monitoring metrics are food producing features that are relatively stable in time (riparian stem densities, woody debris), one year of pre-project inventory may be sufficient to adequately evaluate project impacts, and assess conditions at potential offset sites;
- Up to three years sampling immediately post change, particularly if contingency measures such as vegetation replanting is required; and,
- A revisit ten years after project impact to capture longer-term changes to the site.

6 MIGRATION HABITAT

Barriers to fish passage include artificial physical structures (e.g., dams, culverts, river training structures, causeways, and some breakwaters), hydraulics (e.g., high velocity, turbulence, and low flow), pollution (e.g., effluents), and electromagnetic fields (e.g., underwater electricity transmission). Complete barriers impede fisheries productivity by preventing fish from completing their life cycle, e.g., preventing egg deposition in areas located above an obstacle. Partial or temporal barriers reduce fisheries productivity by impeding migration and movement of a portion of the population during specific life stages, or at different time periods (e.g., periods of high or low flows). Therefore, connectivity between all essential habitats (e.g., spawning, nursery, rearing, and food supply habitats) is required to ensure fish reproduction, growth, and survival at different life stages (Schlosser 1991). The removal of barriers (perched culverts, weirs) can be a particularly effective offsetting measure.

Previously, *effectiveness* monitoring principally focused on passage efficiency. However, offsetting activities designed to increase passage will fail if newly accessible habitats are not used, not present or not functional (e.g., induce poor embryos and juvenile survival or growth). Therefore, the likelihood of success will depend on fish (genitors and juveniles) passage efficiency, but also on the availability, quality, functionality, and connectivity between all habitat types. Hence, the ultimate metric of success of offsetting activities is the colonization rate (production of young-of-the-year in spawning habitats), and survival and growth of juvenile fish in the newly accessible spawning, nursery, rearing, and food supply habitats.

Barriers can alter habitats located above and below an obstruction. For example, hydroelectric developments induce changes in flow and temperature regimes, sediment transport and deposition, nutrient and food supply, and dissolved oxygen concentrations (see Rosenberg et al. 1997 for a review). Similarly, barrier removal may result in habitat destruction downstream of the former obstruction (e.g., sediment transport and deposition in habitats located below a decommissioned dam; see Bednarek (2001) for a review). Offsetting activities will be inefficient if providing access to habitats beyond a former obstruction is counterbalanced by habitat loss or alteration at a broader spatial scale. The impacts on fish habitats are influenced by the type of obstacle, selected offsetting activity, and specific environmental conditions. The potential impacts of barriers or offsetting activities are therefore site or region specific and the likelihood of success is frequently unknown. To determine the overall effectiveness of barrier removal, a long-term evaluation of the potential impacts on fish habitats located above and below the former or partial obstruction should be conducted concordantly with the evaluation of passage efficiency and re-colonization (production of young-of-the year and juvenile fish) in the areas beyond the removed barrier.

Overall, the assessment of the effectiveness of restoring migration habitat should include the evaluation of passage efficiency (fine spatial and broad temporal scales) and fisheries productivity (population level) in the upstream reaches (broad spatial and temporal scales). Fisheries productivity should be compared to productivity values observed in downstream habitats and to regional benchmarks (broad spatial and temporal scales). A long-term evaluation of the potential impacts of offsetting activities should be conducted and the functionality of the habitats should be conducted concordantly with the evaluation of passage efficiency (fine spatial scale and broad temporal scale) and potential for re-colonization (broad spatial and temporal scales) in the areas beyond the restoration. This approach is elaborated in the sections below.

6.1 SUCCESS CRITERIA

Establish the success criteria of increasing habitat connectivity:

- Confirm at the site of the former obstruction that fish passage has been restored for all life stages or if not possible, for all pertinent life stages of the targeted species, at all biologically important time periods (i.e., under different flow conditions), and in upstream, downstream, or both directions as required.
- Acquire information to demonstrate that the newly accessible habitats have been re-colonized (production of young-of-the-year and juvenile fish).
- Acquire evidence that newly accessible habitats (spawning, nursery, rearing or food supply habitats) are connected and functioning as intended.
- If an offsetting activity induces habitat alterations (e.g., hydroelectric development or dam decommissioning), obtain fisheries productivity evidence that habitat alterations do not counterbalance the positive effects of restoring connectivity between habitats.

6.2 TARGETS

Science-based targets should be established at different spatial and temporal scales:

- The evaluation of the functionality of the offsetting activity should aim at successful passage for all life stages or if not possible, for all pertinent life stages of the targeted species, at all biologically important time periods (i.e., under different flow conditions), and in both directions (fine-spatial scale, broad-temporal scale, below-above the former obstruction).
- Following offsetting of the migration habitat, a decline in fish density should be anticipated below the obstruction as fish redistribute into the newly available habitat. In the long-term, the evaluation of the effectiveness of restoring migration habitat should aim at obtaining a similar fisheries productivity below and above the former obstruction and comparable to regional benchmarks. The re-colonization rate is species-specific and delays of up to 20-30 years can occur (Pess et al. 2008). Therefore, monitoring the effectiveness of restoring migration habitat at the population level should be conducted at broad spatial and temporal scales.

6.3 LIKELIHOOD OF SUCCESS

- The likelihood of success is considered to be high when total removal of the obstruction is achieved (Roni et al. 2008) and no habitat alteration occurs downstream of the offsetting activity. The likelihood of success for partial restoration of migration habitat (e.g., fishways) will depend on the type of structures used, the hydraulic conditions prevailing in the structure, the swimming capacity of different life-stages, the presence of other stressors (e.g., habitat alterations below or above the partial obstruction), and the connectivity and functionality of the newly accessible habitats (see Bunt et al. 2012 for passage efficiency).

6.4 METRICS AND INDICATORS FOR MONITORING EFFECTIVENESS

The effectiveness of restoring migration habitat depends on the type of offsetting activity used and the environmental conditions. Offsetting projects can be classified into categories and the effectiveness can be determined based on a subset of study cases from each category. The metrics that should be considered are:

- Functionality of the offsetting activity (fine spatial scale, broad temporal scale):
    - Passage efficiency.
        - Passage of all life stages or if not possible, for all pertinent life stages of the targeted species, at all biologically important time periods (i.e., under different flow conditions), and in upstream, downstream, or both directions as required. Determining the presence or absence of fish beyond a former obstruction only provides information at the individual level and should be avoided. Passage efficiency of 100% of individuals should be targeted, but further research is needed to determine minimum passage efficiency for ensuring viable populations and genetic diversity (see Cooke and Hinch 2013 for a review).
- Effectiveness of the offsetting activity (broad spatial and temporal scale):
    - Fish dispersal above the former obstruction and the production of young-of-the-year.
        - Young-of-the-year production, fish abundance, and biomass as described in other sections. Species richness, species diversity, and community composition remain important metrics to quantify the success of restoring migration corridors.
    - Quality, availability, and functionality of the newly accessible habitats (spawning, nursery, rearing, and food supply habitats).
        - Select appropriate thresholds for physical, chemical, and biological measurements described in other sections.

    - Potential impacts on essential habitats (e.g., effects on flow and temperature regimes, sediment transport and deposition, nutrient and food supply, and dissolved oxygen concentrations).
        - Select appropriate thresholds for physical, chemical, and biological measurements described in other sections.

6.5 MONITORING DESIGN

- Functionality of the offsetting activity (passage efficiency):
    - Preferred methodology is the use of telemetry (acoustic, radio or Passive Integrated Transponder (PIT)-tags; see Cooke et al. 2013 for a review).
    - Direct count or mark and recapture experiments (see Seber 1986 for a review).
- Effectiveness of the offsetting activity (see other sections for detailed information):
    - Comparison of fisheries productivity metrics before and after the offsetting activity occurred, up- and downstream of the former obstruction and regional comparisons.
    - Comparison of habitat availability, quality, and functionality below and above the former obstruction and regional comparisons.
    - Modelling the use of physical habitat measurements to infer survival of juvenile fishes (e.g., determination of percent of fines in the substrate to predict percent of embryo emergence).

6.6 ESTABLISH APPROPRIATE DURATIONS (TIMESCALE) FOR MONITORING

The scientific explanation for the recommended monitoring duration can be found in Section 2.6 above. Effectiveness monitoring of migration habitat requires establishing the passage efficiency, the potential habitat loss (e.g. downstream effects on dam removal), and colonization of the newly accessible habitats. Monitoring of passage efficiency should include all biologically important seasons and flow conditions.

Therefore we recommend:

- Three year prior to restoring connectivity to quantify species abundance above and below the barrier.
- Three years sampling immediately post-change;
- An additional 3 years of sampling at a later time (e.g., four to six years post or some later time); and,
- A revisit ten years after project impact to capture longer-term changes to the site and to verify its ongoing functionality and sustainability. If recolonization did not occur, assess the functionality and connectivity between migration, spawning, nursery and rearing habitats as well as food supply and repeat monitoring every 5 years.

7 ALTERNATIVE MONITORING DESIGNS

In many of the preceding sections the use of the properly implemented BACI-related design is identified as optimal for estimating the benefits of offsetting activities designed to increase fisheries productivity. This design is especially useful for measures that increase the productivity of existing habitats (e.g., changes in flow, structure, shoreline alterations) where there is a need to estimate the productivity of the site prior to the offset to effectively estimate the incremental benefit of the activity. For most biological variables multiple years of pre-offset sampling are required to reasonably estimate the baseline condition (Pearson et al. 2005; Lewis et al. 2013).

The requirement for three or more years of baseline data for the BACI design may be problematic in some settings but there are situations where effective monitoring designs are possible without extensive baseline data.

For projects where there is little or no fisheries productivity at the offset site prior to the implementation of the offsetting plan, a spatial or reference design is appropriate to compare the fisheries productivity of the offsetting activity to other sites or to benchmark values. For example, an offset designed to restore connectivity in a salmon stream would only need presence-absence sampling to confirm the presence of a migration barrier. Consequently, in some cases the need for extensive pre-offset baseline sampling is reduced.

For projects where it is deemed necessary to estimate impacts as part of the environmental assessment process, more complex monitoring programs may be used to both estimate the project’s impacts, and the gains resulting from offsetting activities. It may be possible to gain efficiencies if some of the project baseline sampling can serve as either a control or reference data for estimating gains from offsetting. The nature of the monitoring program design will be contingent on the details of the project and the offsetting plan.

8 SITE SELECTION AND STANDARDIZATION

Initially site selection should be random to avoid bias of subjectively selecting sites due to ease of access or other factors. Random sites should be chosen from a complete set of potential sites that both cover the full area of interest and take into account the particular type of sampling or gear type to be used (e.g., for electrofishing an appropriate type of site would be a set stretch of river or shoreline). If the pool of potential sites is relatively uniform, simple random sampling is appropriate. However, if there is substantial habitat heterogeneity then a stratified random sampling approach is appropriate. Stratified random sampling involves splitting the area into relatively uniform strata based on known or anticipated physical, chemical or biological differences (e.g., river valley segments, lake basins with differing morphometries or major inflows) and then randomly selecting sites from within each defined strata.

Once the monitoring sites are initially selected, there is a choice to repeatedly measure fixed sites, or to randomly select sites each subsequent visit. The fixed station approach has some advantages including establishing and maintaining access and reducing inter-site variance, but the continued random approach would eventually allow one to sample more of the system of interest. The choice of random versus fixed repeat sampling may depend on the monitoring objectives. If the goal of the monitoring is to compare relative abundance or biomass, then fixed sites have been shown to provide unbiased estimates (King et al. 1981; Tuckey and Fabrizio 2013), in opposite, diversity metrics are best represented by ongoing random site monitoring (Tuckey and Fabrizio 2013). In addition, using standard, repeatable methods during the monitoring is critical, as well as considering factors such as seasonality, flow, temperature, etc. to ensure comparability of results, particularly for relative index metrics such as CPUE or its related measure, Biomass-Per-Unit-Effort (BPUE). Detailed information on method standardization is available (Murphy and Willis 1996; Bonar et al. 2009).

9 PROPONENT REPORTING

According to the Fisheries Productivity Investment Policy: A Proponents Guide to Offsetting (DFO 2013b), proponents are responsible for implementing offsetting plans and monitoring their effectiveness, as well as for reporting on implementation and the results of monitoring. Monitoring must be designed to confirm that the offsetting activities have been effective in counterbalancing the *serious harm to fish* and may identify the need for contingency measures should deficiencies be found. Monitoring and reporting conditions should be described in the offsetting plan as they will be included as conditions of the *Fisheries Act* authorization.

Requirements of the content to be included in an offsetting plan are specified in Schedule 1 (13 a-h) of the *Applications for Authorization under Paragraph 35(2)(b) of the Fisheries Act Regulations, SOR/2013-191,* in “An Applicant’s Guide to Submitting an Application for Authorization” (DFO 2013c) and in the Fisheries Productivity Investment Policy (DFO 2013b). From the recommendations included in this report, the *offsetting plan* needs to clearly document the components of the *effectiveness* monitoring plan including:

- The goals of monitoring including success criteria for compliance (meeting the conditions of the authorization for the quantity and nature of the offsetting measures) and effectiveness (quantitative targets in metric common to baseline data and measurement of offset habitat).
- Monitoring design including the baseline and reference sites, metric(s) for success, target for success, sampling intensity, sample size, and schedule/duration of the monitoring program.
- A literature-based justification for duration of time for the offset to become fully functional. This will inform expectations of effectiveness related to the when the quantitative biological target is expected to be met. Benchmarks for measuring progress towards target should be included.

A standardized reporting schedule and format on the *effectiveness* monitoring program needs to be established and followed. A summary section included up front with key points to be included in a database would facilitate electronic data capture and allow quick comparisons among projects with details to be included in the body of the report (with page numbers referenced in summary section). Establishing a standardized reporting format would increase the probability that monitoring data would be used to improve habitat offsets at the site (via adaptive management) or other sites, improving future decision-making. In addition, a component of a successful monitoring plan could be to develop and implement a GIS-based ‘Geospatial Decision Support Tool’ as a framework to aid *effectiveness* monitoring (Bakelaar et al. in press).

A *monitoring report* should be submitted within each year of monitoring prior to commencement of the next field season to allow for adjustment if required. A *monitoring report summary* should be included at the beginning of each report (a template should be provided by DFO Fisheries Protection Program) and include the following key points of information. For all points listed below a clear reference should be given as to where in the report (i.e., the page number) details can be found.

- Area and type of habitat(s) lost, including date of loss (geospatially referenced).
- Area and type of habitat offset(s) including date of completion and date of measurement (geospatially referenced). Photographs could be included.

- Calculated (realized) offset ratio and comparison to the proposed ratio established in the offsetting plan.
- Comment on stability and any structural/habitat changes noted since impact (briefly in summary with details referenced in the report). If offset habitat is demonstrating signs of failure, this should trigger discussions relating to implementation of contingency measures (previously outlined as a condition of *Fisheries Act* authorization) to repair or alter the offset activity for long-term stability.
- Quantitative target for establishing effectiveness (habitat-appropriate biological metric taken from the offsetting plan. This will be the same in each monitoring report).
- Measured effectiveness (mean and error of target biological metric) and date (range) of monitoring. Detailed field methods, sampling intensity and duration to be provided in the monitoring report.
- Comment on the effectiveness of the offset habitat (i.e., how does the biological metric relate to quantitative target, dependent on the age of the offset and benchmark targets established in the offsetting plan). If targets have not been met, this should trigger discussions related to collection of additional target or mechanistic data in subsequent field season(s).
- Supplementary mechanistic data (mean and error in summary section) if collected during prior field season to establish why offset may have failed and provide information for (new) contingency measures to be negotiated to improve effectiveness.
- Note of next field season (date) with reference to detailed timeline (schedule) for ongoing monitoring and reporting in body of report (detailed timeline and sampling design taken from the offsetting plan and will be the same in each report unless changes are required to improve monitoring program).
- Note of next field season metrics (physical, chemical, biological, and additional mechanistic if necessary) to be collected. Details of field methods, sampling intensity and duration to be included in the monitoring report if different from previous field season.
- If the monitoring report is documenting the final scheduled year of monitoring, a comment should be included regarding the need (or not) of additional monitoring depending on the expectation of the ongoing effectiveness, stability, and functionality of the offset habitat.

10 CONCLUSIONS

A comprehensive, well executed, and properly reported *effectiveness* monitoring program would have qualities similar to a well-designed experimental research program, and therefore the potential knowledge to be gained is substantive. Conducting scientific research on the scale of large developments is typically resource prohibitive. Similarly, conducting a poorly designed, executed, and reported monitoring program is essentially a waste of resources since the results lead nowhere. The 19 steps included in this report came from a peer reviewed, formal science advisory process with the details fleshed out by scientists and were adjusted to the new *Fisheries Act*. Should the advice included in this report be formally adopted (i.e., become part of policy), including committing the resources for digital entry of the results of *effectiveness* monitoring programs, it would be possible for DFO Science to conduct a formal review (meta-analysis) of projects on a cyclical basis (circa every five years). Similarly, if geospatially referenced data were captured and incorporated into a centralized geodatabase the eventual accumulation of data may permit assessment of impacts and changes at broader scale such as watershed, and eventually, ecosystem (Bakelaar et al. in press). Such analyses could lead to the long-term improvement of offsetting plans and monitoring design for the ultimate benefit of fisheries productivity and sustainable aquatic ecosystems in Canada.

11 REFERENCES

Bagenel, T.B. and W. Nellen. 1980. Sampling eggs, larvae and juvenile fish. In: Backiel, T. and R.L. Welcomme (eds). Guidelines for sampling fish in inland waters. EIFAC 1980 Tech. Pap. 33. 176 p. Available: http://www.fao.org/3/a-aa044e/AA044E00.htm#TOC (Accessed July, 2014)

Bakelaar, C.N., A.G. Doolittle, R.G. Randall, and J. Thomas. In press. Putting compensation and monitoring on the map: Measuring fish habitat changes using GIS. DFO Can. Sci. Advis. Sec. Res. Doc. 2014/nnn. v + 13 p.

Balon, E.K. 1975. Reproductive guilds of fishes: a proposal and definition. J. Fish. Res. Board Can. 32: 821-864.

Beck, M.W., K.L. Heck, K.W. Able, D.L. Childers, D.B. Eggleston, B.M. Gillanders, B. Halpern, C.G. Hays, K. Hoshino, T.J. Minello, R.J. Orth, P.F. Sheridan, and M.P. Weinstein. 2001. The identification, conservation, and management of estuarine and marine nurseries for fish and invertebrates. BioScience 51: 633-641.

Bednarek, A.T. 2001. Undamming rivers: a review of the ecological impacts of dam removal. J. Environ. Manage. 27:803-814.

Bjornn, T.C. and D.W. Reiser. 1991. Habitat requirements of salmonids in streams. Am. Fish. Soc. Spec. Pub. 19: 83-138.

Bonar, S.A., W.A. Hubert, and D.W. Willis. 2009. Standard methods for sampling North American freshwater fishes. American Fisheries Society, Bethesda, Maryland.

Bradbury, I.R., B.J. Laurel, D.R. Robichaud, G.A. Rose, P.V.R. Snelgrove, R.S. Gregory, D. Cote, and M.J.S. Windle. 2008. Discrete spatial dynamics in a marine broadcast spawner: re-evaluating scales of connectivity and habitat associations in Atlantic cod (*Gadus morhua*) in coastal Newfoundland. Fish. Res. 91: 299-309.

Bradford, M.J., R.G. Randall, K.S. Smokorowski, B.E. Keatley, and K.D. Clarke. 2014. A framework for assessing fisheries productivity for the Fisheries Protection Program. DFO Can. Sci. Advis. Sec. Res. Doc. 2013/067. v + 25 p.

Bunt, C.M., T. Castro-Santos, and A. Haro. 2012. Performance of fish passage structures at upstream barriers to migration. River Res. Appl. 28: 457-478.

Bunte, K. and S.R. Abt. 2001. Sampling surface and subsurface particle-size distributions in wadable gravel- and cobble-bed streams for analyses in sediment transport, hydraulics, and streambed monitoring. United States Department of Agriculture Forest Service, Rocky Mountain Research Station, General Technical Report RMRS-GTR-74., 428 pages.

Clarke, K.D. and Bradford, M.J. 2014. A Review of Equivalency in Offsetting Policies. DFO Can. Sci. Advis. Sec. Res. Doc. 2014/109. v + 18 p.

Cooke, S. J. and S.G. Hinch. 2013. Improving the reliability of fishway attraction and passage efficiency estimates to inform fishway engineering, science, and practice. Ecol. Eng. 58: 123-132.

Cooke, S.J., J.D. Midwood, J.D. Thiem, P. Klimley, M.C. Lucas, E.B. Thorstad, J. Eiler, C. Holbrook, and B.C. Ebner. 2013. Tracking animals in freshwater with electronic tags: past, present, and future. Anim. Biotelem. 1:5.

Cooperman, M.S., S.G. Hinch, S. Bennett, M.A. Branton, R.V. Galbraith, J.T. Quigley, and B.A. Heise. 2007. Streambank restoration effectiveness: lessons learned from a comparative study. Fisheries 32(6): 278-291.

Cote, D., R.S. Gregory, C.J. Morris, B.H. Newton, and D.C. Schneider. 2013. Elevated habitat quality reduces variance in fish community composition. J. Exp. Mar. Biol. Ecol. 440:22-28.

Dawe, N.K., G.E. Bradfield, W.S. Boyd, D.E.C. Tretheway, and A.N. Zolbrod. 2000. Marsh creation in a northern Pacific estuary: Is thirteen years of monitoring vegetation dynamics enough? Cons. Ecol. 4(2):12.

Dawe, N.K., W.S. Boyd, R. Buechert, and A.C. Stewart. 2011. Recent, significant changes to the native marsh vegetation of the Little Qualicum River estuary, British Columbia; a case of too many Canada Geese (*Branta canadensis*)? Brit. Col. Birds 21:11-31.

DFO. 1986. Policy for the Management of Fish Habitat. Fisheries and Oceans Canada. Cat. No. Fs 23-98/1986E. Available: http://www.gov.pe.ca/photos/original/elj_appendixd.pdf (October 2014)

DFO. 2012. Assessing the effectiveness of fish habitat compensation activities in Canada: monitoring design and metrics. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2012/060

DFO. 2013a. Science advice on offsetting techniques for managing the productivity of freshwater fisheries. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2013/074.

DFO. 2013b. Fisheries Productivity Investment Policy: A Proponent's Guide to Offsetting. Catalogue Number: Fs23-596/2013E-PDF. Available: http://www.dfo-mpo.gc.ca/pnw-ppe/offsetting-guide-compensation/offsetting-guide-compensation-eng.pdf (October 2014).

DFO. 2013c. An Applicant's Guide to Submitting an Application for Authorization under Paragraph 35(2)(*b*) of the *Fisheries Act* November 2013. Catalogue Number: Fs23-597/2013E-PDF. Available: http://www.dfo-mpo.gc.ca/pnw-ppe/reviews-revues/Applicant_Guide-Guide_autorisation-eng.pdf (November 2014).

DFO and MNRF. 2008. Conservation Status Report, Atlantic Salmon in Atlantic Canada and Quebec: PART I – Species Information. Can. Man. Rep. Fish. Aquat. Sci. No. 2861, 208 p.

Dumont P., J. D. Amours, S. Thibodeau, N. Dubuc, R. Verdon, S. Garceau, P. Bilodeau, Y. Mailhot and R. Fortin. 2011. Effects of the development of a newly created spawning ground in the Des Prairies River (Quebec, Canada) on the reproductive success of lake sturgeon (*Acipenser fulvescens*). J. Appl. Ichthyol. 27: 394–404.

Eleftheriou, A. (Ed.). 2013. Methods for the study of marine benthos. John Wiley & Sons, Chichester UK.

Fitzsimons, J.D. 1996. The significance of man-made structures for lake trout spawning in the Great Lakes: are they a viable alternative to natural reefs. Can. J. Fish. Aquat. Sci. 3(Suppl. 1): 142-151.

Fitzsimons, J.D. 2014. Assessment of measures to assess compensation and mitigation as related to the creation, rehabilitation, or restoration of spawning habitat for fluvial or lacustrine spawning salmonines Can. Sci. Advis. Sec. Res. Doc. 2013/110. iv + 33 p.

Green, R.H. 1979. Sampling design and statistical methods for environmental biologists. John Wiley & Sons. Toronto.

Haegele, C.W. and J.F. Schweigert. 1985. Distribution and characteristics of herring spawning grounds and description of spawning behavior. Can. J. Fish. Aquat. Sci. 42(S1): 39-55.

Hart, D.D., T.E. Johnson, K.L. Bushaw-Newton, R.J. Horwitz, A.T. Bednarek, D.F. Charles, D.A. Kreeger, and D.J. Velinsky. 2002. Dam Removal: Challenges and Opportunities for Ecological Research and River Restoration. BioScience, 52: 669-682.

House, R.A. 1996. An evaluation of stream restoration structures in a coastal Oregon 1125 stream 1981–1993. N. Am. J. Fish. Manag. 16: 272-281.

Jones, M.L. and J.D. Stockwell. 1995. A rapid assessment procedure for the enumeration of salmonine populations in streams. N. Am. J. Fish. Manag.15: 551-562.

Jones, N.E. and W.M. Tonn. 2004. Enhancing productive capacity in the Canadian arctic: assessing the effectiveness of instream habitat structures in habitat compensation. Trans. Am. Fish. Soc.133: 1356-1365.

Juanes, F. and D.O. Conover. 1995. Advection and the linkage between predator and prey recruitment in young-of-the-year bluefish. Mar. Ecol. Prog. Ser.128:287-304.

Jurajda, P. 1999. Comparative nursery habitat use by 0+ fish in a modified lowland river. Regul. Rivers Res. Manage.15: 113-124.

Kelso, W.E. and D.A. Rutherford. 1996. Collection, preservation, and identification of fish eggs and larvae. pp 255-302. In: B.R. Murphy and D.W. Willis (eds). Fisheries techniques, 2nd edition. American Fisheries Society, Bethesda, Maryland.

King , T.A., J.C. Williams , W.D. Davies, and W.L. Shelton. 1981. Fixed versus random sampling of fishes in a large reservoir. Trans. Am. Fish. Soc.110: 563-568.

Kornfield, I., B.D. Sidell, and P.S. Gagnon. 1982. Stock definition in Atlantic herring (*Clupea harengus harengus*): genetic evidence for discrete fall and spring spawning populations. Can. J. Fish. Aquat. Sci. 39:1610-1621.

Lane, J.A., C.B. Portt, and C.K. Minns. 1996. Spawning habitat characteristics of Great Lakes fishes. Can. Man. Rep. Fish. Aquat. Sci. 2368: v + 48 p.

Laurel, B.J., R.S. Gregory, and J.A. Brown. 2003. Settlement and distribution of age 0 juvenile cod, *Gadus morhua* and *Gadus ogac*, following a large-scale habitat manipulation. Mar. Ecol. Progr. Ser. 262:241-252.

Lennox, M.S., D.J. Lewis, R.D. Jackson, J. Harper, S. Larson, and K.W. Tate. 2011. Development of vegetation and aquatic habitat in restored riparian sites of California's North coast rangelands. Restor. Ecol. 19: 225-233.

Levings, C.D., D.E. Boyle, and T.R. Whitehouse. 1995. Distribution and feeding of juvenile Pacific salmon in freshwater tidal creeks of the lower Fraser River, British Columbia. Fish. Manag. Ecol. 2:299-308.

Levy, D.A. and T.L. Slaney. 1993. A review of habitat capacity for salmon spawning and rearing. Fisheries and Oceans. B.C., 48 p. https://www.for.gov.bc.ca/hts/risc/o_docs/aquatic/036/assets/036.pdf

Lewis, D. M. Lennox, S. Nossman. 2009. Developing a monitoring program for riparian revegetation projects. University of California Division of Agriculture and Natural Resources Publication 8363.

Loughlin, K.G. and K.D. Clarke. 2014. A review of methods used to offset residual impacts of development projects on fisheries productivity. DFO Can. Sci. Advis. Sec. Res. Doc. 2013/097. vi + 72 p.

Merz, J. E., J. D. Setka, G. B. Pasternack, and J. M. Wheaton. 2004. Predicting benefits of spawning-habitat rehabilitation to salmonid (*Oncorhynchus* spp.) fry production in a bregulated California river. Can. J. Fish. Aquat. Sci. 61:1433–1446.

Miller, J.M., J.S. Burke, and G.R. Fitzhugh. 1991. Early life history patterns of Atlantic North American flatfish: likely (and unlikely) factors controlling recruitment. Neth. J. Sea Res. 27:261-275.

Miller, S.W., P Budy and J.C. Schmidt. 2010. Quantifying macroinvertebrate responses to in-stream habitat restoration: applications of meta-analysis to river restoration. Rest. Ecol. 18: 8-19.

Minns, C.K.2006. Compensation ratios needed to offset timing effects of losses and gains and achieve no net loss of productive capacity of fish habitat. Can. J. Fish. Aquat. Sci. 63: 1172-1182.

Minns, C.K., J.R.M. Kelso, and R.G. Randall. 1996. Detecting the response of fish to habitat alterations in freshwater systems. Can. J. Fish. Aquat. Sci. 53(Suppl. 1): 403-414.

Minns, C.K., R.G. Randall, K.E. Smokorowski, K.D. Clarke, A. Vélez-Espino, R.S. Gregory, S. Courtenay, and P. LeBlanc. 2011. Direct and indirect estimates of the productive capacity of fish habitat under Canada's Policy for the Management of Fish Habitat: where have we been, where are we now, and where are we going? Can. J. Fish. Aquat. Sci. 68: 2204-2227

Murphy, B.R. and D.W. Willis. 1996. Fisheries techniques, 2nd edition. American Fisheries Society, Bethesda, Maryland.

Nakashima, B.S. and C.T. Taggart. (2002). Is beach-spawning success for capelin, *Mallotus villosus* (Müller), a function of the beach?. ICES J. Mar. Sci. 59:897-908.
Palm, D., E. Brannas, F. Lepori, K. Nilsson, and S. Stridsman. 2007. The influence of spawning habitat restoration on juvenile brown trout (*Salmo trutta*) density. Can. J. Fish. Aquat. Sci. 64:509-515.
Pearson, M.P., J.T. Quigley, D.J. Harper, and R.V. Galbraith. 2005. Monitoring and assessment of fish habitat compensation and stewardship projects: Study design, methodology and example case studies. Can. Man. Rep. Fish. Aquat. Sci. 2729: xv + 124 p.
Pess, G.R., M.L. McHenry, T.J. Beechie, and J. Davies. 2008. Biological impacts of the Elwha River dams and potential salmonid responses to dam removal. Northwest Sci. 82: 72-90.
Peterson C.H., K.W. Able, C.F. DeJong, M.F. Piehler, C.A. Simenstad, and J.B. Zedler. 2008. Practical proxies for tidal marsh ecosystem services: application to injury and restoration. Adv. Mar. Biol. 54: 222-263.
Portt, C.B., G.A. Coker, D.L. Ming, and R.G. Randall. 2006. A review of fish sampling methods commonly used in Canadian freshwater habitats. Can. Tech. Rep. Fish. Aquat. Sci. 2604. v + 51 p.
Præbel, K., J.S. Christiansen, and S.E. Fevolden. 2009. Temperature and salinity conditions in a sub-Arctic intertidal spawning habitat for capelin. Mar. Biol. Res. 5: 511-514
Quigley, J.T. and D.J. Harper. 2006. Effectiveness of fish habitat compensation in Canada in achieving no net loss. Environ. Manage. 37: 351-366.
Randall, R.G., R. Cunjak, J. Gibson, S. Reid, and A. Velez-Espino. 2013. Using electrofishing data to determine regional benchmarks of habitat productive capacity. DFO Ca. Sci. Advis. Sec. Res. Doc. 2013/095, iv + 13p.
Randall, R.G., Bradford, M.J., Clarke, K.D., and Rice, J.C. 2013. A science-based interpretation of ongoing productivity of commercial, recreational or Aboriginal fisheries. DFO Can. Sci. Advis. Sec. Res. Doc. 2012/112 iv + 26 p.
Reid, S.M., N.E. Jones, and G. Yunker. 2008. Evaluation of single-pass electrofishing and rapid habitat assessment for monitoring redside dace. N. Am. J. Fish. Manag. 28: 50-56.
Reynolds, J.B. 1983. Electrofishing. pp. 147-164. In: L.A. Nielson and D.L Johnson, (eds). Fisheries techniques, 1st edition. American Fisheries Society, Bethesda, Maryland.
Ricklefs, R.E. 1990. Ecology – 3rd Edition. W.H. Freeman and Company. New York.
Roni, P. 2005. Monitoring stream and watershed restoration. American Fisheries Society, Bethesda, Maryland.
Roni, P., T.J. Beechie, R.E. Bilby, F.E. Leonetti, M.M. Pollock, and G.R. Pess. 2002. A review of stream restoration techniques and a hierarchical strategy for prioritizing restoration in Pacific Northwest watersheds. N. Am. J. Fish. Manag. 22: 1-20.

Roni, P., K. Hanson, and T. Beechie. 2008. Global review of the physical and biological effectiveness of stream habitat rehabilitation techniques. N. Am. J. Fish. Manag. 28: 836-890.

Rosenberg, D.M., F. Berkes, R.A. Bodaly, R.E. Hecky, C.A. Kelly, and J.W. Rudd. 1997. Large-scale impacts of hydroelectric development. Environ. Rev. 5: 27-54.

Schlosser, I.J. 1991. Stream fish ecology: a landscape perspective. BioScience 41: 704-712.

Schmitt, R.J. and C.W. Osenberg. 1996. Detecting ecological impacts: concepts and applications in coastal habitats. Academic Press, San Diego, California.

Sear, D. and P. DeVries. 2008. Salmonid spawning habitat in rivers: physical controls, biological responses and approaches to remediation. Am. Fish. Soc. Symp. 65, 376 p.

Seber, G.A. 1986. A review of estimating animal abundance. Biometrics 42: 267-292.

Seitz, R. D., H. Wennhage, U. Bergstrom, R.N. Lipcius, and T. Ysebaert. 2014. Ecological value of coastal habitats for commercially and ecologically important species. ICES J. Mar. Sci. 71: 648-665.

Short F.T., D.M. Burdick, C.A. Short, R.C. Davis, P.A. Morgan. 2000. Developing success criteria for restored eelgrass, salt marsh and mud flat habitats. Ecol Eng. 15: 239-252.

Short, F.T., R.C. Davis, B.S. Kopp, C.A. Short, and D.M. Burdick. 2002. Site-selection model for optimal transplantation of eelgrass *Zostera marina* in the northeastern US. Mar. Ecol. Prog. Ser. 227: 253-267.

Smokorowski, K.E. and T.C. Pratt. 2007. Effect of a change in physical structure and cover on fish and fish habitat in freshwater ecosystems – a review and meta-analysis. Environ. Rev. 15: 15-41.

Souchon, Y, C. Sabaton, R. Deibel, D. Reiser, J. Kershner, M. Gard, C. Katopodis, P. Leonard, N.L. Poff, W.J. Miller, and B.L. Lamb. 2008. Detecting biological responses to flow management: missed opportunities; future directions. Riv. Res. Appl. 24: 506-518.

Smith, E.P. 2012. BACI design. pp: 141-148 In: El-Shaarawi, A.H. and W.W. Piegorsch (eds). Encyclopedia of Environmetrics. John Wiley & Sons, Ltd, Chichester.

Stewart-Oaten, A. and J.R. Bence. 2001. Temporal and spatial variation in environmental impact assessment. Ecol. Monogr. 71: 305-339.

Stoddard, J.L., D.P. Larsen, C.P. Hawkins, R.K. Johnson, and R.H. Norris. 2006. Setting expectations for the ecological condition of streams: the concept of reference condition. Ecol. Appl. 16: 1267-1276.

Thayer, G.W., D.H. Merkey, T.A. McTigue, F.M. Burrows, R.J. Salz, and P.F. Gayaldo. 2005. Science-based restoration monitoring of coastal habitats. NOAA Coastal Ocean Program Decision Analysis Series 23, Vol. 1 and 2.

Thedinga, J.F., A.C. Wertheimer, R.A. Heintz, J.M. Maselko, and S.D. Rice. 2000. Effects of stock, coded-wire tagging, and transplant on straying of pink salmon

(*Oncorhynchus gorbuscha*) in southeastern Alaska. Can. J. Fish. Aquat. Sci. 57: 2076-2085.

Tuckey, T.D. and M.C. Fabrizio. 2013. Influence of survey design on fish assemblages: Implications from a study in Chesapeake Bay tributaries. Trans. Am. Fish. Soc. 142: 957-973.

Underwood, A.J. 1991. Beyond BACI: Experimental designs for detecting human environmental impacts on temporal variations in natural populations. Aust. J. Mar. Freshw. Res. 42: 569-587.

Warren, M.A., R.S. Gregory, B.J. Laurel, and P.V.R. Snelgrove. 2010. Increasing density of juvenile Atlantic (*Gadus morhua*) and Greenland cod (*G. ogac*) in association with spatial expansion and recovery of eelgrass (*Zostera marina*) in a coastal nursery habitat. J. Exp. Mar. Biol. Ecol. 394:154-160.

Wong M.C., C.H. Peterson, and M.F. Piehler. 2011. Evaluating estuarine habitats using secondary production as a proxy for food web support. Mar. Ecol. Prog. Ser. 440: 11-25.

Zippen, C. 1956. An evaluation of the removal method of estimating animal populations. Biometrics 12: 163-189.

12 APPENDIX A

Recommended 19 Step Framework for Standardized *Effectiveness* Monitoring:

Description of the impacted habitat:

1. Characterization of baseline habitat condition (including physical, chemical, and biological 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 impact). 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 an appropriate control (i.e., collection of baseline data, including geospatially referenced 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 offsetting objective will be (i) habitat replacement or (ii) other appropriate offsetting for habitat lost.

10. Establish offsetting goals and success criteria (management role).

Implement *effectiveness* monitoring plan or program:

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.

12. Establish science-based, quantitative targets to evaluate achievement of offsetting goals. For example, as based on regional benchmarks for ongoing productivity or based on pre-impact data collected at the site of impact and/or a reference site.

13. Determine likelihood of success of offsetting (based on documented success):

    - Where uncertainty of offsetting success is high, use a higher frequency/intensity of monitoring; i.e., more offsetting.

    - Where uncertainty of offsetting success is low, use a lower frequency/intensity of monitoring.

14. Define metrics for monitoring (direct and indirect, linked to scale). Metrics should be the same in 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-offsetting activity).

17. Proponent reporting (in a standardized format, which can be incorporated into a common, shared database).

Post-*effectiveness* monitoring:

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 the national Fisheries Protection Program level.