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A Review of Methods Used to Offset Residual Impacts of Development Projects on Fisheries Productivity

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Canada

Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

Research documents are produced in the official language in which they are provided to the Secretariat.

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ABSTRACT

Recent amendments to Canada's *Fisheries Act* (Bill C38, June 2012 and Bill C45, December 2012) will alter the way Fisheries and Oceans Canada (DFO) assesses and manages the impacts of development projects on aquatic ecosystems. Efforts will continue to be made to avoid and mitigate negative impacts to aquatic ecosystems, and offset or compensate for residual impacts, as per current practice within DFO (DFO 2010). In the future, a flexible approach will be taken to compensating residual impacts of project development in order to achieve better outcomes for fish and fish habitat while using measures that are efficient, effective, predictable and measurable. The department will shift to a focus on managing impacts to fisheries, specifically commercial, recreational, and Aboriginal (CRA) fisheries, to ensure their sustainability and ongoing productivity (DFO 2012). When residual impacts are unavoidable and cannot be mitigated, offset techniques such as those described in this report can be used to achieve no net loss or a net gain of fisheries productivity.

The top priority for maintaining or improving fishery productivity will be avoiding impacts to fish and fish habitat via project relocation and reducing impacts via mitigation measures and only after those efforts have been exhausted will other options to offset impacts be considered. The amount of offsetting needed to ensure there are no adverse impacts to fisheries productivity needs to be carefully considered and monitoring should be conducted to ensure that productivity is maintained or increased.

This report includes information on several potential measures to offset impacts to fisheries productivity including fish habitat creation, habitat restoration, stocking, and chemical manipulations (including nutrient addition) and includes a description of habitat banking as a possible approach to implement offset measures. Information and experiences of DFO Fisheries Protection practitioners across Canada are also incorporated into the report and information on fisheries-related policies from other countries including the United States, Australia, and the European Union are briefly summarized. Although not exhaustive, this review also includes information on baseline data needs and monitoring that will be important in developing an offsetting policy for Canadian fisheries.

Examen des méthodes utilisées pour compenser les impacts résiduels des projets de développement sur la productivité des pêches

RÉSUMÉ

Les récentes modifications apportées à la *Loi sur les pêches* (projet de loi C38 en juin 2012 et projet de loi C45 en décembre 2012) vont changer la façon dont Pêches et Océans Canada (MPO) évalue et gère les impacts des projets de développement sur les écosystèmes aquatiques. Les efforts se poursuivront, conformément aux pratiques qui ont cours au MPO, pour éviter et pour atténuer les impacts négatifs sur les écosystèmes aquatiques et pour compenser les impacts résiduels (DFO 2010). À l'avenir, une approche flexible sera adoptée pour compenser les impacts résiduels des projets de développement afin d'obtenir de meilleurs résultats pour le poisson et l'habitat du poisson par la voie de mesures efficientes, efficaces, prévisibles et mesurables. Le MPO se concentrera dorénavant sur la gestion des impacts sur les pêches, particulièrement sur les pêches commerciales, récréatives et autochtones, pour faire en sorte qu'elles soient durables et que leur productivité soit continue (DFO 2012). Lorsque les impacts résiduels sont inévitables et ne peuvent être atténués, il sera possible d'utiliser des techniques de compensation, comme celles décrites dans ce rapport, pour parvenir à éviter les pertes nettes ou pour parvenir à obtenir des gains nets de productivité des pêches.

La priorité absolue relativement au maintien ou à l'amélioration de la productivité consistera à éviter les impacts sur le poisson et l'habitat du poisson en déplaçant un projet, et à réduire les impacts au moyen de mesures d'atténuation. Après, et seulement après, avoir épuisé ces recours, d'autres options pour compenser les impacts pourront être envisagées. La portée de la compensation nécessaire pour faire en sorte qu'il n'y ait pas d'impacts nuisibles sur la productivité des pêches doit être minutieusement évaluée, et une surveillance devrait être effectuée pour veiller à ce que cette productivité soit maintenue ou améliorée.

Ce rapport contient des renseignements sur plusieurs mesures envisageables, notamment l'établissement d'un habitat, la restauration d'un habitat, l'empoissonnement et les manipulations chimiques (y compris l'ajout de nutriments) pour compenser les impacts sur la productivité des pêches. Il contient également une description de l'établissement d'habitats de réserve comme approche envisageable pour mettre en œuvre les mesures de compensation. Le rapport contient également des renseignements de la part de praticiens de la protection des pêches du MPO et au sujet de situations qu'ils ont vécues, ainsi qu'un sommaire des renseignements sur les politiques portant sur les pêches d'autres pays, dont les États-Unis et l'Australie, ainsi que l'Union européenne. Enfin, cet examen, quoique non exhaustif, contient aussi des renseignements sur les besoins en matière de données de base et sur la surveillance qui sera nécessaire afin d'élaborer une politique de compensation pour les besoins des pêches canadiennes.

INTRODUCTION TO OFFSETS

Fish productivity is defined by Minns (1997) as the sum of production rates (mass per unit time per unit area) for all co-occurring fish stocks within a defined area or ecosystem. Fisheries productivity is defined by Randall et al. (2013) as the sustained yield of all component populations and species, and their habitat, which support and contribute to a fishery in a specified area. Productivity can be measured directly via measurement of production rates of fish species of interest or indirectly via measurements such as biomass, catch per unit effort, or fishing yield (Minns 1997). Three recent papers have been prepared within DFO focusing on different aspects of fish productivity. Randall et al. (2013) examined interpretations of the ongoing productivity of fisheries while Bradford et al. (2014) proposed a framework to assess changes to fisheries productivity in Canada as a result of development projects. A third paper by De Kerckhove et al. (*In Prep*) focuses on promising indicators of fisheries productivity. This report is a supplement to these three existing reports and focuses on summarizing practical techniques that have been shown or have the potential to increase or sustain fish productivity.

Offsetting is one of the major concepts that have been explored worldwide in recent years as a means to reduce or mitigate impacts to fish productivity, habitat loss, or other ecosystem functions. Many papers have been published in the last decade describing the concept of biodiversity offsets or simply offsets (Burgin 2008, McKenney and Kiesecker 2010). There are multiple definitions to describe the concept of biodiversity offsets. Burgin (2008) defines biodiversity offsets as: "*conservation activities that are designed to offset residual, unavoidable damage to biodiversity caused by development activities*". Similarly, McKenney and Kiesecker (2010) state that "*offsets seek to compensate for residual environmental impacts of project development, after appropriate steps have been taken to avoid and minimize impacts on site*".

Previous fish habitat compensation activities under the *Fisheries Act* in Canada, as well as all the methods to increase or sustain fisheries productivity that will be described in this report, could be considered activities that fall within these broad definitions.

Offsets are used or are being considered for use in many countries to help preserve or maintain wetlands, terrestrial biodiversity, endangered species, and species assemblages (McKenney and Kiesecker 2010). In most definitions of offsets, however, increasing the productivity of a species or group of species is not the specific goal although increased productivity can potentially result from the activities. In some countries, offsets can include protecting existing land or contributing funds to research programs. However, some argue that protecting land does not increase productivity for any species and can lead to continued loss of productivity as ecosystems are still being destroyed or damaged by development (Bekessy et al. 2010).

There are positive and negative aspects to offsets and offsetting policies outlined in the literature. Some positive aspects of an offset approach can include:

- a national offsetting policy that is aligned with regional/local fisheries management, watershed and land-use planning objectives can result in the creation of larger, connected, and more effective restoration or habitat creation projects;
- in some cases, offset techniques can result in the creation and enhancement of more high-quality habitat or higher productivity areas than the area damaged or destroyed (Gillespie 2012);
- time lags and other sources of uncertainties can be reduced or eliminated by offsetting impacts of a project before the project is constructed;

- economic benefits can occur through the creation of spin-off industries to support some offsetting approaches, in particular, development of banks and support services (monitoring, insurance, legal, technical support) (Gillespie 2012);
- offsets or offset policies often fit well or support existing legal frameworks such as environmental assessment processes (Gillespie 2012).

There are also some potential negative aspects of offsets including:

- most definitions of offsets do not account for the value of ecosystem services or factors that can significantly affect populations such as meta-population dynamics and connectivity (Burgin 2008);
- there is uncertainty in species or ecosystem responses when substituting one area that will be destroyed or damaged by development for another area (the area created, enhanced, or restored through offsetting techniques);
- there can be time lags between the damage caused by development and the functioning of the offset area (Minns 2006, Bekessy et al. 2010, McKenney and Kiesecker 2010);
- it is often difficult to quantify the amount of offsets needed to ensure habitat (or in this case productivity) is maintained or increased;
- there can be uncertainty surrounding determining a biologically or environmentally suitable location for offsetting (McKenney and Kiesecker 2010, Gordon et al. 2011), as well as issues regarding public benefits of offset locations (if the offset is located in a different area from the habitat destroyed there can be public opposition);
- there are often problems with sufficient monitoring to determine offset success or failure and compliance with offset policies (Burgin 2008);
- often impacts of development or results of offsetting practices are not adequately documented (Harper and Quigley 2005, Quigley and Harper 2006, Burgin 2008) or projects do not function as intended;
- some impacts cannot be offset such as destroying unique, vulnerable or irreplaceable habitats or the habitat of an endangered species that could result in the extinction of the species (McKenney and Kiesecker 2010);
- offsets are usually considered for one or a few species only but the offset is more likely multidimensional and non-linear thus making it difficult to set the appropriate offset type and amount.

These problems are experienced for all activities that seek to reduce or eliminate the impacts of development on ecosystems but some can be minimized by adding stringent rules and restrictions to an offsetting policy.

Before attempting to offset impacts to an ecosystem, currencies or metrics have to be established to determine how much habitat or productivity or resource of interest will be lost and how much will need to be offset. Some surrogates that have been used to calculate aquatic and terrestrial biodiversity offsets have included area, habitat quality, species density, species occupancy, or some combination of these. A review of metrics suitable for fisheries productivity measurements has been conducted which should guide mangers in this respect (de Kerckhove *In Prep)*. There also must be sufficient information available on the species/ecosystem that will be affected to appropriately determine the level of impact and what processes will be affected by a proposed development before the impacts can be offset. Many offset policies require that offsets be larger than the anticipated impacts (required the use of multipliers) in order to ensure no net loss and to account for time lags between ecological destruction as a result of the project and offset functioning (McKenney and Kiesecker 2010, Overton et al. 2013).

One program that was designed to develop best practices for offsetting impacts of development on ecosystems is the Business and Biodiversity Offsets Programme. This program is summarized below to illustrate some of the work that has been completed to date on developing offset policies. As well, information is provided on the State of Queensland, Australia's, Marine Fish Habitat Offset Policy. Further information on the potential for an offset policy for Canada can be found in LeBlanc et al. (2013), *A Discussion Paper on a Policy Framework for the Use of Offsets under Canada's Amended Fisheries Act (2012)*.

BUSINESS AND BIODIVERSITY OFFSETS PROGRAMME

The Business and Biodiversity Offsets Programme (BBOP) is a large group of individuals, companies, financial institutions, conservation experts, and governments of various levels and from various countries whose goal is to work together to develop and test best practices for biodiversity offsets and conservation banking throughout the world (BBOP). The BBOP seeks to provide better and more cost-effective conservation outcomes resulting from development than those that currently exist, and also provide more certainty for companies undertaking development.

The BBOP has developed many research documents and completed pilot studies to examine virtually every aspect of offsetting and conservation banking. The group has developed an updated Biodiversity Offset Design Handbook (BBOP 2012a) to describe how to design an offset, engage stakeholders, undertake surveys, quantify residual impacts of development projects, determine potential sites for offsetting, calculate gains from offsetting, and determine final details and locations for offsetting. They have also published a Cost-Benefit Handbook and an Offset Implementation Handbook, as well as resource papers entitled: *No Net Loss and Loss/Gain Calculations in Biodiversity Offsets, Limits to What Can be Offset, Biodiversity Offsets and Stakeholder Participation,* and *Biodiversity Offsets and Impact Assessment.*

The BBOP stress the importance, as do most publications regarding offsets, of avoiding and minimizing impacts of development, then undertaking restoration on-site where possible, and then finally considering offsets as a last resort. They define offsets as "*measures taken to compensate for any residual significant, adverse impacts that cannot be avoided, minimised and/or rehabilitated or restored, in order to achieve no net loss or a net gain of biodiversity. Offsets can take the form of positive management interventions such as restoration of degraded habitat, arrested degradation or averted risk, protecting areas where there is imminent or projected loss of biodiversity*" (BBOP 2012b).

The following guidance on offsets is provided in the Biodiversity Offset Design Handbook. Offsets should be considered as early in the project review process as possible. Offsets should also demonstrate no net loss or a net gain of biodiversity (or productivity) and gains should be additional and linked directly to the offset activity (BBOP 2012c). The BBOP state that this requirement is what distinguishes offsets from other types of conservation activities. Suitable metrics for determining how to measure losses and gains must be determined in consultation with stakeholders. Activities that can be considered offsets fall into three broad categories:

1) Positive management interventions: includes topics that will be discussed in later sections of this report such as habitat restoration and habitat creation, as well as removing existing pressures or threats to an area.
2) Averting Risk: protecting important ecological areas where there is an imminent threat to the area or the population. Can include developing contracts with

companies/individuals whereby they protect habitat in return for payment or other negotiated benefits.

3) Providing compensation: providing payment to stakeholders affected by the proposed offset and development project so that they will support the offset and the project.

It should be noted that categories two and three do not offset impacts to productivity and can ultimately result in a net loss of productivity. Only category one, positive management interventions, will be further discussed in this report.

MARINE FISH HABITAT OFFSET POLICY (STATE OF QUEENSLAND, AUSTRALIA)

In Queensland, Australia under the Fisheries Act (1994) and the Sustainable Planning Act (2009), the Department of Agriculture, Fisheries and Forestry (DAFF), Government of Queensland, developed the Marine Fish Habitat Offset Policy. Any developer that will remove damage or destroy marine plants, or undertake works in a declared Fish Habitat Area (FHA) must offset these impacts. Developers must try to avoid, minimize, and mitigate fish habitat loss and only then are offsets considered to reduce or eliminate any remaining adverse impacts. The amount of offsets needed for a particular development project are calculated using a fish habitat offset package calculator which considers factors such as habitat area lost, costs of rehabilitation in another area, time of rehabilitation, costs of monitoring and management, area proposed for protection (if applicable), and others (Fisheries Queensland 2012).

Suitable offsets can include enhancing, restoring, rehabilitating or creating fish habitat, or protecting fish habitat. Protecting fish habitat must result in additional or new protection for an area, a tenure conversion (i.e. private to public land), or the creation of public reserves. If protection is used as the only offset type then the protected area must be a minimum of five times the size of the impact area. A fourth type of offset is an indirect offset whereby payments or in-kind contributions offset losses to fish habitat. For example, payments can be provided for fisheries research or fish habitat mapping projects or other research that is linked to priorities of the government's Fish Habitat Research and Management Program. Payments can also be provided for fisheries education and training, including scholarships, natural resources management programs, as well as to cover costs of managing and delivering restoration, rehabilitation or creation projects. Direct offsets are preferred over indirect offsets in the offset hierarchy (Fisheries Queensland 2012).

Further information on the Fish Habitat Offset Policy can be found at: Department of Agriculture, Fisheries and Forestry.

METHODS TO OFFSET IMPACTS TO PRODUCTIVITY

The following sections focus on methods that have been proven or have the potential to increase fish productivity. Methods include physical habitat manipulations including habitat restoration, rehabilitation, enhancement and creation; biological manipulations such as stocking; and chemical manipulations including nutrient additions. The emphasis for all sections is freshwater ecosystems, particularly streams, although marine and estuarine work is briefly discussed.

PHYSICAL HABITAT MANIPULATIONS

HABITAT RESTORATION AND REHABILITATION

Habitat restoration is defined by Roni et al. (2008) as returning an ecosystem to its original, pre-disturbance state whereas rehabilitation includes all other human activities that improve an ecosystem but do not completely restore it, including habitat enhancement, habitat creation, and even habitat manipulation. Habitat restoration is defined in DFO's 1986 *Policy for the Management of Fish Habitat* as the treatment or clean-up of fish habitat that has been altered, disrupted or degraded for the purpose of increasing its capability to sustain a productive fisheries resource. Both restoration and rehabilitation can include a suite of techniques whereby habitat that is degraded, damaged or of low value to the species or species assemblage of interest is improved through active human intervention (Roni et al. 2008). This section will focus on the physical rehabilitation or restoration of existing freshwater habitat, with some information provided on marine habitat enhancement through the use of artificial structures.

Habitat restoration and enhancement techniques can be an effective means of maintaining or increasing fish productivity. However, in the past there has been limited information on the effectiveness of different techniques (Roni et al. 2002) and some studies have shown that a considerable amount of restoration is required in order to significantly increase fish production for some species (Roni et al. 2010). Still other studies have shown that in heavily degraded areas such as urban streams, restoration actions at the reach scale do not improve ecological biodiversity (Stranko et al. 2012).

Instream habitat restoration has to be considered in the context of the status of the surrounding watershed and the role that watershed conditions have on instream habitat function. Recently, Null and Lund (2012) used a model to determine which restoration options best increased fish species productivity and recommended this technique be used to determine how to increase fish populations when operating under monetary constraints. They recommend that restoration techniques focus on restoring landscape processes that form and sustain habitats rather than traditional approaches focused on repairing and improving specific habitat conditions. Hughes et al. (2001) and Minns (1997) also recommend using models to better assess impacts on fish ecology in the United Kingdom and Canada. Honea et al. (2009) used a modelling technique to determine how habitat variables influenced Chinook salmon productivity, abundance, spatial structure and diversity. The model indicated how to potentially improve the salmon population by reducing fine sediments in the stream, thereby potentially increasing egg survival. Models can provide valuable information on which habitat or watershed variables should be focused on to improve restoration efforts however, sensitivity analyses should be incorporated into model testing (Steel et al. 2009, McElhany et al. 2010).

Roni et al. (2002) conducted a review of the effectiveness of stream habitat rehabilitation techniques for salmonids and, like Null and Lund (2012) stressed the importance of understanding watershed processes prior to undertaking rehabilitation. They present a hierarchical strategy for undertaking river restoration which involves first protecting areas of intact high-quality habitat, then improving connectivity of high-quality habitats (by removing barriers), thirdly restoring hydrologic, geologic, and riparian processes, and finally conducting habitat enhancement such as adding coarse woody debris, nutrients, etc. Frissell and Nawa (1992) also advocate a hierarchical approach, especially in areas impacted by forestry, involving first preventing channelization, slope erosion and inappropriate floodplain development, secondly rehabilitating failing roads, landslides, and other areas of instability, and finally reforesting floodplains and slopes. They state that unless large-scale negative impacts to a watershed are dealt with first, instream modifications will not be effective. Likewise, in order to ensure that restoration is effective, Kauffman et al. (1997) stress the importance of eliminating the causes of degradation before undertaking restoration. Otherwise, expensive restoration options and modifications will not function as desired. They advise that intact aquatic and riparian ecosystems should be protected first as protecting ecosystems is more cost-effective than restoring them (Kauffman et al. 1997, Hartman 2004, Stranko et al. 2012).

Restoration or rehabilitation of streams and other waterbodies for fish production can include a variety of techniques alone or in combination with others including:

- cessation of anthropogenic disturbance (i.e. stopping livestock grazing of riparian areas, stopping pollution or sediments from entering stream, etc.) and allowing the ecosystem to naturally restore itself (Kauffman et al. 1997);
- removal of debris;
- streambank stabilization and planting of riparian vegetation (Opperman and Merenlender 2004)
- establishing in-stream structure and cover by addition of gravels, cobbles or other substrates (Keeley et al. 1996, McManamay et al. 2010);
- addition of wood or coarse woody debris to increase habitat complexity (Coe et al. 2009);
- removal of barriers such as culverts or dams or diversion structures;
- reconnection of isolated or off-channel habitats such as oxbow lakes and floodplains (Keeley et al. 1996, Bellmore et al. 2012);
- regulation and/or restoration of flows (Clarke et al. 2008);
- installation of habitat structures to modify flow and prevent erosion (i.e. flow deflectors) (Frissell and Nawa 1992);
- changes to channel morphology including widening or deepening channels or adding sinuosity.

The effectiveness of these types of techniques varies widely by site, habitat, and species. Restoration methods may have to be modified for use in different areas and not all techniques will work in all watersheds.

Streambank Stabilization and Riparian Planting

The benefits of intact riparian plant communities are plentiful. Riparian plants shade streams and help control water temperatures, control sedimentation, contribute organic matter to the stream, provide food for invertebrates, contribute to large woody debris in streams and help increase or maintain habitat complexity (Lewis and Ganshorn 2007). Summer water temperatures are typically lower in stream reaches with riparian vegetation, such as large trees, than in cleared areas (Curry et al. 2002). Riparian vegetation can even improve channel form over time, often leading to narrower and deeper streams. In a stream in California with frequent flooding and high sediment loads, stream reaches with riparian areas that were restored 20 years prior (by erecting exclosures to limit browsing) were narrower with more elevation heterogeneity, more large woody debris and debris jams, and lower temperatures than control reaches. The authors argue that riparian vegetation restoration can be more useful and cost-effective for improving salmonid habitat than instream structures (Opperman and Merenlender 2004).

Often riparian communities require natural disturbances such as flooding as they are often composed of species that evolved under a natural disturbance regime. Natural riparian communities can be degraded by water diversion and flood control practices that modify the natural disturbance regime (Kauffman et al. 1997). In a Swedish study, researchers examined if boulder placement and barrier removal in streams following restoration was effective at increasing the ability of plant propagules to reach the riparian zone to enable colonization. They found that boulders did trap plant propagules at low flow but did not enable them to reach the riparian zone. This only occurred at high flows. They recommended that if riparian plant restoration is a key goal of restoration efforts, then designs should consider appropriate boulder placement for high flows (Engstrom et al. 2009). Restoration attempts to mimic natural flow regimes on regulated rivers have been shown to be successful at allowing recruitment of riparian vegetation, subsequently improving the instream and riparian environment (Rood et al. 2005).

A comparison of stream bank stabilization techniques (riprap, riprap with large woody debris (LWD), rock deflectors, rock deflectors with LWD, and LWD) and subsequent impacts on fish density found that riprap sites had the lowest fish densities compared to control sites and LWD sites had the highest densities compared to control sites. The authors found that in-stream LWD cover and overhead riparian cover, were the variables that most often impacted fish densities (Peters et al. 1998). Large woody debris bundles were also found to increase summer rearing densities of Coho Salmon in river reaches in Washington compared to control reaches and densities of salmon were positively related to the number of wood pieces per kilometre (Peters et al. 1996).

Fish have been shown to prefer natural riparian vegetation (wood/grass/reed combination) to artificial embankments such as concrete embankments as well as man-made riparian habitats consisting of reeds and grasses or reeds with a small proportion of woody vegetation in a navigable lowland river in Belgium. Fish species richness, abundance, and functional organization was highest in the natural riparian areas compared to the man-made riparian and concrete embankment areas (Mouton et al. 2012).

In-stream Structures

The addition of spawning gravels has been used to increase salmonid productivity in streams where spawning habitat is thought to be limiting. Based on five studies reviewed by Keeley et al. (1996), on average, spawning gravels increased 8.5-fold following rehabilitation compared to pre-rehabilitation levels. In general, restoration activities increased densities of both juvenile anadromous and resident salmonids (Keeley et al. 1996). Added gravels were utilized for spawning by river chub following restoration of a tailwater stream in North Carolina, although the study found that not enough gravel was added to improve spawning conditions for other species (eg. catostomids) (McManamay et al. 2010). Gravel additions or removal of fine sediments have also been shown to enhance salmonid spawning habitat in several other studies (Merz and Setka 2004, Merz et al. 2004, Suttle et al. 2004).

Coarse woody debris is often added to streams to enhance habitat diversity and cover. However, the positive impacts of coarse woody debris are species, age, and scale-specific. Langford et al. (2012) found that densities of older trout, lampreys, and large eels were positively associated with coarse woody debris at the reach-scale while densities of bullhead and age 0+ trout were negatively associated with coarse woody debris at the reach and habitat-scale. Percentage of pools, percentage of undercut banks, and percentage of coarse woody debris had the most influence on sockeye salmon densities in British Columbia (Braun and

Reynolds 2011). Rehabilitation efforts should consider impacts to different species and age cohorts before adding CWD as a means to increase salmonid densities or production.

Additions of wood in the form of engineered log jams increased periphyton biomass and invertebrate density compared to those on cobbles in streams in Washington (Coe et al. 2009). This can increase nutrients, food availability, and habitat complexity for salmonids and potentially lead to productivity increases. Engineered log jams also increased juvenile salmon and trout densities in a stream in Washington state, although impacts differed by species type and fish length (Pess et al. 2012). In a stream in Newfoundland, the addition of boulders, v dams, and half logs to reaches with different characteristics increased the density of Atlantic salmon and brook trout by increasing habitat heterogeneity and complexity. These in-stream structures impacted water depth, velocity, cover, redistributed bed material and contributed to pool creation (De Jong et al. 1997). In Japan, fish diversity and abundance of the four most dominant fish species was higher in stream reaches with simple wood structures and log jams than in control sites. Effects differed by species and by season (autumn vs. winter) (Nagayama et al. 2012).

The use of instream structures, however, does not always increase fish production and these artificial structures can have a high failure rate after floods or high flow periods or if they are placed without appropriate consideration of stream hydraulics and channel stability. After a flooding event in Oregon and Washington (flood of 2-10 year magnitude), Frissell and Nawa (1992) found that the median damage rate of instream structures in multiple streams was 60%. In their study there were a wide range of failure causes usually due to changes in channel morphology that were not taken into consideration during design. Elaborate structures (such as log weirs) that were put in place to change channel morphology and hydraulics failed most often while structures that failed less were those that minimally changed the channel (such as cables to stabilize woody debris). Unstable streams in watersheds heavily damaged by roads, logging and landslides with streambanks susceptible to erosion were those that were most unsuited to the placement of instream structures. A thorough examination of the watershed characteristics, considering flood occurrence and frequency, should be undertaken before implementing rehabilitation through the use of instream structures or these structures should be considered a complementary technique for habitat enhancement (Nagayama and Nakamura 2010). Other techniques may be more cost-effective and appropriate in some cases.

In some cases, instream structures can have unintended results, depending on site features and hydrological regimes. Eighteen rock weirs installed in a river in Oregon to improve stream habitat for native redband trout actually caused further loss of riffles and an increase in flat water in an already degraded stream. Gravel and sand substrates further declined and silt and clay increased. These negative impacts were likely a result of local erosion downstream of the weirs and backwater effects upstream of weirs. Before attempting restoration, the authors caution that geomorphic and hydrologic processes must be understood for the specific waterway to ensure structures have the impact they were intended to have (Salant et al. 2012).

Removal of Barriers and Reconnection of habitats

Removing physical barriers to fish or installing fish ladders is an obvious method of increasing fish access and potentially productivity, to previously unavailable habitats although this can also lead to negative impacts on some species or assist the spread of aquatic invasive species. Engineered fishways can improve or provide fish passage to otherwise inaccessible areas (Scruton et al. 2008, Hatry et al. 2011) although recent reviews have pointed to the need to improve fishway designs to improve the ability of fish to pass upstream of barriers (Noonan et al. 2012). Removal of natural barriers in five rivers in Newfoundland resulted in colonization by

Atlantic salmon into previously unavailable habitats. Enhancement activities combined with natural straying resulted in increases in the salmon stocks of all five rivers even though overall populations of Atlantic salmon in insular Newfoundland either remained constant or declined (Mullins et al. 2003). Removal of two dams in a Maine stream resulted in the immediate upstream migration of many fish species, including anadramous Atlantic salmon, as well as the homogenization of stream reaches. Further monitoring will indicate the longer term impacts of dam removal (Gardner et al. 2013).

Connecting side channels that may have been cut off from the main stem of a waterway can also be important for increasing fish productivity. Side channels have been shown to be important production areas for Pacific salmonids including chum and Coho salmon (Keeley et al. 1996). In a study in British Columbia, salmonid biomass and density was higher in stream-type side channels compared to pond-type side channels but parr weight was 47% lower in stream-type side channels. There was no difference in smolt production between the two side-channels although this may have been due to a lack of data or data variability. The authors concluded that side-channels need to provide a variety of habitat types including flowing (spawning and rearing) and standing water (rearing and overwintering) to maximize value for salmonids (Rosenfeld et al. 2008).

Cutting off rivers from their floodplains has historically occurred as a result of human activities including agriculture and urban development and can result in negative impacts to fish. In a comparison of 24 stream reaches in Vermont, it was found that fish assemblage diversity was highest at reaches with high floodplain connectivity. Species turnover (measured as β diversity, a measure of the difference in species composition between local assemblages from the main channel to the floodplain) was negatively associated with floodplain connectivity (Sullivan and Watzin 2009). In a study of wetlands in the Great Lakes, overall species richness and piscivore richness increased with aquatic connectivity. Connectivity was found to influence both the local species present and the abundance of these species in a wetland (Bouvier et al. 2009).

Barriers to fish are not always physical and attempts should be made to determine what factors limit species movements prior to restoration. For example, a study in California showed that Coho salmon are likely limited to the downstream 20 km of a 90 km stream due to a water temperature barrier midstream. This barrier developed over 30 years as a result of human activities including stream widening and removal of riparian trees (Madej et al. 2006).

Restoration of Flows

Impacts to flows within rivers and streams can have multiple impacts on fish and other species. Water flows impact fish food supplies, physical habitat, water quality measurements including temperature and turbidity, nutrient dynamics, gas pressure, access to habitats (Clarke et al. 2008), sediment transport, and erosion (Kondolf 1997). Impacts to the natural flow regime of waterways can result from many human modifications such as the construction of dams, hydroelectric facilities, water withdrawal for agricultural or other purposes, and flood control measures (Enders et al. 2009). Low flows resulting from dam construction have been shown to encourage the growth of aquatic plants and thereby decrease the spawning habitat available for Chinook salmon (Merz et al. 2008). Extreme low flows (less than 142 m^3/s) have been found to impact spawning habitat and likely recruitment of Gulf sturgeon (Flowers et al. 2009).

Controlling or restoring flow to waterways has been shown to impact fish productivity. For example, in insular Newfoundland, the placement of hydraulic control structures on a flood bypass channel of the Rose Blanche River provided constant regulated flow to an area that was previously only wetted during snow melt events. Other habitat enhancement measures included creating pools, stabilizing banks, adding spawning gravels, and constructing protection dykes to prevent flooding. Monitoring of the impacts of this controlled flow over three years showed a steady increase in fish biomass (an indicator of productivity) in the channel each year (Scruton et al. 2005). After restoring flow to a dry streambed in British Columbia, adult salmon colonized the area and began spawning within 1-8 months. Juveniles however, did not move into the area in the first year if they were born farther downstream (Decker et al. 2008). Similarly, after a 5-fold increase in flow velocity on a reach of the Rhone river in France, there was a significant change in fish community structure and a significant increase (two to four-fold) in abundance of species favoring fast-flowing and/or deep habitats within only 4 years (Lamouroux et al. 2006).

Conversely, restoring 50% of the flow in the Trinity River of California, along with other rehabilitation methods including gravel placement and mechanical rehabilitation, did not result in a higher abundance or a higher condition of threatened Coho salmon in restored reaches compared to reference reaches (Chase et al. 2013). As well, although pacific salmonid abundance increased following experimental flow release in a regulated river in British Columbia, increases were due to the re-watering of a previously dry channel below the dam. Reaches that had continual water had higher salmonid abundances after the flow release than the re-wetted channel (Bradford et al. 2011). The study findings conflicted with habitat models for the stream, as well as with holistic in-stream flow approaches.

Flow releases have variable impacts on biota and the physical environment and further information is needed to determine the long-term impacts of ecological flow releases (Konrad et al. 2012). In a review of 165 papers on the impacts of flow alteration on ecological responses, it was found that ecological responses of macroinvertebrates, riparian vegetation, and fish were highly variable and 92% of papers reported decreased values for measured ecological metrics in response to flow alteration. Fish abundance, demographic rates, and diversity were found to consistently decline in response to both elevated and reduced flows (change in flow in all studies was more than 50%). Fish were the only species group to show consistent negative impacts to both increased and decreased flows (Poff and Zimmerman 2010). A study on the impacts of flow increases at 17 sites in five streams in France over 4 to 12 years on brown trout populations revealed variable results by monitoring year as well as by site. Numbers of adult trout increased 22.8% overall, but effects varied considerably with year and site. For young trout, almost all sites showed growth in numbers, with an average increase of 1014% for the 0+ class and 99% for the 1+ class. For adults, mean biomass was higher at control sites compared to experimental sites and the mean at experimental sites was slightly higher pre-treatment compared to post-treatment, but again results were highly variable (Sabaton et al. 2008).

Many studies of effects of flow restoration use reference reaches to compare impacts on biota from changes in flow. However, Downs et al. (2011) point out that many regulated rivers do not have an appropriate reference reach as there is no historical data available for the river or the river is so impacted by dams and other structures that no reference reach exists upstream or downstream. They recommend that a true reference for restoration in regulated rivers should be created by collecting baseline data on the river in its current condition, and using models to develop realistic reference conditions. They argue that this method helps managers to more accurately determine how management actions will impact the river.

Channel modifications

Channel modifications following rehabilitation or restoration typically decrease stream gradient, shear stresses, erosion and water velocity and increase pool: riffle ratios, habitat heterogeneity and instream cover (Baldigo and Warren 2008). Natural Channel Design (NCD) is sometimes a goal of restoration projects that modify stream channels. The concept of NCD is that data from stable stream reaches in the area are used to restore unstable reaches with the ultimate goal of balancing processes in the stream and allowing the stream to reach a state of dynamic equilibrium (Baldigo and Warren 2008). Baldigo and Warren (2008) used NCD techniques on four reaches in three streams in New York State to decrease erosion and sediment loads and found that following restoration, community biomass and richness increased by almost one third. On average across the four reaches, salmonid density (dominated by brown trout) increased substantially following restoration to 0.16 fish/m^2 (a 253% increase) and density increased to 3.65 g/m^2 (a 239% increase) whereas the density and biomass of species such as dace and slimy sculpin did not change significantly.

A major channel modification project is currently ongoing in the State of Florida. The Kissimmee River, once a 103 mile long meandering river was channelized in the 1960s into a 56 mile long canal to provide flood control. Due to the environmental impacts of the channelization, a multi-year restoration project began in the 1990s to increase water storage in the upper Kissimmee Basin, backfill 22 miles of the canal, recreate nine miles of river channel, remove two water control structures, and remove floodplain levees (Dahm et al. 1995, Florida Department of Environment Protection 2013). The first phase of reconstruction was completed in 2012 and an assessment of the restoration impacts is planned for 2017. Although a complete assessment of the impacts of restoration are not yet known, some studies that have taken place to examine impacts of partial restoration on fish, such as largemouth bass, have been varied, with no conclusive results (Allen et al. 2003).

Much information can be found in existing literature on restoring flood plains and recreating stream meanders to improve biological and hydrological function (Brookes and Shields 1996), but little information seems to be readily available on follow-up studies to quantify impacts to fish productivity or overall ecosystem productivity.

Marine and Shoreline Structures

Numerous studies in the marine environment have shown that the addition of hard substrates to otherwise sandy substrate areas can impact many forms of aquatic life. Offshore wind power foundations in the North Sea have been shown to increase macrozoobenthos biomass, dominated by blue mussel (*Mytilus edulis*), up to 35 times more than biomass at comparably-sized sandy substrates (present before the wind power foundations were installed) (Krone et al. 2013). Reubens et al. (2013) compared the spatio-temporal variability of Atlantic cod and pouting at artificial wind power reefs (foundations), shipwrecks, and sandy-bottom sites, also in the North Sea, and found that the highest population densities (catch per unit effort) were at the artificial wind power reefs, showing that these types of artificial structures can have significant impacts on fish species. Another study in Santa Maria Bay, Cape Verde, showed that artificial reefs can have comparable species richness to natural reefs (after 1-3 years) and promote fish biodiversity in areas where natural reefs may be under threat (Santos et al. 2013).

The type and arrangement of hard substrate is important, however, in determining impacts to aquatic species. A study in Thailand found that a wave-breaking wall composed of ten rows of adjoining concrete poles along a sandy coastline did not significantly influence the abundance of fish, shrimp, or zooplankton in the area although it did increase the abundance of macroepifauna (also referred to as fouling organisms) such as *Balunus* spp (Hajisamae et al. 2013). As well, shoreline hardening, where structures such as riprap or retaining walls are used to harden shorelines and prevent erosion, can have significant impacts on species. Atlantic silverside, who spawn in the intertidal zone, were found to preferentially choose to spawn along natural shorelines with *Spartina alterniflora* in association with green algae rather than shorelines hardened with artificial structures such as riprap and bulkhead or those inhabited by *Phragmites australis* (Balouskus and Targett 2012). In wetland shorelines of the

Upper Winnebago Pool Lakes of Wisconsin, fish were twice as abundant at natural shoreline sites as compared to shorelines armoured with riprap (Gabriel and Bodensteiner 2012).

HABITAT CREATION OR CONSTRUCTION

In some cases, restoration or rehabilitation of habitat is not an option and in order to provide habitat or increase the productivity of fish, new habitat must be constructed. In this report, habitat construction refers to the creation or expansion of aquatic habitat such as ponds, streams, or wetlands into a previously dry area.

Stream Habitat Creation

There are several examples of freshwater stream habitat construction projects in the published literature. In the Northwest Territories, a 3.4 km artificial stream was constructed to provide habitat connectivity and provide spawning and rearing habitat for Arctic Grayling, to compensate for the habitat lost following the destruction of two ponds and their tributaries to develop a diamond mine. Several studies were conducted following construction of the artificial stream and showed that the constructed stream was of lower quality than existing reference streams and had a lower biomass of grayling than reference streams (Jones et al. 2003). During at least the first four years following construction, the new stream had less: riparian vegetation, coarse particulate organic matter, large woody debris, aquatic vegetation, and macroinvertebrate diversity and richness (Jones et al. 2008). In the Pacific Northwest, eleven groundwater–fed constructed side channels were compared with reference sites and were also found to have lower canopy cover, woody debris, and physical habitat diversity but they had higher densities of Coho salmon than the reference sites. Constructed channels were also deeper than reference sites. Both the reference and constructed channels supported high densities of fish including trout and Coho salmon (Morley et al. 2005).

Another stream creation project, necessitated by fish habitat destruction due to the development of a mine in Labrador, was the creation of the Tinto Brook channel, measuring 5680 m^2. The brook was created to provide spawning and rearing habitat for brook trout. Monitoring has shown that the created habitat is stable with adequate flows for brook trout but brook trout abundance in the stream has been low. However, monitoring in 2009 and 2010 indicated that brook trout may be using the brook for spawning although further monitoring is needed to confirm and to determine abundance in the stream (Roberge and Warren In press-a).

Another stream creation project that has been shown to be very successful as spawning habitat for landlocked salmon is Compensation Creek. This creek was engineered in Newfoundland to create habitat for Atlantic salmon (ouananiche) and brook trout as a result of the destruction of habitat following construction of a hydroelectric development. The creek consisted of a main channel measuring 15 m wide by 1600 m long designed to provide spawning habitat for ouananiche and two side channels (4.5 m wide and 400 m long and 4.5 m wide and 570 m long), designed to provide spawning habitat for brook trout. Various studies have been undertaken within the creek including a study on fish habitat use (Enders et al. 2007), the benthic macroinvertebrate community (Gabriel et al. 2010), and use of the creek by spawning ouananiche from the adjacent Meelpaeg Reservoir (Clarke In press). These studies have shown that the creek is functioning as designed and that ouananiche from all sampled areas of the reservoir are using the creek for spawning (unpublished data; Clarke In press).

Another study in Newfoundland showed that fish biomass could be increased in a relatively small stream creation project. In the Seal Cove River of Newfoundland a 195 meter long portion of river was created to compensate for the destruction of 162 meters of river for a highway project. The newly created portion of the river was designed for brook trout with a high pool:riffle ratio and overhead cover areas (Scruton 1996). The density and biomass of brook trout was calculated before destruction, for several years after construction of the new habitat (1991-1994), and then again five years later (1999), and finally again, 8 years later (2007). By 2007, 25% of the brook trout in the new habitat were longer than 150 mm while the size distributions of trout in control streams did not change. This increased the trout biomass of the stream considerably (Clarke In press).

Another study in British Columbia found that artificial side channels provided rearing habitat for young Coho salmon although benefits to salmon were increased in side channels with upwelling groundwater and the authors stressed the importance of routine maintenance (i.e. removal of beaver dams, removal of excessive vegetation growth) in order to ensure continued effectiveness. Eight of ten constructed side channels functioned as designed with four functioning very well and supporting large numbers of fish (Cooperman et al. 2006). An earlier study also indicated the abundance of Coho salmon in these types of constructed streams was strongly dependent on the availability of instream cover (Sheng et al. 1990).

Many projects involving aquatic habitat creation lack follow-up study and often data is not published or published documents are difficult to find. There are very few comprehensive reviews or meta-analyses available on the effectiveness of creating fish habitat. Wilders and Lirette (1994) state that several artificial streams were created in British Columbia to provide spawning habitat for salmonids but do not provide references, only referring to personal communication. They report on inconclusive results of the use of an artificial spawning channel at Sheridan Lake, B.C. to provide habitat for spawning rainbow trout (Wilders and Lirette 1994). Bradford et al. (In press) point to the importance of long-term monitoring in restoration and creation projects, due to deterioration of man-made structures over time and changes to artificial habitats such as infilling due to sedimentation. Hartman and Miles (2001) surveyed regional DFO staff in British Columbia to determine the success of spawning channel creation and enhancement to existing inlets and outlets for spawning by rainbow trout and found that 63% of the projects had limited or no success and 37% had moderate or outstanding success. For 10% of the projects there was insufficient information to determine success or failure.

Wetland Habitat Creation

Wetland habitat creation projects have been undertaken many times, particularly in the United States, although most reported studies of wetland creation focus on wetland function or habitat creation for birds or other species, rather than directly examining the impacts of wetland creation on fish or fish productivity. Smokorowski et al. (1998) reviewed projects involving the creation of new wetlands and found that most studies involved pond excavation and planting of macrophytes and quantitative fish surveys were usually not undertaken. Frisk et al. (2011), however, published results of one study in Delaware Bay estuary where wetland habitat creation involved increasing total marsh area by 3% and this created habitat was calculated via modelling to have increased the total biomass of the ecosystem by 47t/km^2/year. Gains were species specific but most species did show biomass gains with several fish species showing large gains including menhaden, striped bass, and bay anchovy.

In some cases, wetland restoration can be combined with fish habitat creation. One example is the restoration of a salt marsh in California that included the creation of artificial pools to enhance food supply for fishes. These pools quickly developed an invertebrate food supply for fishes that exceeded the abundance of invertebrates in natural pools. The authors conclude that these types of created pools can help support fish populations in restored marshes (Larkin et al. 2009). Similarly, in Delaware Bay, a marsh (once a salt-hay farm bordering the bay) restored in 1996 had greater numbers of striped bass that a reference marsh by 1998, although food habits and utilization of connecting creeks was similar (Tupper and Able 2000). Williams and Zedler (1999) compared fish assemblages in estuarine channels in four constructed and four natural marshes San Diego Bay, California and found indicators that physical channel characteristics were more important in determining fish use than restoration status (channel age). Fish were found to rapidly colonize newly created channels and no effect of channel age was found on fish density.

In contrast, another study of salt marsh creation in North Carolina found that, after three years of monitoring, the created marsh had a much lower abundance of mummichog (*Fundulus heteroclitus*) than natural marshes in the area, possibly due to less protective cover or lack of spawning areas in the new marsh. The authors provide some methods to improve the created salt marsh for fish but point out that natural salt marshes cannot be replaced by new marsh creation, at least not without considerable time lags (Moy and Levin 1991). An estuarine restoration study in the Campbell River estuary on Vancouver Island, designed to create a networks of channels for juvenile salmonids, also found a considerable time lag for created sites to reach the level of vegetation in reference sites, consisting of seven to thirteen years (Bradford et al. In press).

BIOLOGICAL MANIPULATIONS

STOCKING

There are several terms used in the literature with respect to stocking including re-stocking and stock enhancement. Stock enhancement or supportive breeding is defined as the augmentation of a natural supply of juveniles to increase the productivity of a wild population to overcome a recruitment limitation. Re-stocking is the release of artificially-reared juveniles into a wild population to help restore depleted spawning biomass to a level where it can provide regular, sustainable yields (Bartley and Bell 2008). In some cases, stocking is used to create a put-and-take fishery. Since the early 20th century, stocking has been used as a method to increase fishery yields and boost declining fish stocks worldwide (Buhle et al. 2009). In recent years, however, stocking has been shown to have negative impacts and its use is becoming controversial.

Stocked fish can have negative impacts on wild populations by reducing the reproductive fitness of wild populations through breeding. The genetic diversity of wild populations can be homogenized by breeding with artificially reared individuals and this can impact the resiliency of the wild population to environmental changes (Hess et al. 2012). In Australia, endangered eastern freshwater cod (*Maccullochella ikei*) showed a 21% loss in heterozygosity and 24% decline in allelic richness compared to historic levels, mainly as a result of a hatchery breeding program used to help re-establish and supplement remnant populations (Nock et al. 2011). These genetic impacts are of particular concern for rare and endangered species.

Hatchery-reared juveniles often have lower survival, lower reproductive fitness, or lower reproductive success than their wild counterparts or they may reduce the survival of wild fish through competition or increased predator abundances. Fleming and Gross (1992) found that wild and hatchery-raised Coho salmon behaved differently and showed physiological differences during spawning, with hatchery males being less active and less aggressive than wild males, and hatchery females having lower fecundity but larger egg size than wild females. These differences can result in lower reproductive potential in hatchery fish. In another study, four Atlantic salmon populations showed moderate to high levels of genetic admixture (12 to 60 %) with hatchery fish following stocking. This admixture can result in a loss in fitness and in local adaptations in wild fish. Simulation models show that stocked fish had a 10-25 times lower survival than wild fish (Perrier et al. 2013). Negative impacts of stocking have been shown in many other studies on various fish species including Atlantic salmon, brook trout, brown trout, steelhead trout, rainbow trout, Coho salmon and other Pacific salmon (*Oncorhynchus spp*.) (Buhle et al. 2009, Pine et al. 2009, Araki and Schmid 2010, Anderson et al. 2013).

Some stocking and enhancement programs have shown mixed results. An enhancement program for Atlantic salmon in Northern Ireland conducted from 1996-2005 significantly enhanced smolt recruitment but the biological quality of individuals resulting from the stocking activities were inferior to wild fish. Stocked 1+ year smolts were lighter than their wild counterparts and smolts derived from hatchery-fry tended to run earlier than wild smolts. Smaller smolts have lower marine survival rates and earlier running smolts may undergo transition to saltwater outside the optimal time period again adding to decreased survival. Overall, for this program, marine survival of stocked smolts has continued to decrease and thus, adult returns have not increased (Kennedy et al. 2012).

Widespread hatchery programs have been used in the 1980s and 1990s in an attempt to restore stocks of Pacific salmon in western North America. Impacts of recent reductions (1990s) in Coho salmon stocking on the Oregon coast were examined by Buhle et al. (2009) and they found that salmon productivity (in the absence of harvest), improved when the density of hatchery-origin fish declined (including hatchery fish spawning as adults and hatchery smolts released into rivers). Poor ocean conditions combined with high rates of stocking had the most negative impacts on wild salmon productivity. Rather than stocking, the authors suggest that reducing other threats to salmon such as reducing harvest rates and restoring habitats may be more effective at increasing salmon populations.

The authors do point out, however, that supplementation hatcheries, which they state are designed to integrate both wild and captive-reared animals, may help minimize some of the negative impacts of stocking found in their study. This is in keeping with the findings of Hess et al. (2012) who used molecular markers to track two generations of Chinook salmon (wild and hatchery-reared) breeding in the Columbia River in Idaho and found that for salmon that reproduced, there was no significant difference in the reproductive success of hatchery or wild salmon. Hatchery fish produced more adult offspring and adult grand-offspring than wild fish. The authors concluded that the supportive breeding program, which used local, wild-origin broodstock, did successfully boost population size without significant impact to the fitness of wild salmon.

Araki et al. (2007a) also found that steelhead from a supplementation hatchery (reared in hatchery but allowed to spawn in wild) had the same reproductive success of wild fish. However, fish from a traditional hatchery (nonlocal broodstock, raised for multiple generations in captivity) spawning in the same river had significantly lower fitness than wild fish. As well, crosses between traditional and supplementation hatchery fish also had lower fitness than expected. Araki et al. (2007b) also found that the reproductive fitness of hatchery-reared steelhead trout allowed to spawn in the wild declined approximately 40% per captive –reared generation in the Hood River in Oregon.

Araki and Schmid (2010) reviewed 266 scientific studies on hatchery stocking to determine if stocking is helpful or harmful. They divided the studies into categories including ecological studies on fitness and genetic studies on fitness. Of 18 ecological studies that compared hatchery and wild stocks and addressed fitness effects, 11 showed negative impacts of hatchery rearing on fitness, 9 out of those 11 suggested that stocked fish had lower survival or higher susceptibility to predation, and three studies implied that hatchery fish had lower breeding success, lower growth rates or behaved differently than wild fish. Three studies indicated positive impacts of stocking and included species such as Atlantic cod (positive impacts in 6 of 16 population samples), steelhead trout, and European lobster. There were 21 genetic studies that compared hatchery and wild stocks and addressed effects on fitness. Of these studies, 12 showed negative impacts of hatchery rearing on the fitness of hatchery fish with 8 studies suggesting hatchery fish have lower reproductive success and 4 studies suggesting that hatchery fish have lower survival than their wild counterparts. Six studies did not find any negative fitness impacts of stocking however there were very few studies that indicated hatchery stocking enhanced wild stocks.

On the other hand, there are some studies that have shown stocking to be beneficial or found no negative impacts of stocking. For example, in a series of interconnected lakes in Australia, regulated for irrigation purposes, stocking significantly increased the abundance of adult golden perch to support recreational fishing (Hunt et al. 2010). Another study in Washington found no significant difference in breeding success between wild and hatchery Chinook salmon males after one generation in the hatchery, at least in an experimental artificial stream setting, although wild males were found to be more aggressive (Schroder et al. 2010).

Should managers choose to consider stocking as a means to boost fish populations, Araki and Schmid (2010) recommend that genetic sampling be undertaken before, during and after stocking to ensure that the reproductive contribution of stocked fish can be determined. Managers need to know what factors are limiting a population prior to undertaking a stocking program and should be able to reasonably predict the ecosystem impacts of a stocking program on other aquatic species (Bartley and Bell 2008). Stocking programs should consider:

- management objectives (increase harvest, increase productivity, maintain populations, etc.) (Aprahamian et al. 2003);
- cost:benefit analyses – cost of stocking activities versus benefit to wild fish stocks or fishers;
- availability or surplus of wild spawning adults to obtain broodstock or knowledge of the genetic origin of other broodstock material (Kennedy et al. 2012);
- possible fitness and genetic impacts on wild fish (Araki and Schmid 2010);
- density-dependent impacts on juveniles (Vincenzi et al. 2012);
- predation of juveniles;
- predator population dynamics and activity periods;
- timing of release of stocked fry or smolts;
- stocking fed versus unfed fry (Kennedy et al. 2012)
- methods and locations of release of stocked fish (Thorstad et al. 2012);
- quantities of released fish (Aprahamian et al. 2003);
- availability of habitats for increased fish numbers, especially juvenile and spawning habitat;
- food availability;
- impacts on other species (in one study, stocked fish resulted in lower mercury levels of sport fish (walleye) in reservoirs (Lepak et al. 2012)).

If hatchery fish are released into habitats where the existing/wild population is at or near its carrying capacity (food or habitats may be limiting a population) the benefits of the release will be greatly diminished. As well, if released fish are immediately destroyed by predators or compete with wild stocks for limited resources then stocking is not effective (Bartley and Bell 2008). Due to the negative and mixed impacts of stocking, it should not be undertaken without thorough study of the fish population, the ecosystem impacts, and careful consideration of the stocking and rearing techniques to be used.

DFO reports in *Canada's Policy for Conservation of Wild Atlantic Salmon* that government-owned hatcheries were once used in Newfoundland, the Maritimes and Québec to augment production of salmon for enhanced economic returns in the commercial and recreational fisheries. These practices were ended by DFO in the 1990s and any remaining facilities now focus on maintaining genetic diversity in populations listed as 'endangered' under the *Species At Risk Act* or those that are at risk of extirpation in the near future (DFO 2009). In the Pacific region, the Salmonid Enhancement Program which began in 1977 has been used to enhance Pacific salmon populations through natural and artificial enhancement techniques. Due to the known risks of using hatcheries to enhance salmon stocks, SEP has developed guidelines and annual planning processes to manage spawning and hatchery practices to maintain genetic diversity and minimize impacts to wild fish. In addition, all fish movements are reviewed and licenced under Section 55/56 of the Fishery (General) Regulations (DFO 2005).

TRANSLOCATIONS

In some cases, fish species are introduced to new waters, in an attempt to create a new fishery, enhance existing fisheries, or increase the population size of a species by placing them in previously fishless waters. Studies of these types of translocations have shown that populations are able to establish in new waters but there has been little study of the impacts of these species on the rest of the ecosystem (Vincenzi et al. 2012). Some researchers suggest that introductions or translocations should not ever occur due to uncertainty of the impacts, especially under changing climatic conditions (Ricciardi and Simberloff 2009). In a review by Kerr and Grant (2000) on the impacts of fish introductions in Ontario, several potential negative impacts of introductions or translocations on wild fish were listed. These included:

- increased predation;
- introduction of diseases and parasites;
- change in the genetics of wild population;
- changes to fish community composition and dynamics;
- impacts to other aquatic flora and fauna;
- habitat alteration;
- behavioural and physiological changes in other species.

Despite these potential impacts, numerous translocations of various fish species have occurred and have been deemed successful (from a fishery perspective) by managers. Hartman and Miles (2001) report that rainbow trout were translocated into hundreds of barren lakes in British Columbia, although few records were kept in the past. Translocations have occurred all over North America including Labrador. Due to two different development projects in Labrador, several lakes were destroyed, and to compensate for the loss of fish habitat, fish were translocated into previously fishless lakes. Extensive surveys were conducted prior to fish transfer to ensure the receiving lake was suitable for fish and provided all necessary habitats for all life stages (Roberge and Warren In press-b). In one example, brook trout and lake chub were translocated from Hakim Lake (destroyed) into fishless White Lake. Additional spawning and rearing habitat was created at a pond outflow for brook trout. Fish were translocated in 2003 and monitoring using a variety of metrics was undertaken until 2010. Population estimates of lake chub in 2008 showed that the population was sustaining in White Lake, while the brook trout populations had increased in size. In the second example from Labrador, brook trout and Arctic charr were translocated from Headwater Pond into Pond 61 (part of the same watershed). The transfer took place in 2004 with monitoring to occur until 2014. As of 2010, Arctic charr showed considerable increase in population size while the brook trout population decreased dramatically following transfer with a subsequent increase by 2010. Further monitoring will indicate the status of the brook trout population (Roberge and Warren In press-b).

Another translocation study was conducted in an effort to boost Marble trout populations; a species of conservation concern in Slovenia. Trout were translocated into previously fishless streams within the native habitat range of the species. Monitoring of the translocated populations over 15 years has shown that trout successfully reproduce within the streams. The populations are also thought to be fairly resilient to extinction although they are impacted by severe flood events (Vincenzi et al. 2012).

Other translocations have involved American eels, which have been translocated into the upper St. Lawrence River and Lake Ontario from sites in the Maritimes, as there have been significant declines in American eel recruitment in these areas. Although rates of dispersal and survival of these elvers is unknown, they have been shown to disperse around Lake Ontario, move downstream and were shown to have rapid growth rates. Further monitoring is needed to ensure these translocated eels do not negatively impact naturally migrating eels (particularly large, fecund females) that migrate into Lake Ontario. As well, monitoring is needed to determine if these eels will successfully initiate spawning migration with naturally migrating eels (Pratt and Threader 2011). Earlier research, by Verreault et al.(2010) indicated that translocated American eels began silvering and out-migrating to the St. Lawrence River from the Richelieu River (500 km upstream) within four years of stocking, indicating that this may be possible in other locations as well.

CHEMICAL MANIPULATIONS

Chemical additions to aquatic habitat in the form of nutrients (e.g. fertilizers, carcasses) can be used as a method to boost primary productivity and ultimately, boost fish productivity. Adding nutrients may be a viable method of increasing productivity, particularly in oligotrophic lakes and rivers or in regulated rivers where man-made structures block nutrients from flowing downstream (Stockner and Macisaac 1996) or hydraulic alterations affect nutrient dynamics (Matzinger et al. 2007).

Pacific salmon spawn in streams, rivers and lakes and juveniles rear in lakes and streams for 0-2 years before heading to sea. Pacific salmon die after spawning and their carcasses provide marine-derived nutrients (MDN) to generally nutrient-poor freshwater lakes and rivers. These nutrients are taken up by riparian and aquatic vegetation, contribute to phytoplankton growth, and contribute to the growth and survival of subsequent salmon generations (Helfield and Naiman 2001). Salmon carcasses in rivers have been shown to increase the fork lengths of the following generation of juvenile salmon and up to 40% of the carbon in a juvenile smolt has been shown to be derived from MDN (Gresh et al. 2000). A positive-feedback mechanism exists between salmon adults, riparian vegetation, and salmon egg and fry survival. Nutrients from adult salmon spawning contribute to riparian forest growth which further improves spawning habitat by stabilizing habitat, filtering sediment, providing allocthonous organic matter, and contributing to the deposit of large woody debris (Helfield and Naiman 2001). Due to significant declines in returns of Pacific salmon in Canada and the US, there have been substantial declines in the amount of nutrients transported to freshwater lakes and rivers, resulting in lower quality conditions for juvenile salmon and potentially smaller sized juveniles with lower survival rates.

As a result of this situation, fishery managers have added nutrients to freshwater lakes and rivers to enhance salmon populations. In British Columbia, from 1976 to the late 80s, Fisheries and Oceans Canada added nutrients once per week throughout the growing season (5 months) to 20 sockeye salmon nursery lakes. A study published in 1996 showed that there was increased bacteria activity and abundance in the lakes, picoplankton and phytoplankton abundances increased significantly, and primary production and zooplankton biomass doubled in some lakes. Smolt weights of juveniles increased more than 60% and juveniles showed increased survival (Stockner and Macisaac 1996). Fertilization of the Keogh River in British Columbia with nitrogen and phosphorus from 1983 to 1986 resulted in 1.4 to 2.0-fold increases in the weight of steelhead trout and coho salmon fry and increases in the size of fry (Johnston et al. 1990). A review of fertilization impacts on sockeye salmon nursery lakes published in 2004 revealed that all reviewed studies involving whole-lake fertilization showed increased chlorophyll a concentrations, zooplankton biomass, and average smolt weights. Four of four studies showed increased egg-to-smolt survival, three of three showed increased smolt-to-adult survival, and eleven of thirteen showed increased smolt biomass (Hyatt et al. 2004).

Several studies have explored the use of salmon carcass analogs to enrich oligotrophic waters. Carcass analogs are generally pellet-shaped dried, ground and pasteurized salmon carcasses that may be combined with other ingredients such as marine fish bone meal (Pearsons et al. 2007, Kohler et al. 2012). They can be added to waterways where they sink to the bottom and are eaten or dissolve. One study in the Columbia River basin, in Washington, Oregon and Idaho, used salmon carcass analogs to enrich 15 streams from August to October, resulting in significant increases in periphyton crop, macroinvertebrate density, salmonid growth rates and stomach fullness measures. The amount of carcass analogs added to the streams was based on target carcass levels from earlier studies. The authors found no increase in dissolved nutrient levels during the study period which differs from studies that have added full carcasses to waterways. It may have been that the biological demand for nutrients was so high it exceeded the supply. The authors also point out that both entire salmon carcass additions to waterways, as well as carcass analogs, do not provide all the benefits that come from natural salmon spawning and decomposing in streams. They stress that further research is needed on the impacts of carcass and carcass analog additions to streams and that restoring natural spawning cycles should be the ultimate goal of any restoration (Kohler et al. 2012).

Despite successes with nutrient additions, there can be negative impacts. Fertilization can increase the growth of blue green algae or ungrazeable diatoms (such as *Rhizosolenia eriensis*) which absorb much of the nutrients resulting in decreased volume of grazeable diatoms. There can be an increase in competition causing an increase in non-targeted species (for example, mysids and sticklebacks have been shown to compete with salmon for resources). There can be variability in the impact of fertilization depending on lake size, depth, and turnover time (Hyatt et al. 2004). Only a tiny proportion of the fertilizer added to a lake makes its way to the target fish in the food chain, resulting in potentially high expense for minimal gain. For example, as reported in Hyatt et al. (2004), during fertilizer additions to Woss Lake, BC in 2000-2003, it was estimated that it cost approximately $200 for each kilogram of enhanced sockeye smolt production. Most nutrient addition-related problems can be minimized with appropriate use and timing of limiting nutrients (controlling nitrogen vs. phosphorous), monitoring, predator control of non-target species, and determining the factors limiting the target fish population prior to taking action. It should be noted however, that nutrient enrichment through addition of fertilizers is not self-sustaining and in most cases the benefits of nutrient enrichment cease immediately or within a few years after fertilization is stopped (Findlay and Kasian 1987, Mills and Chalanchuk 1987, Shearer et al. 1987).

In contrast to nutrient additions to oligotrophic waters, many restoration projects seek to reduce impacts of human-induced eutrophication of waters. Countless studies illustrate the negative impacts of eutrophication on aquatic ecosystems including algal blooms, reductions in fitness of aquatic organisms including fish, corals (Vermeij et al. 2010), and other species (Kraufvelin et al. 2006), hypoxia (Diaz and Rosenberg 2011), extinction of submerged aquatic plants, loss of sea grass beds (Cardoso et al. 2004), loss of biodiversity, loss of water clarity and quality, ecosystem instability and loss of complexity (Qin et al. 2013). Reducing or eliminating nutrient inputs can help halt the process of eutrophication. Several studies have found, however, that ecosystems are very slow to respond after nutrient additions from pollution sources have been removed and some may never return to historical conditions even with further intensive restoration action (Bachmann et al. 1999, Lappalainen and Pesonen 2000, Hilt et al. 2010, Jarvie et al. 2013). Other studies, however, have shown that significant improvements can be made to water quality and progress can be made toward reducing eutrophication. For example, nutrient loads in Tampa Bay, Florida resulted in the loss of half the seagrass habitat in the bay since 1950. A restoration program was implemented in the mid-1990s focused on reducing nutrient inputs to the bay and restoring seagrass beds. Industrial and agricultural partners were heavily involved in developing a multi-partner strategy for reducing nutrient loads throughout the bay and targets were set for nitrogen loading and chlorophyll a concentrations. Progress has been shown in reducing nutrients and targets are met in most years. As of 2006, the amount of seagrass in the bay has increased by 25% (Greening and Janicki 2006).

Phosphorous reduction programs in Lake Erie have shown that fish communities have responded to improved water quality. Phosphorous abatement programs started in 1969 and by the 1990s, several fish species tolerant of a eutrophic environment (such as brown bullhead, common carp, channel catfish) had declined and intolerant species (such as rock bass, smallmouth bass) had increased in abundance (Ludsin et al. 2001).

Other methods to reduce the impacts of eutrophication can supplement nutrient reductions. In Chesapeake Bay researchers have examined using oysters to help reduce the impacts of eutrophication by reducing phytoplankton although improvements have been variable and models indicate that very high oyster biomass is required to achieve appreciable improvement in water quality (Fulford et al. 2007, Fulford et al. 2010). Coastal wetland restoration has been used to increase denitrification and retain phosphorous in an effort to minimize nutrient additions to coastal waters. However, nitrogen and phosphorous cycling is complex and some researchers indicate that there needs to be a better understanding of these processes before using wetland restoration to try to reverse eutrophication (Ardon et al. 2010). Wave barriers designed parallel to the shore to protect areas of calm water and support macrophyte growth have been suggested to improve water quality conditions in a large, shallow lake subject to high levels of re-suspended sediments in Florida (Bachmann et al. 1999).

Hypolimnetic withdrawal treatments have been shown to be successful in reducing nutrient levels in thermally stratified lakes. In this method, nutrient rich bottom water from the hypolimnion is removed via a pump. In many cases withdrawn water is treated like wastewater to prevent contaminating downstream waters. This generally cost-effective method of lake restoration is common in Europe and used occasionally in North America. A summary of the impacts of hypolimnetic withdrawal impacts across Europe and North America showed that this method effectively improves water quality by reducing epilimnetic and hypolimnetic phosphorous and chlorophyll concentrations, reducing anoxia, and improving Secchi disk transparency. Impacts vary by lake characteristics, hydrology, and timing of treatment (Nurnberg 2007).

Increasing the pH of acidic lakes and streams is another restoration method that can be effective at reducing the impacts of acid deposition and thereby improving fish productivity. Many fish species are sensitive to low pH levels, including species such as lake trout which suffer reproductive failure if lake pH drops below 5.4-5.6 (Gunn and Mills 1998). When SO_2 levels from local smelters were reduced in an acidified lake in Canada, Whitepine Lake, lake pH increased naturally above 5.5 and the lake trout population increased in abundance. However, examples of natural recovery of populations are not common and two other acid-sensitive species (burbot and white sucker) in the lake have not recovered to the same extent. Acid neutralization can increase overall water pH levels in lakes or streams via the addition of lime in various forms. Gunn and Mills (1998) provide several examples of lakes in Canada which have shown considerable improvement in lake trout or zooplankton abundance through liming. The extent of impacts varies depending on a variety of limnological and biological factors including characteristics of the target fish species, community composition, flushing rate, and dissolved organic carbon in the waterbody.

Angeler and Goedkoop (2010) state that almost all studies of the effects of liming show that communities resulting from liming are not stable and there is often a return to an acidified state when liming is discontinued. They found less food web complexity and fewer associations between functional feeding groups in lakes subject to liming compared to other lakes. Therefore, liming applications may require long-term maintenance and this may make it a less attractive restoration option than other methods.

EXPERIENCES OF FISHERIES PROTECTION PRACTITIONERS IN CANADA

Fisheries Protection Practitioners across Canada have a wealth of knowledge and experience in developing and studying fish habitat compensation projects under the *Fisheries Act*. As stated in the introduction, many of these projects can be considered to offset impacts to fish and fish habitat and provide important precedents for operational implementation of the altered *Fisheries Act*. In an effort to collect information on the experiences of FPP staff, and determine their experience with both projects deemed to be successful and unsuccessful from a fisheries perspective, FPP staff in all regions were sent a brief questionnaire to provide information on projects that impacted fish productivity.

The following questions were asked to staff:

1) In your experience with fish habitat compensation under the 1986 *Policy for the Management of Fish Habitat* and the *Fisheries Act*, what compensation projects do you think have been most successful and least successful in your region? Describe the project(s), why it was needed (what were the impacts to fish habitat?), and why it was considered successful or unsuccessful
    a) What were the indicators of success or failure for the project (i.e. what was measured – habitat stability, fish abundance, etc.)?
    b) Was the productivity of fish or fish habitat or a surrogate for fish productivity such as biomass, abundance, or reproductive success measured as part of the project(s)? If not, why?
    c) What was the time period for monitoring the project? Why was this period of time deemed appropriate?
    d) Were any publicly-available documents or data published as a result of the project(s)? Please provide references.
    e) Could the project outcome have been improved through modification in design, timing, etc.?

Responses to the questionnaire, along with findings of related publications, were summarized in Table 1 below. Complete questionnaire responses are included in Appendix I. Table 2 includes examples of each of the major categories of offset techniques described in this report. These examples are from Canadian locations although not all studies in Table 2 were fish habitat compensation projects.

Table 1. Examples of fish habitat compensation (FHC) projects across Canada. Further information can be found in Appendix I.

Region	Project and Location	Type of loss (species and habitat)	FHC Works	CRA fishery feature gained	Before impact baseline (y/n)	Key Metrics	Monitoring Time	Time before compensation effect shown	Success (y/n)	Main reason for considering this a success or failure	PATH Number	Case Study Source
Pacific	Atagi Wharf RedevelomentSteveston, BC	estuary, Pacific Salmon	intertidal marsh creation	Pacific Salmon	yes	stability, square area, survival and growth of created intertidal marsh	3 years of annual monitoring	indicators of success after 1 year	Yes to date. Annual monitoring of compensation to continue	created intertidal marsh functioning as intended (key metrics have been met)	10-HPAC-PA2-00413	Brian Naito - Assessor
Pacific	Road stabilization, Lardeau River, BC	Riverine, rainbow trout feeding, rearing, spawning, kokanee rearing	Side channel access, shear log intake structure	Rainbow trout, kokanee	yes	Juvenile rearing and adult enumeration plus wetted usable area	5 years	One year	yes	Stream functioning as designed, provides connectivity, allows fish migration, and provides spawning and nursery habitat for species of interest	07-HPAC-PA7-0327, 06-HPAC-PA7-0326	Tola Coopper
Pacific	BC Hydro, Columbia Water Use Plan, Revelstoke Minimum Flow Management	White sturgeon, rainbow trout, whitefish feeding and rearing	Flow management	Bulltrout, rainbow trout, whitefish	yes	Habitat wetted area, PHABSIM, Habitat Suitability Indices	5 years before, 10 years more	Immediate – dry to wet	?	Currently 32% increase in wetted area		Tola Coopper
Central and Arctic	Ekati Diamond Mine, Northwest Territories	riverine, Arctic grayling spawning habitat	stream creation	Arctic grayling	created stream compared to reference streams	growth rates of grayling, temperature and flow, fish abundance, stability of habitat	10 years (full monitoring) followed by several years reduced monitoring	some indicators of success within 3 years	indicators of success but time lags evident; lower productivity than reference streams, less riparian vegetation and organic inputs to stream, less habitat complexity	stream functioning as designed, provides connectivity, allows fish migration, and provides spawning and nursery habitat for grayling	95-HCAA-CA6-00308	Jones et al. 2008
Central and Arctic	Oil Sands, Jackpine Mine, Alberta	riverine and lacustrine, multiple species	lake creation	Multiple species	yes	stratified fish sampling, habitat evaluation, fish species biomass per unit area, measurement of physical variables	35 years	TBD	TBD - Monitoring ongoing	NA - Ongoing	01-HCAA-CA1-00743	Marek Janowicz - FPP
Central and Arctic	Bridge Construction, Winnipeg River	riverine, lake sturgeon and other species	rocky shoal creation	Multiple species	yes	fish abundance	2 years	No effect shown	Unknown - assessment methodologies not sufficient	No increase in fish abundance; may be due to failure of project or assessment techniques	09-HCAA-CA1-01715	Todd Schartz - FPP

Region	Project and Location	Type of loss (species and habitat)	FHC Works	CRA fishery feature gained	Before impact baseline (y/n)	Key Metrics	Monitoring Time	Time before compensation effect shown	Success (y/n)	Main reason for considering this a success or failure	PATH Number	Case Study Source
Central and Arctic	Causeway Construction, Lac Seul, northwestern Ontario	lacustrine, pike and other cyprinids	creation of fish feeding/ nursery channels in a peat bog linked to Lac Seul	Pike and walleye	unknown	presence of cyprinids in channel	Unknown	Unknown	yes	use of channels by young cyprinids	08-HCAA-CA4-00443	Neville Ward - FPP
Quebec	Baie de Plaisance, Magdalen Islands	Destruction and deterioration of marine coastal habitat	Creation of habitat bank- construction of 8 artificial reefs	American lobster	yes	presence of lobster of different developmental stages	3 years	Colonization and settlement were seen after first year of monitoring	yes	all stages of lobster were found after three years of follow-up	09-HQUE-LZ3-00338	Gendron et al. (in prep)
Quebec	Nicolet River	Yellow perch, northern pike, brown bullhead and cyprinids feeding and growing habitat	weir and culvert construction to provide access and maintain water	Multiple species	yes	stability of structures, permanent water maintenance, fish use of channel	3 monitoring periods over 5 years	After the first year, fishes used the channel for nursery and feeding	yes	structures are stable, maintaining water, 20 fish species captured in channel	99-HLAU-LZ3-00218	Reports from consultants firms
Quebec	Ile du Milieu, Berthierville	Destruction and deterioration of feeding and migration habitat, multiple species	marsh habitat, installation of control structure to maintain specific flood level	Multiple species	no	fish use of marsh, ability of fish to clear structures during flooding and low water periods	3 years	After the first year of monitoring, it was considered that all objectives were achieved	yes	fish use of marsh	08-HQUE-LZ3-00164	Reports from consultants firms
Quebec	St. Maurice River	smallmouth bass breeding habitat, white sucker spawning shoal, white sucker spawning habitat	Creation of spawning habitat	Multiple species	yes	size, integrity and characteristics of spawning habitat; number of spawner nests	3 monitoring periods over 5 years	Some eggs were observed after the first year of monitoring	yes	Spawning habitat is stable and meets size requirements, increased number of spawner nests compared to baseline data	93-HLAU-LZ4-00120	Reports from consultants firms
Quebec	Bonaventure Barachois, Gaspésie	Destruction and deterioration of marine coastal habitat	creation of eelgrass bed	Multiple species	no	survival rate of transplanted eelgrass	two monitoring periods over three years	N/A	no	less than 25% eelgrass survival	04-HQUE-LZ3-00125	Reports from consultants firms
Quebec	Manouane River	Loss of spawning habitat, Ouananiche	creation of rearing habitat by weir installation	Multiple species	N/A	presence of target species, no stranding, size, stability and characteristics of created habitat	5 years with additional 3 years due to problems with silting	N/A	no	Issues with silting causing aquatic plants not to establish and limiting fry access to the development	97-HLAU-LZ3-00033	Reports from consultants firms
Quebec	Petit Pabos River, Gaspésie	Destruction of feeding area – occasionally frequented areas for forage species	improved brook trout passage and spawning and rearing habitat	brook trout	no	physical characteristics of habitat, free passage of brook trout, fish use of habitat	3 monitoring periods over 4 years	N/A	no	beavers created barriers to fish passage, corrective actions were unsuccessful	05-HQUE-LZ3-00265	Reports from consultants firms

Region	Project and Location	Type of loss (species and habitat)	FHC Works	CRA fishery feature gained	Before impact baseline (y/n)	Key Metrics	Monitoring Time	Time before compensation effect shown	Success (y/n)	Main reason for considering this a success or failure	PATH Number	Case Study Source
Gulf	Southern Gulf of St. Lawrence	marine	artificial reefs	American lobster	yes	% sunken structures, % of lobster or lobster structures, average lobster density, 0-age lobster density, presence of other benthic species	9 years		yes	increased lobster density compared to natural reefs		Paulette Hall, Guy Robichaud
Maritimes	Rock reef study, compensation for multiple projects in eastern NS - Inner Sambro Island and Cook Head	Typical nearshore marine habitat, rocky intertidal, subtidal mud, multiple species	artificial rock pile reefs	Multiple species	yes	invertebrate biomass, vertebrate biomass, macroalgae biomass	2 years	Within first year, almost immediate colonization, community succession	yes	Productivity of the rock reef structures was determined relative to three types of adjacent habitats	None, though linked to a number of Small Craft Harbour files in Eastern Nova Scotia	Donald Humphrey -FPP
Maritimes	Cheverie Creek, Hants County, Nova Scotia	Creation of habitat bank – typical nearshore marine habitat, multiple species	replacement of undersized culvert, marsh restoration (increased from 5.4 to 43.08 ha),	Atlantic silverside	yes	fish abundance, benthic and invertebrate abundance, geospatial attributes, hydrology, vegetation, soil and sediment characteristics	7 years	2 years	yes	Increased relative abundance of fish following construction	05-HMAR-MA7-00178	Bowron et al. 2009
Maritimes	Walton River	Creation of habitat bank – typical wetland habitat loss	water control structure removal and dyke breach to restore tidal flow to salt marsh	Atlantic silverside	yes	fish abundance, fish density, benthic and invertebrate abundance, geospatial attributes, hydrology, vegetation, soil and sediment characteristics	5 to 7 years	1 year	yes	Increase in relative abundance of fish following construction, higher fish density at post-restoration site for most years	05-HMAR-MA7-00167	van Proosdij et al. 2010
Newfoundland & Labrador	Rose Blanche Hydroelectric Development, southwest coast of Newfoundland	riverine, salmonid spawning and rearing habitat	creation and enhancement of salmonid spawning and rearing habitat; provision of salmonid passage	salmonids	yes	strucutural integrity of works, fish biomass, flows through fishway, presence of fish above fishway	5 years	3 years	yes	Increased salmonid biomass in created/enhanced channel compared to area destroyed and mainstem habitat	91-HNFL-NA1-00001	Scruton et al. 2005, M.M. Roberge
Newfoundland & Labrador	Nugget Pond Gold Mine and Mill, Baie Verte Peninsula, NL	riverine and lacustrine salmonid habitat	Providing access to previously inaccessible habitat by constructing a fishway	Atlantic salmon	no	fishway effectiveness and hydrological evaluations (adequate flow maintained in fishway)	2 years	N/A	no	Fishway is structurally stable with adequate flows but no fish have been demonstrated to use it	94-HNFL-NA1-00256	M.M. Roberge

Table 2. Published studies of examples of each major category of offset methods described in report. Please see references for further information and study results.

Type of Manipulation	Category	Project	Reference(s)
Physical Habitat	Restoration	Effect of stream habitat characteristics on density of spawning sockeye salmon in 32 lakes, British Columbia	(Braun and Reynolds 2011)
	Restoration	Effect of instream structures on Atlantic salmon, Newfoundland and Labrador	(De Jong et al. 1997)
	Restoration	Removal of natural habitat barriers in streams to provide access to Atlantic salmon, Newfoundland and Labrador	(Mullins et al. 2003)
	Restoration	Impact of environmental flow release in a regulated river on salmonid productivity, British Columbia	(Bradford et al. 2011)
	Creation	Artificial stream construction, Northwest Territories	(Jones et al. 2003, Jones and Tonn 2004a, b, Jones et al. 2008)
	Creation	Stream construction, Seal Cove, Newfoundland and Labrador	(Scruton 1996)
	Creation/ Enhancement	Creation and enhancement of groundwater-fed side channels, British Columbia	(Sheng et al. 1990, Cooperman et al. 2006)
Biological	Stocking	Evaluation of sockeye salmon hatchery fry stocking in 2 lakes, British Columbia (and Alaska)	(Hyatt et al. 2005)
	Translocation	Transfer of fish into fishless lakes, Newfoundland and Labrador	(Roberge and Warren In press-b)
	Translocation/ Stocking	Transfer of American eels from Maritime locations into Lake Ontario, Ontario	(Pratt and Threader 2011)
Chemical	Lacustrine Nutrient Additions	Lake Enrichment Program, British Columbia	(Stockner and Macisaac 1996)
	Lacustrine Nutrient Additions	Fertilization of sockeye salmon nursery lakes, British Columbia (Alaska and Idaho included in review as well)	(Hyatt et al. 2004)
	Restoration of acidified lakes	Review of studies on attempts to restore lake trout in acid damaged lakes, Ontario	(Gunn and Mills 1998)

BASELINE DATA REQUIREMENTS

Baseline studies that assess the factors limiting fisheries productivity in a given watershed are critical before undertaking any program to offset or increase fishery productivity. Many restoration projects assume food availability or spawning habitats are limited but this can be proven not to be the case (Kauffman et al. 1997, Gutreuter 2004, Bellmore et al. 2012). In a review of the impacts of grazing on riparian zones and fish habitat, Larsen et al. (1998) found that the majority of studies did not provide pre-treatment data to compare to findings; did not provide adequate information on grazing practices, and/or had weak experimental designs. In an examination of fish habitat compensation projects in British Columbia, Bradford et al. (In press) also found that baseline information was missing for many projects and therefore sampling sites had to be compared to control or reference areas.

Before undertaking offsetting efforts it is important to understand:

- problems facing the watershed system including the landscape practices preventing natural recovery (Kauffman et al. 1997);
- processes currently ongoing within the watershed (for example, sediment transport, issues impacting juvenile fish survival, etc.);
- processes occurring in the watershed prior to human disturbance (Kauffman et al. 1997, Roni et al. 2008) or historic land use practices in the watershed which may still be impacting current processes (for example, logging of a riparian zone can impact streams for years) (Maloney et al. 2008);
- natural disturbance patterns in the area such as climate patterns, flood frequency;
- potential impacts to species other than the target species or target guild and;
- costs and benefits of various offsetting techniques and options (Hartman 2004).

Managers must have clear goals or targets for their offsetting activities. Researchers caution against a species-only or single-process approach to restoration as these types of restoration actions typically fail. Instead, a watershed approach focused on restoring natural processes in a dynamic ecosystem is more likely to be successful (Kauffman et al. 1997). Although it is often impossible to know all the factors impacting a watershed prior to undertaking offsetting activities, strong efforts should be made to determine as much about the watershed as possible to better predict potential outcomes of any restoration activities.

CLIMATE CHANGE

Almost all aquatic ecosystems worldwide are impacted to some extent by human activities (Palmer et al. 2009). All restoration actions designed to improve aquatic systems, or increase or restore fish productivity, must consider environmental and social aspects of restoration including continuing threats to populations, changing ocean conditions, changing weather patterns and flood/storm frequencies, changing species range distributions, fishing and lifestyle practices, pollution, and public interest. All of these issues have the potential to impact restoration or offsetting activities.

Climate change in particular, can have major impacts on aquatic ecosystems and restoration activities (Minns 2009, Palmer et al. 2009). A predicted increase in global temperature of 1.8 to 4.0 degrees Celsius will result in river and lake warming. Unique flow regimes of rivers will be impacted by changes in discharge resulting from earlier snow melts and potentially higher quantities of precipitation in some areas and lower quantities in others (Palmer et al. 2009).

Storms may become more severe and frequent and impacts of runoff, washouts, floods and other disturbances may become more pronounced. Water quality may be reduced in areas with increased turbidity and temperature. Growth and reproductive rates of fish are likely to increase as the water warms unless thermal tolerances are exceeded. Species with good dispersal abilities may be able to shift their ranges into more northerly areas but some may become isolated and become extinct or be seriously impacted by changes to flows and discharge (Chu et al. 2005, Palmer et al. 2009).

Impacts of climate change will be highly regional and even watershed-specific and this should be considered in any offsetting plans. Battin et al. (2007) modelled the expected impacts of climate change on Chinook salmon in a Pacific Northwest basin and found a potential strong negative impact of climate warming on salmon populations. These impacts could be partly ameliorated through river restoration and protection but impacts would vary from high to low elevations. High-elevation streams are likely to be more impacted by climate change but restoration options in these areas are limited. Therefore, the authors found that restoration activities in lower-elevation streams would be more likely to be successful at enhancing salmon populations over the long-term.

Invasive or non-native species can be a problem in any restoration project, and impacts may be exacerbated by a changing climate, subsequent changes to species ranges, and increased pressures from human development. Some studies suggest that walleye and smallmouth bass will expand their range northward as a result of climate warming. The range expansion of these predators may dramatically impact fish communities in new areas, and increased predation combined with possible habitat loss due to climate change and development may drive some fish populations to local extinction (Chu et al. 2005, Sharma et al. 2009).

Restoration activities may become more necessary in the future due to the disturbances and changes to flows outlined above. As well, structures already in place to enhance fish habitat will need monitoring to ensure their stability and continued functioning. Palmer et al. (2009) recommend six major actions that should take place to minimize and ameliorate impacts of climate change including: enhancing local monitoring, providing technical assistance at local levels, enhancing river protection, providing further groundwater/surface water management, initiating restoration projects prior to damage, and diversifying and replicating habitat and populations. Mulholland et al. (1997) recommend that further research should be undertaken to develop and test restoration strategies to counteract the impacts of climate change.

A TOOL FOR IMPLEMENTING OFFSET METHODS – HABITAT BANKING

The idea of banking within the concept of offsets seeks to add a credit/debit marketing scheme to the conservation of habitats or species whereby individuals or companies that enhance and protect biodiversity/wetlands/habitat generate credits which can then be sold to companies to offset impacts to biodiversity/wetlands/habitat caused by development. In some cases, banking is considered a form of third party compensation, as the bank owner is ultimately responsible for the continued functioning and monitoring of the bank site, rather than a developer (US Environmental Protection Agency 2012).

There are several benefits to habitat banking such as: restoration/creation projects are undertaken by professional ecologists and biologists rather than developers, developers do not have to provide on-site compensation (which may be of lower quality than off-site options), costs of habitat compensation are pre-defined and known before any habitat is damaged by development, banking can provide for large-scale restoration projects which function better ecologically than smaller, piecemeal projects and larger projects often have more public support (Briggs et al. 2009). The major benefit of banking, however, is that areas are restored/created or enhanced before habitat destruction can occur, eliminating time lags and reducing the uncertainty that habitats will function as designed.

Several groups are involved with habitat banking including regulators, project proponents (developers), and bank owners and each has their own role to play. Bank owners can be private companies, consultants, or individuals that are responsible for restoring, enhancing, creating, and preserving the bank site, as well as monitoring and maintaining the site for the long-term. They work with regulators to determine how much credit can be offered from the bank site (i.e. how much credit can be sold from the site), and manage the site as specified in a formal banking agreement (SENES Consultants Limited 2013). Regulators oversee the establishment of a bank, establish the rules for the bank, and determine how many credits can be earned from a site and how many a bank owner can sell. They can also function as auditors of the bank. Developers whose projects will negatively impact habitat or productivity can then buy credits from the bank owner to offset the impacts of their project on the environment (SENES Consultants Limited 2013).

In habitat banking, the amount of compensation credits needed to offset impacts of development must be determined. Various metrics are used in different countries including habitat based, population based or ecosystem based. In the United States, where wetland mitigation is well-established, the value of credits is determined by quantifying the wetland functions or determining the acres of wetland restored or created (US Environmental Protection Agency 2012). Briggs et al. (2009) outline factors to be taken into account when calculating the cost of credits including: costs of suitable land for restoration, costs of creating different habitat types, costs of managing habitat, costs of project management and monitoring, costs of compensation procedures, and costs of a return on investment.

There are a number of other aspects of habitat banking that will not be discussed in detail in this report. They include developing realistic performance standards for establishing and monitoring bank sites and ensuring bank owners and regulators have proper training in assessing candidate sites for banking, applying appropriate field techniques, and calculating how many credits can be sold for a given site (SENES Consultants Limited 2013). Further information can be found in the references below.

Several detailed reports on habitat banking have been produced by DFO or prepared for DFO by consultants. One such report called *Fish Habitat Banking in Canada: Opportunities and Challenges* was completed by SENES Consultants Limited in 2011 (Hunt et al. 2011). This document provides an overview of habitat banking in Canada and other countries and includes case studies from Canada and the United States. A report of a summary of a workshop on the application of habitat conservation banking in Ontario for offsets under the *Fisheries Act* is also available for further information (SENES Consultants Limited 2013), as is a report on a habitat conservation banking workshop in Ottawa (SENES Consultants Limited 2012).

Several countries have habitat banking or similar-type policies and legislation in place and some of these are summarized below.

UNITED STATES

Mitigation Banking

Under Section 404 of the *Clean Water Act*, as well as under the 1989 No Net Loss Policy for Wetlands, any development that infills or destroys wetlands must compensate for these impacts by creating, enhancing, restoring, or in some cases preserving, another wetland. One of the methods to ensure no net loss of wetlands is through mitigation banking. Mitigation banks are well established in the United States and involve multiple federal organizations including the Environmental Protection Agency, the US Army Corps of Engineers (USACE), Fish and Wildlife Service, National Resources Conservation Service, and the National Marine Fisheries Service. Credit values are based on the rarity of the banked resource (i.e. wetland or stream) and therefore, a higher market price is required for wetlands in areas with high development pressures and few options for compensation (Hunt et al. 2011). The value of a bank is defined at the number of credits they have available for sale. As of 2005, USACE estimated that there were a total of 450 approved mitigation banks in the US, with a further 198 in the proposal stage (US Environmental Protection Agency 2012).

Mitigation banks are found to be the most reliable form of compensation for wetlands in the US and thus the *Water Resources Development Act* (WRDA) of 2007 identified mitigation banking as the "preferred mechanism for offsetting unavoidable wetland impacts associated with Corps Civil Works projects". The Act states that "in carrying out a water resources project that involves wetlands mitigation and that has impacts that occur within the service area of a mitigation bank, the Secretary [of the Army], where appropriate, shall first consider the use of the mitigation bank if the bank contains sufficient available credits to offset the impact" (US Environmental Protection Agency 2012).

Conservation Banking

Conservation banks are based on the idea of mitigation banks but were created to preserve existing habitats for species under the United States *Endangered Species Act*. The US Fish and Wildlife Service (USFWS) define conservation banks as "permanently protected lands that contain natural resource values. These lands are conserved and permanently managed for species that are endangered, threatened, candidates for listing, or are otherwise species-at-risk". In 2003, the USFWS released federal guidelines to promote conservation banks as a tool for mitigating negative impacts to species. The guidelines are designed to standardize the establishment and operation of conservation banks nationally (US Fish and Wildlife Service 2012).

In a 2005 review of conservation banking in the US, it was reported that conservation credits ranged in price from $3000 to $125,000/per acre (Fox and Nino-Murcia 2005). Hunt et al. (2011) reported that in 2009, there were 77 active, 20 pending and 19 sold out conservation banks in the United States. Due to the fact that conservation banks are designed to protect existing habitat, they can be heavily criticized as habitat losses still occur as a result of development (Hunt et al. 2011).

AUSTRALIA

Biobanking (New South Wales)

In an effort to help address the loss of biodiversity and threatened species, the Biodiversity Banking and Offsets Scheme (BioBanking) was created by the New South Wales Department of Environment and Climate Change (DECC) under the *Threatened Species Conservation Act* 1995 (DECC 2007). In biobanking, landowners can establish biobank sites by carrying out management actions, specified in a formal banking agreement, which are expected to improve biodiversity over time. Credits are issued for approved biobank sites and these credits can be sold to offsets impacts to biodiversity. The value of credits is determined by the DECC using a Biobanking Assessment Methodology and Credit Calculator that takes into account site and landscape factors. Some payments to owners of biobank sites are managed by a Biobanking

Trust Fund, which invests funds deposited through the sale of biobanking credits, and then these funds, along with investment earnings, are used to make payments to the biobank owner to manage the site over time. In biobanking, there is a need to demonstrate that biodiversity can be "improved or maintained" despite the development. The DECC reports that a compliance program will ensure that biobank sites are managed appropriately (DECC 2007).

BushBroker (Victoria)

Bushbroker is a form of banking to offset impacts to vegetation in the state of Victoria. Landowners can improve the quality or quantity of native vegetation and generate credits which can be sold to companies who wish to clear vegetation for development.   The Department of Sustainability and Environment (DSE) maintains a Native Vegetation Register of approved credits that can be searched for purchase opportunities. Activities to improve native vegetation can include weed control, stock exclusion, rabbit control, protecting large old trees, planting new recruits into previously cleared areas, and others. In the BushBroker program, sites must undergo assessments by qualified accredited individuals to determine how many credits can be generated, banking agreements must be developed, and management plans must be put in place for each site (DSE 2012). Banking schemes in Australia have been criticized for allowing clearance of vegetation to be offset by protection of existing vegetation, which reduces the total amount of habitat in the landscape and thus does not result in no net loss of vegetation (Bekessy et al. 2010).

FISHERIES-RELATED POLICIES IN OTHER COUNTRIES

This section briefly outlines policies and legislation directly or indirectly related to fisheries and fish habitat in other countries, other than those related to habitat banking which were outlined in an earlier section. A report prepared by G.A. Packman and Associates Inc. in 2006 for the former Fish Habitat Management Program (now Fisheries Protection Program) of Fisheries and Oceans Canada provides more detailed information on many of these policies. Further information can also be found on the websites for the departments in each country that oversee the various policies or pieces of legislation.

EUROPEAN UNION WATER FRAMEWORK DIRECTIVE (WFD)

The goal of the European Union Water Framework Directive (WFD) is to set goals to achieve good ecological status or potential for all surface waters in the European Community by set dates (Matthews et al. 2010). The WFD was adopted in 2000 by the European Commission. All countries in the EU must complete river basin management plans (to be updated every 6 years) which outline actions to be taken to achieve good ecological and chemical status and to meet protected area objectives, all within the timescale required. Plans must include characteristics of the river basin, overviews of the impacts of human activity in the basin, estimation of the impacts of existing legislation and how to improve or change it to meet objectives, and economic analysis of water use within the basin (European Commission 2012). The focus on improving water quality will ultimately benefit fish species in the future.

UNITED STATES NATIONAL FISH HABITAT ACTION PLAN

The goal of the US National Fish Habitat Action Plan (NFHP) is to *protect, restore and enhance the nation's fish and aquatic communities through partnerships that foster fish habitat conservation and improve the quality of life for the American people*. The plan began in 2001 when a group of individuals decided to explore the development of partnerships among fishing groups, NGOs, and federal and state governments and organizations in order to protect fish habitat and populations on a nationwide scale. The plan was based on the North American Waterfowl Management Plan and the success that initiative had on protecting and enhancing waterfowl habitat and populations. By 2006 the NFHP was operating by bringing together the public and private sectors with the goal of protecting fish habitat.

The NFHP states that it will achieve its goals by: "supporting existing fish habitat partnerships and fostering new efforts; mobilizing and focusing national and local support for achieving fish habitat conservation goals; setting national and regional fish habitat conservation goals; measuring and communicating the status and needs of fish habitats; and providing national leadership and coordination to conserve fish habitats". The NFHP is a partnership-driven, non-regulatory, science-based landscape-scale fish habitat conservation effort (G.A. Packman and Associates Inc. 2006).

In March 2013, the 2nd edition of the NFHP was released. The updated plan reports that as a result of efforts since 2006, there are now 18 regional Fish Habitat Partnerships operating nationwide to conserve, enhance and protect fish habitat and 346 conservation projects have been completed in 46 states. A national assessment of fish habitat has been completed and the projected long-term value of the future benefits of habitat restored by the NFHP is estimated to be $805.7 million and 19,300 jobs. There is significant government and state support provided to the NFHP that is vital to its success. The US Departments of the Interior (includes US Fish and Wildlife Services, US Geological Survey, National Park Service), Agriculture (include Forest Service, Natural Resources Conservation Service) and Commerce (includes the National Oceanic and Atmospheric Administration, Fisheries Service, National Ocean Service) have signed a five year agreement to support the NFHP and committed to supporting the implementation of the plan by, among other things, incorporating the goals of the plan into federal plans, providing technical assistance, services, support, matching funds to projects that support the goals of the plan, and considering the goals of the plan when issuing any permits. Federal and state officials are members of the National Fish Habitat Board and committees and federal agencies provide additional support through: leadership, funding, data sharing and database development, education, recruiting partners, monitoring and evaluation, strategic planning, and technical expertise. Other federal agencies involved in the NFCP include the Environmental Protection Agency, Department of Defense, Department of Transportation, and Department of Homeland Security (National Fish Habitat Partnership 2012).

AUSTRALIAN ENVIRONMENT PROTECTION AND BIODIVERSITY CONSERVATION ACT

The *Environment Protection and Biodiversity Conservation Act* (EPBC) is the main piece of legislation, federally in Australia, that relates to the protection, conservation, and management of fish habitat. It provides a legal framework to protect and manage nationally and internationally important flora, fauna, ecological communities and heritage places which are defined in the Act as matters of national environmental significance. The Act is administered by the Department of Sustainability, Environment, Water, Population and Communities. There are eight 'matters of national environmental significance' to which the EPBC Act applies. These include:

- world heritage sites
- national heritage places
- wetlands of international importance ('Ramsar' wetlands)
- nationally threatened species and ecological communities
- migratory species
- Commonwealth marine areas

- the Great Barrier Reef Marine Park
- nuclear actions.

The Act also seeks to ensure that environmental protection is considered for all projects that take place on Commonwealth land or are carried out by a Commonwealth agency (Australian Government: Department of Sustainability Environment Water Population and Communities 2010).

Many states in Australia also have legislation which directly or indirectly protects fish and fish habitat. For example, the state of Queensland administers the *Fisheries Act*, which provides for the protection and management of freshwater and marine fish resources and habitats, within the state, and the *Nature Conservation Act*, which provides for the listing and protection of threatened species and protection and management of national parks (G.A. Packman and Associates Inc. 2006). Many other states have similar types of protection which are not discussed here.

MONITORING

The primary goals of all the offsetting techniques described in this report are to improve or maintain fish habitat or fish productivity. Monitoring the impacts of these techniques is crucial in order to determine if techniques are biologically and cost-effective, stable in the long-term, and whether or not further human intervention is required (Koning et al. 1998). There can be unexpected results of restoration activities, as demonstrated by Pine et al. (2009) in a review of responses of fish populations to management actions. As well, restoration structures have been known to fail in many cases (Frissell and Nawa 1992, Hartman 2004). In many restoration reviews it has been found that most monitoring programs to assess the effectiveness of habitat restoration are too short; for example ten years or more of monitoring are often required to detect salmonid responses to restoration (Lawson 1993, Roni et al. 2002). Long-term multiscale monitoring is especially necessary when restoration activities involve treating a variety of disturbances with the goal of improving fish productivity (Tomlinson et al. 2011).

Matthews et al. (2010) found that ecological restoration following improvements to a watershed may take decades to achieve but advise that indicators of progress toward the restoration goals be determined and measured in the first five years to indicate if improvements are occurring. In their review they found that the indicator groups that showed the highest proportion of positive change toward restoration goals in the first five years of monitoring were hydrological, terrestrial flora and fauna, morphological, and habitat structure indicators. Fish showed a positive response approximately 50 percent of the time and they indicate that longer monitoring periods (more than 5 years) may be needed to determine responses of fish to restoration. They also point out that improvements in indicator groups were seen more quickly in larger rivers than in smaller streams, likely as a result of colonization from other parts of the watershed.

Souchon et al. (2008) propose a monitoring framework that studies should follow to ensure monitoring is effective. Their framework consists of nine steps:

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.

Bradford et al. (In press) also stress the importance of monitoring and describe several types of monitoring, one of which is similar to that described by Souchon et al., which they refer to as a fully-designed scientific monitoring study. A 2011 draft report prepared by the former Habitat Management Program of DFO discusses the importance of developing methods to determine the effectiveness of habitat compensation projects. Previous studies have found that effectiveness could be improved (Harper and Quigley 2005, Quigley and Harper 2006) and DFO recognizes the importance and need for effective monitoring. Pearson et al. (2005) outline a strategy for monitoring fish habitat compensation projects that could be applied to offsetting projects in the future.

CONCLUSION

All offset techniques, whether they include restoration, habitat creation, banking, stocking, or others have positive and negative aspects. Habitat restoration projects can improve fish productivity but may experience structural failure due to changing environmental conditions. Habitat creation may improve fish productivity but there can be long time-lags before created habitat functions as effectively as natural habitat. Habitat banking using restoration/creation techniques can have many advantages for developers and sellers but again, relies on the effectiveness of restoration/creation techniques. Fish stocking may increase productivity but can result in negative impacts to the reproductive success or fitness of natural populations. Due to these types of issues, all impacts to the ecosystem must be carefully considered before undertaking management actions as a recent review of many studies has shown that there are often unintended, unexpected and undesired consequences of aquatic ecosystem management (Pine et al. 2009).

This report provides a brief summary of some methods that have been used, on their own or in combination with other techniques, to boost fish productivity. Although project outcomes are location and species-specific, and results can be highly variable, some combination of these methods combined with careful collection of baseline data and a good understanding of the watershed, can be used to maintain or improve fish populations. Regional DFO staff can provide valuable expertise to help determine effective methods to offset impacts to productivity, and existing policies relating to fisheries management in other countries can help guide the creation of an offsetting policy for Canadian fisheries.

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REFERENCES

NOTE: In addition to the references below, a larger database of references relevant to this report has been created in EndNote Web. To obtain access to this database, a user can create an EndNote Web account (no cost for employees of DFO) and then contact Kristin.loughlin@dfo-mpo.gc.ca to request access to the existing database.

Allen, M. S., K. I. Tugend, and M. J. Mann. 2003. Largemouth bass abundance and angler catch rates following a habitat enhancement project at Lake Kissimmee, Florida. North American Journal of Fisheries Management **23**:845-855.

Anderson, J. H., P. L. Faulds, W. I. Atlas, and T. P. Quinn. 2013. Reproductive success of captively bred and naturally spawned Chinook salmon colonizing newly accessible habitat. Evolutionary Applications **6**:165-179.

Angeler, D. G., and W. Goedkoop. 2010. Biological responses to liming in boreal lakes: an assessment using plankton, macroinvertebrate and fish communities. Journal of Applied Ecology **47**:478-486.

Aprahamian, M. W., K. M. Smith, P. McGinnity, S. McKelvey, and J. Taylor. 2003. Restocking of salmonids - opportunities and limitations. Fisheries Research **62**:211-227.

Araki, H., W. R. Ardren, E. Olsen, B. Cooper, and M. S. Blouin. 2007a. Reproductive success of captive-bred steelhead trout in the wild: Evaluation of three hatchery programs in the Hood River. Conservation Biology **21**:181-190.

Araki, H., B. Cooper, and M. S. Blouin. 2007b. Genetic effects of captive breeding cause a rapid, cumulative fitness decline in the wild. Science **318**:100-103.

Araki, H., and C. Schmid. 2010. Is hatchery stocking a help or harm? Evidence, limitations and future directions in ecological and genetic surveys. Aquaculture **308**:S2-S11.

Ardon, M., J. L. Morse, M. W. Doyle, and E. S. Bernhardt. 2010. The water quality consequences of restoring wetland hydrology to a large agricultural watershed in the southeastern coastal plain. Ecosystems **13**:1060-1078.

Australian Government: Department of Sustainability Environment Water Population and Communities. 2010. EPBC Act - Frequently Asked Questions.

Bachmann, R. W., M. V. Hoyer, and D. E. Canfield. 1999. The restoration of Lake Apopka in relation to alternative stable states. Hydrobiologia **394**:219-232.

Baldigo, B. P., and D. R. Warren. 2008. Response of fish populations to natural channel design restoration in streams of the Catskill Mountains, New York. North American Journal of Fisheries Management **28**:954-969.

Balouskus, R. G., and T. E. Targett. 2012. Egg Deposition by Atlantic Silverside, Menidia menidia: Substrate Utilization and Comparison of Natural and Altered Shoreline Type. Estuaries and Coasts **35**:1100-1109.

Bartley, D., and J. Bell. 2008. Restocking, stock enhancement, and sea ranching: Arenas of progress. Reviews in Fisheries Science **16**:357-365.

Battin, J., M. W. Wiley, M. H. Ruckelshaus, R. N. Palmer, E. Korb, K. K. Bartz, and H. Imaki. 2007. Projected impacts of climate change on salmon habitat restoration. Proceedings of the National Academy of Sciences **104**:6720-6725.

BBOP. 2012a. Biodiversity Offset Design Handbook-Updated. Business and Biodiversity Offsets Programme.

BBOP. 2012b. Guidance Notes to the Standard on Biodiversity Offsets. Business and Biodiversity Offsets Programme, Washington, D.C.

BBOP. 2012c. Resource Paper: No Net Loss and Loss-Gain Calculations in Biodiversity Offsets. Business and Biodiversity Offsets Programme, Washington, D.C.

Bekessy, S., B. Wintle, D. Lindenmayer, M. Mccarthy, M. Colyvan, M. Burgman, and H. Possingham. 2010. The biodiversity bank cannot be a lending bank. Conservation Letters **3**:151-158.

Bellmore, J. R., C. V. Baxter, A. M. Ray, L. Denny, K. Tardy, and E. Galloway. 2012. Assessing the Potential for Salmon Recovery via Floodplain Restoration: A Multitrophic Level Comparison of Dredge-Mined to Reference Segments. Environmental Management **49**:734-750.

Bouvier, L. D., K. Cottenie, and S. E. Doka. 2009. Aquatic connectivity and fish metacommunities in wetlands of the lower Great Lakes. Canadian Journal of Fisheries and Aquatic Sciences **66**:933-948.

Bradford, M., J. Macdonald, and C. Levings. In press. Monitoring fish habitat compensation in the Pacific region: lessons from the past 30 years.

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

Bradford, M. J., P. S. Higgins, J. Korman, and J. Sneep. 2011. Test of an environmental flow release in a British Columbia river: does more water mean more fish? Freshwater Biology **56**:2119-2134.

Braun, D. C., and J. D. Reynolds. 2011. Relationships between habitat characteristics and breeding population densities in sockeye salmon (*Oncorhynchus nerka*). Canadian Journal of Fisheries and Aquatic Sciences **68**:758-767.

Briggs, B. D. J., D. A. Hill, and R. Gillespie. 2009. Habitat Banking - how it could work in the UK. Journal for Nature Conservation **17**:112-122.

Brookes, A., and F. D. Shields, editors. 1996. River Channel Restoration: Guiding Principles for Sustainable Projects. John Wiley & Sons, Chichester, England.

Buhle, E., K. Holsman, M. Scheuerell, and A. Albaugh. 2009. Using an unplanned experiment to evaluate the effects of hatcheries and environmental variation on threatened populations of wild salmon. Biological Conservation **142**:2449-2455.

Burgin, S. 2008. BioBanking: an environmental scientist's view of the role of biodiversity banking offsets in conservation. Biodiversity and Conservation **17**:807-816.

Cardoso, P. G., M. A. Pardal, A. I. Lillebo, S. M. Ferreira, D. Raffaelli, and J. C. Marques. 2004. Dynamic changes in seagrass assemblages under eutrophication and implications for recovery. Journal of Experimental Marine Biology and Ecology **302**:233-248.

Chase, R., N. Hemphill, J. Beeman, S. Juhnke, J. Hannon, and A. M. Jenkins. 2013. Assessment of juvenile coho salmon movement and behavior in relation to rehabilitation efforts in the Trinity River, California, using PIT tags and radiotelemetry. Environmental Biology of Fishes **96**:303-314.

Chu, C., N. Mandrak, and C. Minns. 2005. Potential impacts of climate change on the distributions of several common and rare freshwater fishes in Canada. Diversity and Distributions **11**:299-310.

Clarke, K., T. Pratt, R. Randall, D. Scruton, and K. Smokorowski. 2008. Validation of the flow management pathway: effects of altered flow on fish habitat and fishes downstream from a hydropower dam. Page vi + 111p. Can. Tech. Rep. Fish. Aquat. Sci.

Clarke, K. D. In press. Evaluating Habitat Compensation in Insular Newfoundland Rivers: What have we learned? , Fisheries and Oceans Canada.

Coe, H. J., P. M. Kiffney, G. R. Pess, K. K. Kloehn, and M. L. McHenry. 2009. Periphyton and invertebrate response to wood placement in large Pacific coastal rivers. River Research and Applications **25**:1025-1035.

Cooperman, M. S., S. G. Hinch, S. Bennett, J. T. Quigley, R. V. Galbraith, and M. A. Branton. 2006. Rapid Assessment of the Effectiveness of Engineered Off-Channel Habitats in the Southern Interior of British Columbia for Coho Salmon Production. Can. Manuscr. Rep. Fish. Aquat. Sci. 2768: v + 30 pgs.

Curry, R. A., D. A. Scruton, and K. D. Clarke. 2002. The thermal regimes of brook trout incubation habitats and evidence of changes during forestry operations. Canadian Journal of Forest Research-Revue Canadienne De Recherche Forestiere **32**:1200-1207.

Dahm, C. N., K. W. Cummins, H. M. Valett, and R. L. Coleman. 1995. An ecosystem view of the restoration of the Kissimmee River Restoration Ecology **3**:225-238.

De Jong, M. C. V., I. G. Cowx, and D. A. Scruton. 1997. An evaluation of instream habitat restoration techniques on salmonid populations in a Newfoundland stream. Regulated Rivers-Research & Management **13**:603-614.

de Kerckhove, D. In Prep. A Review of Promising Indicators of Fisheries Productivity for the Fisheries Protection Program Assessment Framework. Prepared by Expedition Environmental Consultants for Fisheries and Oceans Canada.

DECC. 2007. Biobanking (Biodiversity Banking and Offsets Scheme) Scheme Overview. New South Wales Department of Environment and Climate Change, Sydney South.

Decker, A. S., M. J. Bradford, and P. S. Higgins. 2008. Rate of biotic colonization following flow restoration below a diversion dam in the Bridge River, British Columbia. River Research and Applications **24**:876-883.

DFO. 2005. Canada's Policy for Conservation of Wild Pacific Salmon. Fishereis and Oceans Canada, Vancouver, BC.

DFO. 2009. Canada's Policy for Conservation of Wild Atlantic Salmon. Fisheries and Oceans Canada.

DFO. 2010. Practitioners Guide to Habitat Compensation. Fisheries and Oceans Canada, Ottawa, ON.

DFO. 2012. DFO Backgrounder 2012. Frequently Asked Questions - New Fisheries Protection Measures. Fisheries and Oceans Canada, Ottawa, ON.

Diaz, R. J., and R. Rosenberg. 2011. Introduction to environmental and economic consequences of hypoxia. International Journal of Water Resources Development **27**:71-82.

Downs, P. W., M. S. Singer, B. K. Orr, Z. E. Diggory, and T. C. Church. 2011. Restoring ecological integrity in highly regulated rivers: the role of baseline data and analytical references. Environmental Management **48**:847-864.

DSE. 2012. Introduction to BushBroker: information sheet number 1. Victorian Department of Sustainability and the Environment, East Melbourne.

Enders, E., D. Scruton, and K. Clarke. 2009. The 'natural flow paradigm' and Atlantic salmon - moving from concept to practice. River Research and Applications **25**:2-15.

Enders, E., K. Smokorowski, C. Pennell, K. Clarke, B. Sellers, and D. Scruton. 2007. Habitat use and fish activity of landlocked Atlantic salmon and brook charr in a newly developed habitat compensation facility. Hydrobiologia **582**:133-142.

Engstrom, J., C. Nilsson, and R. Jansson. 2009. Effects of stream restoration on dispersal of plant propagules. Journal of Applied Ecology **46**:397-405.

European Commission. 2012. Introduction to the new EU Water Framework Directive.

Findlay, D. L., and S. E. M. Kasian. 1987. Phytoplankton Community Responses to Nutrient Addition in Lake 226, Experimental Lakes Area, Northwestern Ontario. Canadian Journal of Fisheries and Aquatic Sciences **44**:s35-s46.

Fisheries Queensland. 2012. Marine Fish Habitat Offset Policy. Fisheries Queensland, Department of Agriculture, Fisheries and Forestry.

Fleming, I. A., and M. R. Gross. 1992. Reproductive behavior of hatchery and wild coho salmon (Oncorhynchus kisutch): does it differ? Aquaculture **103**:101-121.

Florida Department of Environment Protection. 2013. Kissimmee River Watershed.

Flowers, H. J., W. E. Pine, A. C. Dutterer, K. G. Johnson, J. W. Ziewitz, M. S. Allen, and F. M. Parauka. 2009. Spawning Site Selection and Potential Implications of Modified Flow Regimes on Viability of Gulf Sturgeon Populations. Transactions of the American Fisheries Society **138**:1266-1284.

Fox, J., and A. Nino-Murcia. 2005. Status of species conservation banking in the United States. Conservation Biology **19**:996-1007.

Frisk, M. G., T. J. Miller, R. J. Latour, and S. J. D. Martell. 2011. Assessing biomass gains from marsh restoration in Delaware Bay using Ecopath with Ecosim. Ecological Modelling **222**:190-200.

Frissell, C., and R. Nawa. 1992. Incidence and causes of physical failure of artificial habitat structures in streams of western Oregon and Washington. North American Journal of Fisheries Management **12**:182-197.

Fulford, R. S., D. L. Breitburg, M. Luckenbach, and R. I. E. Newell. 2010. Evaluating ecosystem response to oyster restoration and nutrient load reduction with a multispecies bioenergetics model. Ecological Applications **20**:915-934.

Fulford, R. S., D. L. Breitburg, R. I. E. Newell, W. M. Kemp, and M. Luckenbach. 2007. Effects of oyster population restoration strategies on phytoplankton biomass in Chesapeake Bay: a flexible modeling approach. Marine Ecology Progress Series **336**:43-61.

G.A. Packman and Associates Inc. 2006. Fish Habitat Management: International Practice in Relation to Canada and a Potential Policy Agenda. Department of Fisheries and Oceans, Ottawa, ON.

Gabriel, A. O., and L. R. Bodensteiner. 2012. Impacts of Riprap on Wetland Shorelines, Upper Winnebago Pool Lakes, Wisconsin. Wetlands **32**:105-117.

Gabriel, C., K. Clarke, and C. Campbell. 2010. Invertebrate communties in Compensation Creek, a man-made stream in boreal Newfoundland: the influence of large woody debris. River Research and Applications **26**:1005-1018.

Gardner, C., S. M. Coghlan, J. Zydlewski, and R. Saunders. 2013. Distribution and abundance of stream fishes in relation to barriers: implications for monitoring stream recovery after barrier removal. River Research and Applications **29**:65-78.

Gillespie, A. 2012. A missing piece of the conservation puzzle: biodiversity offsets. New Zealand Department of Conservation.

Gordon, A., W. Langford, J. Todd, M. White, D. Mullerworth, and S. Bekessy. 2011. Assessing the impacts of biodiversity offset policies. Environmental Modelling & Software **26**:1481-1488.

Greening, H., and A. Janicki. 2006. Toward reversal of eutrophic conditions in a subtropical estuary: Water quality and seagrass response to nitrogen loading reductions in Tampa Bay, Florida, USA. Environmental Management **38**:163-178.

Gresh, T., J. Lichatowich, and P. Schoonmaker. 2000. An estimation of historic and current levels of salmon production in the Northeast Pacific ecosystem: evidence of a nutrient deficit in the freshwater systems of the Pacific Northwest. Fisheries **25**:15-21.

Gunn, J. M., and K. H. Mills. 1998. The potential for restoration of acid-damaged lake trout lakes. Restoration Ecology **6**:390-397.

Gutreuter, S. 2004. Challenging the assumption of habitat limitation: An example from centrarchid fishes over an intermediate spatial scale. River Research and Applications **20**:413-425.

Hajisamae, S., R. Ruangchuay, and N. Kwanthong. 2013. Can wave breaking walls in shallow coastal areas serve as habitat for aquatic organisms? Journal of Coastal Research **29**:339-346.

Harper, D. J., and J. T. Quigley. 2005. A comparison of the areal extent of fish habitat gains and losses associated with selected compensation projects in Canada. Fisheries **30**:18-25.

Hartman, G. 2004. Chapter 32 - Forest management and watershed restoration: repairing past damage is part of the future.*in* T. Northcote and G. Hartman, editors. Fishes and Forestry: Worldwide Watershed Interactions and Management. Blackwell Science Ltd., Oxford, UK.

Hartman, G., and M. Miles. 2001. Assessment of techniques for rainbow trout transplanting and habitat management in British Columbia. Fisheries and Oceans Canada.

Hatry, C., T. Binder, C. Hasler, K. Clarke, C. Kat0potis, K. Smokorowski, and S. Cooke. 2011. Development of a national fish passage database for Canada (CanFishPass): rationale, approach, utility, and potential applicabilitly to other regions. Canadian Water Resources Journal **36**:219-228.

Helfield, J. M., and R. J. Naiman. 2001. Effects of salmon-derived nitrogen on riparian forest growth and implications for stream productivity. Ecology **82**:2403-2409.

Hess, M. A., C. D. Rabe, J. L. Vogel, J. J. Stephenson, D. D. Nelson, and S. R. Narum. 2012. Supportive breeding boosts natural population abundance with minimal negative impacts on fitness of a wild population of Chinook salmon. Molecular Ecology **21**:5236-5250.

Hilt, S., K. Van de Weyer, A. Kohler, and I. Chorus. 2010. Submerged macrophyte responses to reduced phosphorus concentrations in two peri-urban lakes. Restoration Ecology **18**:452-461.

Honea, J. M., J. C. Jorgensen, M. M. McClure, T. D. Cooney, K. Engie, D. M. Holzer, and R. Hilborn. 2009. Evaluating habitat effects on population status: influence of habitat restoration on spring-run Chinook salmon. Freshwater Biology **54**:1576-1592.

Hughes, S., M. Aprahamian, J. Armstrong, R. Gardiner, and N. Milner. 2001. Status of freshwater fish habitat science in Great Britain. Aquatic Ecosystem Health and Management **4**:393-400.

Hunt, K., P. Patrick, and M. Connell. 2011. Fish habitat banking in Canada: opportunities and challenges. Page vi + 66. Economic and Commercial Analysis Report.

Hunt, T. L., M. S. Allen, J. Douglas, and A. Gason. 2010. Evaluation of a Sport Fish Stocking Program in Lakes of the Southern Murray-Darling Basin, Australia. North American Journal of Fisheries Management **30**:805-811.

Hyatt, K., K. Mathias, D. McQueen, B. Mercer, P. Milligan, and D. Rankin. 2005. Evaluation of hatchery versus wild sockeye salmon fry growth and survival in two British Columbia lakes. North American Journal of Fisheries Management **25**:745-762.

Hyatt, K. D., D. J. McQueen, K. S. Shortreed, and D. P. Rankin. 2004. Sockeye salmon (Oncorhynchus nerka) nursery lake fertilization: Review and summary of results. Environmental Reviews **12**:133-162.

Jarvie, H. P., A. N. Sharpley, P. J. A. Withers, J. T. Scott, B. E. Haggard, and C. Neal. 2013. Phosphorus mitigation to control river eutrophication: murky waters, inconvenient truths, and "postnormal" science. Journal of Environmental Quality **42**:295-304.

Johnston, N. T., C. J. Perrin, P. A. Slaney, and B. R. Ward. 1990. Increased Juvenile Salmonid Growth by Whole-River Fertilization. Canadian Journal of Fisheries and Aquatic Sciences **47**:862-872.

Jones, N. E., G. J. Scrimgeour, and W. M. Tonn. 2008. Assessing the Effectiveness of a Constructed Arctic Stream Using Multiple Biological Attributes. Environmental Management **42**:1064-1076.

Jones, N. E., and W. M. Tonn. 2004a. Enhancing productive capacity in the Canadian Arctic: Assessing the effectiveness of instream habitat structures in habitat compensation. Transactions of the American Fisheries Society **133**:1356-1365.

Jones, N. E., and W. M. Tonn. 2004b. Resource selection functions for age-0 Arctic grayling (Thymallus arcticus) and their application to stream habitat compensation. Canadian Journal of Fisheries and Aquatic Sciences **61**:1736-1746.

Jones, N. E., W. M. Tonn, G. J. Scrimgeour, and C. Katopodis. 2003. Productive capacity of an artificial stream in the Canadian Arctic: assessing the effectiveness of fish habitat compensation. Canadian Journal of Fisheries and Aquatic Sciences **60**:849-863.

Kauffman, J. B., R. L. Beschta, N. Otting, and D. Lytjen. 1997. An Ecological Perspective of Riparian and Stream Restoration in the Western United States. Fisheries **22**:12-24.

Keeley, E., P. Slaney, and D. Zaldokas. 1996. Estimates of production benefits for salmonid fishes from stream restoration initiatives. Province of British Columbia, Ministry of Environment, Lands and Parks, and Ministry of Forests.

Kennedy, R., W. Crozier, and M. Allen. 2012. The effect of stocking with 0+ year age-class Atlantic salmon Salmo salar fry: a case study from the River Bush, Northern Ireland. Journal of Fish Biology **81**:1730-1746.

Kerr, S., and R. Grant. 2000. Ecological Impacts of Fish Introductions: Evaluating the Risk. Ontario Ministry of Natural Resources, Peterborough, ON.

Kohler, A. E., T. N. Pearsons, J. S. Zendt, M. G. Mesa, C. L. Johnson, and P. J. Connolly. 2012. Nutrient Enrichment with Salmon Carcass Analogs in the Columbia River Basin, USA: A Stream Food Web Analysis. Transactions of the American Fisheries Society **141**:802-824.

Kondolf, G. M. 1997. Hungry water: Effects of dams and gravel mining on river channels. Environmental Management **21**:533-551.

Koning, C., P. Slaney, M. Gaboury, and M. Feduk. 1998. Techniques to evaluated the effectiveness of fish habitat restoration works in streams impacted by logging activities. Canadian Water Resources Journal **23**:191-203.

Konrad, C. P., A. Warner, and J. V. Higgins. 2012. Evaluating dam re-operation for freshwater conservation in the sustainable rivers project. River Research and Applications **28**:777-792.

Kraufvelin, P., S. Salovius, H. Christie, F. E. Moy, R. Karez, and M. F. Pedersen. 2006. Eutrophication-induced changes in benthic algae affect the behaviour and fitness of the marine amphipod Gammarus locusta. Aquatic Botany **84**:199-209.

Krone, R., L. Gutow, T. J. Joschko, and A. Schroder. 2013. Epifauna dynamics at an offshore foundation - Implications of future wind power farming in the North Sea. Marine Environmental Research **85**:1-12.

Lamouroux, N., J. M. Olivier, H. Capra, M. Zylberblat, A. Chandesris, and P. Roger. 2006. Fish community changes after minimum flow increase: testing quantitative predictions in the Rhone River at Pierre-Benite, France. Freshwater Biology **51**:1730-1743.

Langford, T. E. L., J. Langford, and S. J. Hawkins. 2012. Conflicting effects of woody debris on stream fish populations: implications for management. Freshwater Biology **57**:1096-1111.

Lappalainen, A., and L. Pesonen. 2000. Changes in fish community structure after cessation of waste water discharge in a coastal bay area west of Helsinki, northern Baltic Sea. Archive of Fishery and Marine Research **48**:226-241.

Larkin, D. J., J. M. West, and J. B. Zedler. 2009. Created pools and food availability for fishes in a restored salt marsh. Ecological Engineering **35**:65-74.

Larsen, R. E., W. C. Krueger, M. R. George, M. R. Barrington, J. C. Buckhouse, and D. E. Johnson. 1998. Viewpoint: Livestock Influences on Riparian Zones and Fish Habitat: Literature Classification. Journal of Range Management **51**:661-664.

Lawson, P. W. 1993. Cycles in Ocean Productivity, Trends in Habitat Quality, and the Restoration of Salmon Runs in Oregon. Fisheries **18**:6-10.

LeBlanc, P., P. Patrick, and D. Gorber. 2013. A Discussion Paper on a Policy Framework for the Use of Offsets under Canada's Amended *Fisheries Act* (2012). Prepared for DFO by SENES Consultants Ltd.

Lepak, J., M. Hooten, and B. Johnson. 2012. The influence of external subsidies on diet, growth and Hg concentrations of freshwater sport fish: implications for management and fish consumption advisories. Ecotoxicology **21**:1878-1888.

Lewis, A., and K. Ganshorn. 2007. Literature Review of Habitat Productivity Models for Pacific Salmon Species. Consultant's report prepared for the Departmen of Fisheries and Oceans, Habitat Management Division, Vancouver, BC.

Ludsin, S. A., M. W. Kershner, K. A. Blocksom, R. L. Knight, and R. A. Stein. 2001. Life After Death in Lake Erie: Nutrient Controls Drive Fish Species Richness, Rehabilitation. Ecological Applications **11**:731-746.

Madej, M. A., C. Currens, V. Ozaki, J. Yee, and D. G. Anderson. 2006. Assessing possible thermal rearing restrictions for juvenile coho salmon (Oncorhynchus kisutch) through thermal infrared imaging and in-stream monitoring, Redwood Creek, California. Canadian Journal of Fisheries and Aquatic Sciences **63**:1384-1396.

Maloney, K. O., J. W. Feminella, R. M. Mitchell, S. A. Miller, P. J. Mulholland, and J. N. Houser. 2008. Landuse legacies and small streams: identifying relationships between historical land use and contemporary stream conditions. Journal of the North American Benthological Society **27**:280-294.

Matthews, J., B. Reeze, C. K. Feld, and A. J. Hendriks. 2010. Lessons from practice: assessing early progress and success in river rehabilitation. Hydrobiologia **655**:1-14.

Matzinger, A., R. Pieters, K. I. Ashley, G. A. Lawrence, and A. Wüest. 2007. Effects of Impoundment on Nutrient Availability and Productivity in Lakes. Limnology and Oceanography **52**:2629-2640.

McElhany, P., E. A. Steel, K. Avery, N. Yoder, C. Busack, and B. Thompson. 2010. Dealing with uncertainty in ecosystem models: lessons from a complex salmon model. Ecological Applications **20**:465-482.

McKenney, B., and J. Kiesecker. 2010. Policy development for biodiversity offsets: A review of offset frameworks. Environmental Management **45**:165-176.

McManamay, R., D. Orth, C. Dolloff, and M. Cantrell. 2010. Gravel addition as a habitat restoration technique for tailwaters. North American Journal of Fisheries Management **30**.

Merz, J. E., and J. D. Setka. 2004. Evaluation of a spawning habitat enhancement site for Chinook salmon in a regulated California River. North American Journal of Fisheries Management **24**:397-407.

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 regulated California river. Canadian Journal of Fisheries and Aquatic Sciences **61**:1433-1446.

Merz, J. E., J. R. Smith, M. L. Workman, J. D. Setka, and B. Mulchaey. 2008. Aquatic Macrophyte Encroachment in Chinook Salmon Spawning Beds: Lessons Learned from Gravel Enhancement Monitoring in the Lower Mokelumne River, California. North American Journal of Fisheries Management **28**:1568-1577.

Mills, K. H., and S. M. Chalanchuk. 1987. Population Dynamics of Lake Whitefish (Coregonus clupeaformis) During and After the Fertilization of Lake 226, the Experimental Lakes Area. Canadian Journal of Fisheries and Aquatic Sciences **44**:s55-s63.

Minns, C. 1997. Quantifying "no net loss" of productivity of fish habitats. Canadian Journal of Fisheries and Aquatic Sciences **54**:2463-2473.

Minns, C. 2006. Compensation ratios needed to offset timing effects of losses and gains and achieve no net loss of productive capacity of fish habitat. Canadian Journal of Fisheries and Aquatic Sciences **63**:1172-1182.

Minns, C. 2009. The potential future impact of climate warming and other human activities on the productive capacity of Canada's lake fisheries: a meta-model. Aquatic Ecosystem Health & Management **12**:152-167.

Morley, S. A., P. S. Garcia, T. R. Bennett, and R. Philip. 2005. Juvenile salmonid (Oncorhynchus spp.) use of constructed and natural side channels in Pacific Northwest rivers. Canadian Journal of Fisheries and Aquatic Sciences **62**:2811-2821.

Mouton, A. M., D. Buysse, M. Stevens, T. Van den Neucker, and J. Coeck. 2012. Evaluation of riparian habitat restoration in a lowland river. River Research and Applications **28**:845-857.

Moy, L. D., and L. A. Levin. 1991. Are *Spartina* marshes a replaceable resource - A functional approach to evaluation of marsh creation efforts Estuaries **14**:1-16.

Mulholland, P. J., G. R. Best, C. C. Coutant, G. M. Hornberger, J. L. Meyer, P. J. Robinson, J. R. Stenberg, R. E. Turner, F. VeraHerrera, and R. G. Wetzel. 1997. Effects of climate change on freshwater ecosystems of the south-eastern United States and the Gulf Coast of Mexico. Hydrological Processes **11**:949-970.

Mullins, C. C., C. E. Bourgeois, and T. R. Porter. 2003. Chapter 17 - Opening up new habitat: Atlantic salmon (*Salmo salar L.*) enhancement in Newfoundland.*in* D. Mills, editor. Salmon at the Edge. Blackwell Science Ltd., Oxford, UK.

Nagayama, S., and F. Nakamura. 2010. Fish habitat rehabilitation using wood in the world. Landscape and Ecological Engineering **6**:289-305.

Nagayama, S., F. Nakamura, Y. Kawaguchi, and D. Nakano. 2012. Effects of configuration of instream wood on autumn and winter habitat use by fish in a large remeandering reach. Hydrobiologia **680**:159-170.

National Fish Habitat Partnership. 2012. National Fish Habitat Action Plan, 2nd Edition. Association of Fish and Wildlife Agencies, Washington, DC.

Nock, C., J. Ovenden, G. Butler, I. Wooden, A. Moore, and P. Baverstock. 2011. Population structure, effective population size and adverse effects of stocking in the endangered Australian eastern freshwater cod Maccullochella ikei. Journal of Fish Biology **78**:303-321.

Noonan, M. J., J. W. A. Grant, and C. D. Jackson. 2012. A quantitative assessment of fish passage efficiency. Fish and Fisheries **13**:450-464.

Null, S. E., and J. R. Lund. 2012. Fish habitat optimization to prioritize river restoration decisions River Research and Applications **28**:1378-1393.

Nurnberg, G. K. 2007. Lake responses to long-term hypolimnetic withdrawal treatments. Lake and Reservoir Management **23**:388-409.

Opperman, J., and A. Merenlender. 2004. The effectiveness of riparian restoration for improving instream fish habitat in four hardwood-dominated California streams. North American Journal of Fisheries Management **24**:822-834.

Overton, J. C., R. T. T. Stephens, and S. Ferrier. 2013. Net present biodiversity value and the design of biodiversity offsets. Ambio **42**:100-110.

Palmer, M. A., D. P. Lettenmaier, N. L. Poff, S. L. Postel, B. Richter, and R. Warner. 2009. Climate Change and River Ecosystems: Protection and Adaptation Options. Environmental Management **44**:1053-1068.

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. Fisheries and Oceans Canada.

Pearsons, T. N., D. D. Roley, and C. L. Johnson. 2007. Development of a carcass analog for nutrient restoration in streams. Fisheries **32**:114-124.

Perrier, C., J. L. Bagliniere, and G. Evanno. 2013. Understanding admixture patterns in supplemented populations: a case study combining molecular analyses and temporally explicit simulations in Atlantic salmon. Evolutionary Applications **6**:218-230.

Pess, G. R., M. C. Liermann, M. L. McHenry, R. J. Peters, and T. R. Bennett. 2012. Juvenile salmon response to the placement of engineered log jams (ELJS) in the Elwha River, Washington State, USA. River Research and Applications **28**:872-881.

Peters, R., E. Knudsen, G. Pauley, and C. Cederholm. 1996. An evaluation of introduced woody debris bundles to increase summer densities of juvenile coho salmon in the mainstem Clearwater River, Washington. USFWS, Western Washington Fishery Resource Office, Olympia, Washington.

Peters, R., B. Missildine, and D. Low. 1998. Seasonal fish densities near river banks stabilized with various stabilization methods: first year report of the flood technical assistance project. USFWS. Western WA office, Aquatic Resources Division, Lacey, WA.

Pine, W. E., S. J. D. Martell, C. J. Walters, and J. F. Kitchell. 2009. Counterintuitive Responses of Fish Populations to Management Actions: Some Common Causes and Implications for Predictions Based on Ecosystem Modeling. Fisheries **34**:165-180.

Poff, N. L., and J. K. H. Zimmerman. 2010. Ecological responses to altered flow regimes: a literature review to inform the science and management of environmental flows. Freshwater Biology **55**:194-205.

Pratt, T. C., and R. W. Threader. 2011. Preliminary evaluation of a large-scale American eel conservation stocking experiment. North American Journal of Fisheries Management **31**:619-628.

Qin, B. Q., G. Gao, G. W. Zhu, Y. L. Zhang, Y. Z. Song, X. M. Tang, H. Xu, and J. M. Deng. 2013. Lake eutrophication and its ecosystem response. Chinese Science Bulletin **58**:961-970.

Quigley, J. T., and D. J. Harper. 2006. Compliance with Canada's Fisheries Act: A field audit of habitat compensation projects. Environmental Management **37**:336-350.

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.

Reubens, J. T., U. Braeckman, J. Vanaverbeke, C. Van Colen, S. Degraer, and M. Vincx. 2013. Aggregation at windmill artificial reefs: CPUE of Atlantic cod (*Gadus morhua*) and pouting (*Trisopterus luscus*) at different habitats in the Belgian part of the North Sea. Fisheries Research **139**:28-34.

Ricciardi, A., and D. Simberloff. 2009. Assisted colonization is not a viable conservation strategy. Trends in Ecology & Evolution **24**:248-253.

Roberge, M., and T. Warren. In press-a. Methods used in evaluating the effectiveness of creating/enhancing stream habitats in Newfoundland and Labrador.

Roberge, M., and T. Warren. In press-b. Monitoring to determine the efficacy of utilizing fishless lakes as fish habitat compensation in Labrador. Fisheries and Oceans Canada.

Roni, P., T. Beechie, R. Bilby, F. Leonetti, M. Pollock, and G. Pess. 2002. A review of stream restoration techniques and a hierarchical strategy for prioritizing restoration in pacific northwest watersheds. Pages 1-20. North American Journal of Fisheries Management.

Roni, P., K. Hanson, and T. Beechie. 2008. Global review of the physical and biological effectiveness of stream habitat rehabilitation techniques. North American Journal of Fisheries Management **28**:856-890.

Roni, P., G. Pess, T. Beechie, and S. Morley. 2010. Estimating Changes in Coho Salmon and Steelhead Abundance from Watershed Restoration: How Much Restoration Is Needed to Measurably Increase Smolt Production? North American Journal of Fisheries Management **30**:1469-1484.

Rood, S. B., G. M. Samuelson, J. H. Braatne, C. R. Gourley, F. M. R. Hughes, and J. M. Mahoney. 2005. Managing river flows to restore floodplain forests. Frontiers in Ecology and the Environment **3**:193-201.

Rosenfeld, J. S., E. Raeburn, P. C. Carrier, and R. Johnson. 2008. Effects of side channel structure on productivity of floodplain habitats for juvenile coho salmon. North American Journal of Fisheries Management **28**:1108-1119.

Sabaton, C., Y. Souchon, H. Capra, V. Gouraud, J. M. Lascaux, and L. Tissot. 2008. Long-term brown trout populations responses to flow manipulation. River Research and Applications **24**:476-505.

Salant, N. L., J. C. Schmidt, P. Budy, and P. R. Wilcock. 2012. Unintended consequences of restoration: Loss of riffles and gravel substrates following weir installation. Journal of Environmental Management **109**:154-163.

Santos, M. N., M. T. Oliveira, and J. Curdia. 2013. A comparison of the fish assemblages on natural and artificial reefs off Sal Island (Cape Verde). Journal of the Marine Biological Association of the United Kingdom **93**:437-452.

Schroder, S. L., C. M. Knudsen, T. N. Pearsons, T. W. Kassler, S. F. Young, E. P. Beall, and D. E. Fast. 2010. Behavior and Breeding Success of Wild and First-Generation Hatchery Male Spring Chinook Salmon Spawning in an Artificial Stream. Transactions of the American Fisheries Society **139**:989-1003.

Scruton, D. 1996. Evaluation of the construction of artificial fluvial salmonid habitat in a habitat compensation project, Newfoundland, Canada. Regulated Rivers: Research and Management **12**:171-183.

Scruton, D., K. Clarke, M. Roberge, J. Kelly, and M. Dawe. 2005. A case study of habitat compensation to ameliorate impacts of hydroelectric development: effectiveness of re-watering and habitat enhancement of an intermittent flood overflow channel. Journal of Fish Biology **67 (Supplement B)**:244-260.

Scruton, D., C. Pennell, C. Bourgeois, R. Goosney, L. King, R. Booth, W. Eddy, T. Porter, L. Ollerhead, and K. Clarke. 2008. Hydroelectricity and fish: a synopsis of comprehensive studies of upstream and downstream passage of anadramous wild Atlantic salmon, Salmo salar, on the Exploits River, Canada. Hydrobiologia **609**:225-239.

SENES Consultants Limited. 2012. Report of the June 27-28 Habitat Conservation Banking Workshop. Fisheries and Oceans Canada, Ottawa.

SENES Consultants Limited. 2013. Report of the November 20-21, 2012 workshop on the application of habitat conservation banking in Ontario for offsets under the Fisheries Act. Fisheries and Oceans Canada.

Sharma, S., D. Jackson, and C. Minns. 2009. Quantifying the potential effects of climate change and the invasion of smallmouth bass on native lake trout populations across Canadian lakes. Ecography **32**:517-525.

Shearer, J. A., E. J. Fee, E. R. DeBruyn, and D. R. DeClercq. 1987. Phytoplankton Productivity Changes in a Small, Double-Basin Lake in Response to Termination of Experimental Fertilization. Canadian Journal of Fisheries and Aquatic Sciences **44**:s47-s54.

Sheng, M. D., M. Foy, and A. Y. Fedorenko. 1990. Coho salmon enhancement in British Columbia using improved groundwater-fed side channels. Can. MS. Rep. Fish. Aquat. Sci. 2071: 81 p.

Smokorowski, K. E., K. J. Withers, and J. R. M. Kelso. 1998. Does habitat creation contribute to management goals? An evaluation of literature documenting freshwater habitat rehabilitation of enhancement projects. Canadian Technical Report of Fisheries and Aquatic Sciences No. 2249.

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. River Research and Applications **24**:506-518.

Steel, E. A., P. McElhany, N. J. Yoder, M. D. Purser, K. Malone, B. E. Thompson, K. A. Avery, D. Jensen, G. Blair, C. Busack, M. D. Bowen, J. Hubble, and T. Kantz. 2009. Making the Best Use of Modeled Data: Multiple Approaches to Sensitivity Analysis of a Fish-Habitat Model. Fisheries **34**:330-339.

Stockner, J. G., and E. A. Macisaac. 1996. British Columbia lake enrichment programme: Two decades of habitat enhancement for sockeye salmon. Regulated Rivers-Research & Management **12**:547-561.

Stranko, S. A., R. H. Hilderbrand, and M. A. Palmer. 2012. Comparing the Fish and Benthic Macroinvertebrate Diversity of Restored Urban Streams to Reference Streams. Restoration Ecology **20**:747-755.

Sullivan, S. M. P., and M. C. Watzin. 2009. Stream-floodplain connectivity and fish assemblage diversity in the Champlain Valley, Vermont, USA. Journal of Fish Biology **74**:1394-1418.

Suttle, K. B., M. E. Power, J. M. Levine, and C. McNeely. 2004. How Fine Sediment in Riverbeds Impairs Growth and Survival of Juvenile Salmonids. Ecological Applications **14**:969-974.

Thorstad, E. B., I. Uglem, B. Finstad, C. M. Chittenden, R. Nilsen, F. Okland, and P. A. Bjorn. 2012. Stocking location and predation by marine fishes affect survival of hatchery-reared Atlantic salmon smolts. Fisheries Management and Ecology **19**:400-409.

Tomlinson, M. J., S. E. Gergel, T. J. Beechie, and M. M. McClure. 2011. Long-term changes in river-floodplain dynamics: implications for salmonid habitat in the Interior Columbia Basin, USA. Ecological Applications **21**:1643-1658.

Tupper, M., and K. W. Able. 2000. Movements and food habits of striped bass (Morone saxatilis) in Delaware Bay (USA) salt marshes: comparison of a restored and a reference marsh. Marine Biology **137**:1049-1058.

US Environmental Protection Agency. 2012. Mitigation Banking Fact Sheet.

US Fish and Wildlife Service. 2012. Conservation banking: incentives for stewardship. Pages Arlington, VA. US Fish and Wildlife Service.

Vermeij, M. J. A., I. van Moorselaar, S. Engelhard, C. Hornlein, S. M. Vonk, and P. M. Visser. 2010. The Effects of Nutrient Enrichment and Herbivore Abundance on the Ability of Turf Algae to Overgrow Coral in the Caribbean. Plos One **5**:8.

Verreault, G., P. Dumont, J. Dussureault, and R. Tardif. 2010. First record of migrating silver American eels (Anguilla rostrata) in the St. Lawrence Estuary originating from a stocking program. Journal of Great Lakes Research **36**:794-797.

Vincenzi, S., A. J. Crivelli, D. Jesensek, and G. A. De Leo. 2012. Translocation of stream-dwelling salmonids in headwaters: insights from a 15-year reintroduction experience. Reviews in Fish Biology and Fisheries **22**:437-455.

Wilders, D., and M. G. Lirette. 1994. Assessment of an artificial spawning channel at Sheridan Lake. Williams Lake, BC.

Williams, G. D., and J. B. Zedler. 1999. Fish assemblage composition in constructed and natural tidal marshes of San Diego Bay: Relative influence of channel morphology and restoration history. Estuaries **22**:702-716.

APPENDIX I: FISHERIES PROTECTION PROGRAM (FPP) STAFF EXPERIENCE

Below are responses from Fisheries Protection Program staff and/or Science staff on their experiences with fish habitat compensation under DFO's 1986 Policy for the Management of Fish Habitat. Some responses are in the form of case studies while others provide general information on projects or situations in the regions. All information was provided and written by individuals from each region, with minor editing to fit the format of this document.

PACIFIC REGION

Case Study 1 – Nechako River

The Nechako River was dammed in the 1950s and a significant portion of the water was diverted out of the watershed through a tunnel to a hydroelectric generating facility on a coastal river. In the 1980s, the proponent (Alcan) had plans to divert additional water out of the watershed and further reduce flows in the Nechako. There were significant concerns, court injunctions, and protests and this was resolved by an agreement signed by the federal government, provincial government and Alcan. The agreement said that monitoring would be required prior to the planned flow reduction, and would be required after the planned flow reduction along with a series of remedial measures to make sure that key fisheries targets were maintained.

The remedial measures included the installation of structures, mostly resembling log jams, intended to offset the expected reduction of those types of habitat features following the proposed reduction in flows. As a pilot project, dozens of these were constructed using various designs, and monitored to determine the level of success from biological (fish use) and physical (durability) perspectives.

The studies were initiated in 1987 when the project was approved, but the proposed flow change did not occur and was eventually cancelled in 1997. Monitoring of the remedial structures was phased out at that time, but the annual program of studies to monitor the Chinook population continued until 2005. Since 2006, basic monitoring has occurred every year, with more significant studies scheduled for every 5 years.

Data collected

There was a fairly significant monitoring program developed. The focus was on maintaining populations of Chinook salmon and sockeye salmon. They key parameter assessed for sockeye was water temperature and there is a degree of ability to control water temperature by manipulating flows from the storage dam. For Chinook, maintaining the freshwater conditions to support a target population was desired, and this involved looking at a number of parameters including:

- The number of spawning adults
- Egg to fry to survival
- Juvenile outmigration

A number of secondary factors were also monitored including:

- Substrate conditions
- Ice conditions
- Predation

Outcomes

The Chinook in the system return predominantly as 5 year olds, so we have data covering 25 years or 5 cycles. There have been some significant variations in the returns over the years, and there have been variations in the flow conditions the fish experience in the Nechako. In most years, the water flows are controlled and are generally managed to targets that were thought to provide for the needs of Chinook. In some years, when there is a high snowpack, flows will be greater than normal, in some cases much greater at certain times of year. We have not done a great deal of analysis on the data because the program has a fairly narrow and specific mandate, and as such, the monitoring and data analysis look to see if the objectives of the agreement signed in 1987 are being met. However, over the course of the monitoring program, we have learned that:

- Egg to fry survival and fry to smolt estimates seem to be fairly stable indicating that the spawning, incubating and rearing environment seems to be stable and able to support productivity throughout this lifestage consistent with target objectives.
- There are some anomalies that we have not developed explanations for:
    - Adult returns seem to be higher coming off years when flows during the rearing period are significantly higher than normal. We are not clear if there is a linkage here or not, and if it is indicating a possible limiting factor. If it is, we don't know what the factor is. It could be related to the flow itself (reducing predation?) or it could be that the flow provides access to habitat where the juvenile Chinook are more successful.
    - There are results for some years that do not seem to fit within the "normal" range for these studies. We have not really figured out what this might be attributed to and have not figured out if there is useful knowledge to be gained from this or not.

Some key points?

- Targets at the start need to be clear. The targets for this work were negotiated under fairly onerous circumstances and left some significant points open to interpretation.
- Monitoring/studies need to be carefully planned so that they measure parameters that are meaningful and answer the target questions.
- It can take a long time to get meaningful results. In this case, 20 years only provided feedback on 4 generations of Chinook and it took this long for most involved to be confident in even the most basic statements about what the data was showing us.
- It can take a lot of effort, resources and time to generate data that informs key questions. Even with all of this monitoring effort and having data that would not be available for an average project, we still are not able to say a lot about productivity for Chinook in this system.
- It probably requires more expertise in experimental design and data analysis than the average biologist is capable of to design an appropriate program and to evaluate and assess the results.

Reports from this program can be found at the Nechako Fisheries Conservation Program website.

Case Study 2 – Columbia River Revelstoke Flow Management Plan Water Use Plan (WUP)

There was an exercise started about 10 years ago to bring a series of socio-economic values into consideration for major hydro-electric facilities operated by BC Hydro. The traditional operation of these facilities was focused on electricity generation and flood control, and the idea was to bring other considerations into the operating decisions. This included bringing the annual operations into line with the *Fisheries Act*. The WUP (Water Use Plan) was essentially a multi-interest trade-off evaluation with the outcome being a series of operational rules to accommodate interests (including fisheries), an ongoing adaptive management exercise, and monitoring and studies to support all of that. It is ongoing and is expected to continue for the foreseeable future. Further information can be found on BC Hydro's website.

CENTRAL AND ARCTIC REGION

Four questionnaire responses were received from Central and Arctic and are described as individual case studies below. As well, general information on fish passage projects in Manitoba was also provided and briefly described.

Case Study 1 – Ekati Diamond Mine

The Panda Diversion Channel was created to divert water from North Panda Lake to Kodiak Lake to compensate for stream habitat destroyed due to mining activities at BHP Billiton's Ekati Diamond Mine. The main objective of the monitoring program was to determine suitability as fish habitat, comparing it against reference streams in the area. Arctic grayling are the predominant fish species utilizing the channel for spawning and rearing but other species also use it as a migration corridor. The channel overall has been a success although it took a number of years to have vegetation start to establish since the channel was blasted into bedrock. Lessons learned from the Panda Diversion Channel continue to inform recent diversion channel projects including the Pigeon Stream Diversion, also at the Ekati mine site.

The indicators of success or failure were:

- Comparison of growth rates of Arctic grayling in the Panda Diversion Channel to reference streams.
- Temperature and flow compared to reference streams
- Numbers of fish/ biological data compared to reference streams
- Assessment of created habitat features stability

Ten years was deemed appropriate for monitoring as it would take time for the channel to begin to mimic the productivity of natural streams (establishment of vegetation, benthic community, etc.). After Year 10, a reduced monitoring program continued specifically to monitor the return of Arctic Grayling that had been hatched in the channel and marked with a clipped adipose fin. In addition, the original team involved with a University of Alberta study (1998-2001) to assess the effectiveness of the channel as habitat compensation conducted a follow up assessment in 2011 in partnership with Rescan, the company's consultant. Early monitoring in 1999-2000 showed that the new stream had less riparian vegetation, coarse particulate organic matter, large woody debris, aquatic vegetation, macroinvertebrate diversity and richness, and Arctic grayling growth compared to reference streams (Jones et al. 2008). Follow-up monitoring in 2011 again showed that Arctic Grayling growth remained lower in the created stream compared to reference streams, as did accumulation and retention of organic matter. Other features such as macroinvertebrate community composition and abundance were similar in the created and reference streams.

A straight channel constructed in bedrock was a challenge to convert into a productive stream habitat. However, early on it was uncertain whether the channel would be a permanent feature after closure of the mine or not. Lessons learned through this process however have been very valuable for the design of new and proposed diversion channels in the north.

A number of peer reviewed papers were published on the project, as well as annual monitoring reports, and another peer reviewed paper should be published in 2013 documenting the assessment in 2011. References include:

Jones, N.E., G.J. Scrimgeour, W.M. Tonn. 2008. Assesing the effectiveness of a constructed arctic stream using multiple biological attributes. Environmental Management 42: 1064-1076.

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. Transactions of the American Fisheries Society 133: 1356-1365.

Jones, N.E. and W.M. Tonn. 2004. Resource selection functions for age-0 Arctic grayling (*Thymallus arcticus*) and their application to stream habitat compensation. Can. J. Fish. Aquatic. Sci. 61: 1736-1746.

Jones, N.E., W.M. Tonn, G.J. Scrimgeour, C. Katopodis. 2003. Productive capacity of an artificial stream in the Canadian Arctic: assessing the effectiveness of fish habitat compensation. Can. J. Fish. Aquatic. Sci. 60: 849-863.

Case Study 2 – Jackpine Mine

The longest existing compensation project in the oil sands is only 6 years old and success to date cannot yet be determined. One of the compensation projects constructed for the Jackpine Mine has the potential to be really very successful as the preliminary monitoring indicates an increase in productivity and extension of sport fish distribution.

Total estimated habitat losses for all watercourses affected by alterations as a result of the mine were 6,431,178 HUs, and that included includes 277,150 for northern pike, 42,413 for Arctic grayling, 201,344 for walleye, 730,254 for longnose sucker, 647,242 for white sucker, 1,123,322 for lake chub, 761,983 for brook stickleback, 474,187 for fathead minnow, 1,234,346 for pearl dace, 446,422 for slimy sculpin, 153,926 for spoonhead sculpin and 338,589 for spottail shiner.

The compensation plan for the project involved the development of a new lake in the lower reach of the existing Muskeg Creek, near its confluence with the Muskeg River, as well as the reconstruction of small part of Muskeg Creek. As the lake was filled only in 2009, the first year of monitoring was conducted in 2010 but the first 2 years of monitoring did not generate any significant results in terms of increased fish productivity. In year 3 monitoring, it was found that the populations of sport fish and particularly northern pike increased significantly. In year 2 of monitoring only 2 northern pike were caught during sampling, in year 3 of monitoring, very limited sampling involving hoop nets and seine nets (monitoring for fish will increase in time) yielded over 50 northern pike of all age classes. Further monitoring will include evaluations to determine the effectiveness of the compensation lake to support a sustainable fishery (including, but not limited to: measurements of fish abundance, community structure, and recruitment).

The components of Plan Monitoring are intended to evaluate the effectiveness of habitat compensation measures in meeting the quantitative objectives of the Compensation Plan, and also to verify predictions of the Plan, including the Habitat Suitability Index (HSI) models that were used for habitat quantification. Plan Monitoring includes the data collection requirements described below.

- Evaluation of representative areas of the constructed and natural fish habitat. This information will be used to verify or improve the HSI models, as well as to verify that compensation is adequate. Representative diversion channel, natural channel and lake habitat will be selected that provides a high diversity of mesohabitat types and fish species present.
- Stratified sampling of the fish habitat in the lakes with intensive study areas selected in the diversion streams that function as fish habitat and in the natural channels that are not altered by the project.
- Determination of biomass per unit area for each species in each mesohabitat type within the intensive study areas and extrapolation to determine the total biomass by species and to evaluate whether compensation has been achieved.
- Measurement of the habitat variables used in the HSI models in the intensive study areas. This will entail installation of temperature data loggers, measurement of pH and dissolved oxygen, mesohabitat mapping, substrate particle size sampling, macrophyte sampling, and measurement of the other habitat characteristics used in the models.

The Authorization is issued for a period of 35 years (until 2039) but some conditions may extend beyond the valid Authorization period. The success of compensation is not tied to any particular time limit, and it is dependent on the functionality of fish habitat compensation. Excerpts from the Authorization include:

a) Monitoring of the compensation habitat and habitat improvements shall continue until compensation has been achieved to the satisfaction of DFO.

b) At the end of the project the Proponent will fund an independent third party (the Auditor) mutually agreed to by the Proponent and DFO, to determine whether and to what extent the compensation lake is functioning as expected and to the satisfaction of DFO, and would include the audit of the results of previous monitoring and a final audit for compensation habitat. The audit will verify the Proponent predictions that compensation for the fish and fish habitat losses meets the quantitative objective of the Compensation Ratio and the compensation lake is functioning physically and ecologically as intended and specified in this Authorization. Subject to approval by DFO, the Auditor's report will be released to the public. The Auditor shall be someone with appropriate expertise but not employed by the Proponent. The Auditor shall be funded by the Proponent and the deliverables provided directly to DFO.

Two monitoring reports were presented to the regulators and to aboriginal groups in the area, but no documents have been published to date.

Several conditions of Authorization impose adaptive management on the Proponent, and modification of design, timing, etc. can be changed based on results of monitoring and to the satisfaction of DFO.

Case Study 3 – Bridge Construction

Recently DFO required the construction of an 80 m^2 rocky shoal as fish habitat compensation for a 900 m^2 infill caused by construction of bridge abutment on the Winnipeg River. Destroyed habitat was a mixture of bedrock, rubble and gravel and some shallow muddy bottom with aquatic vegetation. The habitat supported Lake Sturgeon along with pike, walleye, sauger, yellow perch, rock bass, smallmouth bass, white sucker, longnose sucker, quillback sucker, and a variety of forage fish species. The primary function of the habitat was food production. Construction occurred in 2010.

The proponent monitored the rocky shoal area before and for two years after placement and found that there was no statistical difference in fish abundance between on and off reef areas before and after construction. After reviewing their assessment DFO came to the conclusion that their assessment methodologies were not sufficient to detect a difference because: 1) most fish species sampled were schooling fish and so gill net captures were highly variable, 2) the fish species were unlikely to set up a home range on a rocky shoal that was so small and 3) it is likely that the fish species behaviour favours a migratory feeding strategy which will more randomly distribute fish around the reach of river so that they will only spend a limited time at this or any other reef in search of food. DFO did not require further monitoring on this project although the methods could not discriminate if the small reef compensation project had enhanced fish use or productivity in the area.

A better measure of success in this case would have been to assess lower trophic levels, macro-invertebrates and forage fish at the reef site before and after construction. If the base of the food chain was significantly improved after construction of the reef you could expect some benefit to be spread to the entire population. In this case however, 80 m^2 of habitat enhancement would likely translate to an undetectably small increase in overall food production for the river reach.

Case Study 4 – Lac Seul Causeway Construction

Three causeway bridge crossings were offset with the creation of fish nursery/feeding channels in a peat bog in Lac Seul (northwestern Ontario). These crossings provided access to timber harvesting areas (Loon Rapids: 525-4739) and linked Lac Seul First Nation (FN) islands with the mainland (Whitefish Channel: KE-04-2460 and Kejick Island to Archie's Landing: KE-08-0443). The impact to fish habitat was the infill of Lac Seul for the creation of causeways with a bridge installed to allow for water flow, fish movements and boat traffic.

A channel constructed in 1999, created in the winter months with a backhoe, was lengthened to offset the causeways built to link the Lac Seul FN communities by road. New channels were also constructed. Other peat bogs in Lac Seul were considered, but their connection to Lac Seul was shallower and thus access of cyprinids and predators to and from the channels was unlikely. The creation of nursery channels was considered successful as seining in late summer resulted in the capture of thousands of small fish (primarily cyprinids). Seining was first done about 10 years ago and captured numerous small fish utilizing the two year old dredged channel. Seining was done in 2008 in both the 10 year old and new channels and again an abundance of cyprinids were found, including one or two young pike.

Biomass (weight) or abundance (numbers) of fish was not recorded during seining due to the time and effort required and potential risks of fish mortality. Photographic evidence of fish in the seine was enough to prove the channels were heavily utilized by fish as a nursery/feeding area and probably spawning area for cyprinids. No night-time netting was done to see if walleye moved in to feed. Large fish would have been able to swim away from a slowly moving seine haul, thus a gill net, 4 foot trap net or boat electrofishing would have to be used.

The assessment of fish utilization for the Whitefish channel and Kejick Island causeways was summarized in an internal report. This included some underwater camera photos of small fish utilizing the interstitial spaces in the rock fill, and walleye being caught by angling and short set gillnets near the causeway - probably attracted to the causeways as a new feeding area.

There was limited time available for monitoring since the priority for fish habitat management staff was to process referrals that came into the office on a daily basis which required talking to people, processing paper, entering information into PATH and in some cases visiting the site. This didn't leave much time to monitor habitat compensation projects, and any monitoring was usually quick and linked with site visits for new referrals in the same area.

General Information - Manitoba – Fish Passage

In many of the waters of the prairies, given inter-annual variability of flows on prairie streams, monitoring years have been too wet or too dry to see if compensation works have been fully successful or not even in a qualitative fashion. On prairie streams the most obvious improvement to fisheries has been improving fish passage at man-made barriers. In many streams access to seasonal spawning habitats are limited by stream crossings, low head weirs and other man-made barriers. There are dozens of streams where the worst barrier is the furthest downstream structure, as often this is where the highest gradient is and so is the best place for a dam, or the most likely place for a culvert to become perched. This can effectively isolate the entire stream from seasonal fish use. Occasionally large year classes of various sport fish occur in Prairie streams however, they are generally linked to large floods that usually blow out the bad stream crossings and allow fish passage. For example on Lake Winnipeg strong year classes of walleye were seen in 1995, 1997 and 2001 which correspond to very large flood events in the south and west tributaries to the South Basin of the lake.

In some streams with perennial flow there are permanent forage fish populations that can feed downstream fisheries. Fall out-migrations from forage fish streams have been documented around the south basin of Lake Winnipeg, and it is believed to be the driver for the traditional fall migration of walleye from the lake into the larger tributary streams where these forage fish collect in abundance.

Several fish passage projects have been done in Manitoba, and several have been monitored that have demonstrated that fish are passing installed structures, however, no estimated improvements to fish populations following barrier remediation have been provided. Given the oscillation between high flow and low flow years within the province, it would take a prolonged monitoring program (10 years) before a good estimate of the success of barrier remediation on a population can be achieved. That kind of extended monitoring has not normally been a requirement in our Authorizations as it would not be affordable for most proponents in Manitoba.

QUEBEC REGION

Background

Fisheries and Oceans Canada (DFO), Quebec Region, has monitored over 340 compensation projects and 28 habitat banks since 1998. Questions are answered in a general manner in the examples below, though these are not necessarily representative of all the projects.

Evaluation of success

The success of a compensation project is determined based on the objectives requested and stipulated in the Authorization. These objectives are directly related to the identified and documented problem. For example, if the identified problem is fish habitat fragmentation due to obstruction of fish passage (e.g., misplaced culvert or water level regulation work), the project will be considered a success if fish passage is restored.

Indicators used to evaluate success

The indicators that are most commonly requested include:

a) demonstration that developments and their characteristics are in line with plans and specifications submitted to DFO;
b) stability of developments;
c) demonstration or confirmation that fish are using the habitat development.

Productivity or abundance indicators

Indicators such as biomass, abundance or reproductive success are not usually requested because these indicators are not evaluated for Harmful Alteration, Disruption or Destruction (HADD) of fish habitat. It is therefore not deemed necessary to obtain these indicators in cases where they cannot be compared with the loss.

Number and frequency of monitoring periods

On average, two to three monitoring periods over a period of three to five years are requested, among other things, to monitor the stability of developments over a period long enough for them to be subject to various hydraulic conditions.

Documents and data

DFO receives a work report (in writing or electronically) and a monitoring report for each compensation project. All reports are kept for a minimum of 10 years. These reports are not published in scientific, technical or extension journals. However, it is possible to request a copy from the proponent or to obtain documents through an Access to Information request.

Possibility of improving results through design or other changes

The purpose of monitoring is, among other things, to allow for the correction of compensation projects when developments do not yield the expected results. Corrections are often requested.

Furthermore, to improve compensation project results, we try to share lessons learned with proponents and their consultants by publishing recommendation documents to help plan and design various types of projects. The following is an example:

Fleury, M. and Boula, D. 2012. Recommandations pour la planification et la conception d'aménagements d'habitats pour l'omble de fontaine (*Salvelinus fontinalis*). Rapp.tech.cansci.halieut.aquat. 3008 : vi+33 p. [In French only]

The following are internal documents (not yet available to the public) to help analysts direct project design:

a) Guidance document to assess whether stream redevelopment should be monitored and, if necessary, to define the monitoring program
b) Recommendations for habitat development planning and design for species spawning in whitewater areas (working document)
c) Recommendations for developing flood plains (in preparation)
d) Designing concrete artificial reefs. Preliminary knowledge and recommendations

Compensation projects considered a success

Marine environment

Project title: Construction of multigenerational artificial reefs for the American lobster in Placentia Bay, Magdalen Island

Project: Multigenerational artificial reefs for lobster were created in Placentia Bay (Magdalen Islands) to compensate for habitat loss. The project was carried out in three steps: 1) characterizing a portion of Placentia Bay's sea floor to target an environment suitable for artificial reefs for lobster; 2) constructing eight 200 m^2 reefs equally divided between two sites; and 3) monitoring the general state and colonization of the reefs for two years and the lobster's benthic deposition for three years to document the effectiveness of these artificial reefs.

Project status: The project was considered a success because benthic deposition (lobster post-larvae) was observed from the very first year as well as in subsequent years, and the reefs are stable and provide shelter to commercial-size and pre-commercial-size lobster.

Indicators used:

Regarding the integrity of the development:

- The surface area of the habitat development: Each reef must measure 20 m by 10 m and be divided into five sections. The central section must measure 5 m wide and be made from small stones (10–20 cm in diameter). Each adjacent section must measure 4 m wide and be composed of medium-sized stones (20-40 cm in diameter). Each section at the end of the reef must measure 3.5 m wide and be composed of large stones (40–75 cm in diameter).
- The condition of the reefs (deterioration, stability, silting).

Regarding biology:

- Evaluation of reef colonization (species, stages of development, abundance, etc.) focusing on the various stages of lobster development.

Productivity criteria: The Authorization includes no abundance targets. However, through monitoring, the abundance of lobster post-larvae observed on the reefs was compared with the abundance observed in a natural nursery about 1.5 km away.

Monitoring period: Three monitoring periods over three years.

Documents accessible to the public: Monitoring reports must be requested from the proponent or obtained through an Access to Information request. A technical report is being prepared:

Gendron, L., F. Hazel, N. Paille, P. Tremblay, S. Pereira, M. Desrosiers, L. Roberge and R. Vaudry. 2013. Aménagement de récifs artificiels multigénérationnels pour le homard d'Amérique (*Homarus americanus*) dans la baie de Plaisance aux Îles-de-la-Madeleine, Québec. Rapp. tech. can. sci. halieut. aquat. ####. xii+76p. [In French Only]

Improving results

Suggestions were provided for possible changes to the reef stability monitoring methodology, but in view of the project's success, it is not considered that it could have achieved better results.

Monitoring reports

CJB Environment inc. 2009. Projet de compensation d'habitat du poisson. Aménagement de récifs pour le homard dans la baie de Plaisance, Îles-de-la-Madeleine. Étude de caractérisation du milieu. Report presented to Public Works and Government Services Canada, Fisheries and Oceans Canada and Transport Canada. CJB Environment inc., Québec, Quebec. ii+83 p. [In French Only]

CJB Environment inc. 2010. Projet de compensation d'habitat du poisson. Aménagement de récifs pour le homard dans la baie de Plaisance, Îles-de-la-Madeleine. Suivi de conformité des habitats aménagés. Report presented to Public Works and Government Services Canada, Fisheries and Oceans Canada and Transport Canada. CJB Environment inc., Québec, Quebec. ii+57 p. [In French Only]

CJB Environment inc. 2011. Suivi après un an sur les récifs artificiels TC et MPO-PPB. Placentia Bay, Magdalen Islands. Report presented to Public Works and Government Services Canada, Fisheries and Oceans Canada and Transport Canada. CJB Environment inc., Québec, Quebec. ii+19 p. + appendices. [In French Only]

CJB Environment inc. 2012. Suivi (2e année) sur les récifs artificiels à homards. Placentia Bay, Magdalen Islands. Report presented to Public Works and Government Services Canada, Fisheries and Oceans Canada and Transport Canada. CJB Environment inc., Québec, Quebec. i+19 p. + appendices. [In French Only]

Freshwater environment

Project title: Construction of eight weirs and a culvert, Nicolet River

Project: Construction of a culvert and eight weirs to permanently maintain water in the channel west of Île à Toinette (Nicolet River). These developments provide access to potential feeding, nursery and rearing grounds for species such as the walleye, brown bullhead, channel catfish, perch, smallmouth bass, red eye fish, sunfish, northern pike, silver redhorse, shorthead redhorse, banded killifish, golden shiner and mimic shiner.

Project status: The project is considered a success because the culvert and eight weirs were constructed to maintain water permanently in the channel west of Île à Toinette in accordance with the Authorization, and the aquatic developments are stable. No signs of erosion were observed, and the natural vegetation provides adequate cover. Through various fish inventory surveys, over 20 fish species were captured in the channel during flood and low-water periods.

Indicators used:

Regarding the integrity of the development:

- The developments (weirs and pits), culvert, riprap and vegetation must be stable and withstand ice and floods without being torn out;
- The surface area of the embankment's stabilized plants at the entrance of the west channel (close to the culvert) must be at least 144 m^2 under the high water mark (HWM);
- The gain in fish habitat surface area must be 2160 m^2 during flood periods and 5400 m^2 during low-water periods;
- The increased water level must not cause erosion in the channel west of Île à Toinette.

Regarding biology:

- The shrub (sandbar willow) survival rate must be greater than 80%;
- Herbaceous plant cover must be over 80% of the vegetated surface area;
- Fish must be present and use the developed environment.

Productivity criteria: Stocktaking and identification of harvested fish species were requested.

Monitoring period: Three monitoring periods over five years. However, monitoring periods were staggered over time because of work delays and the fact that there was no low-water period in 2008. DFO also cancelled spring monitoring for subsequent years.

Documents accessible to the public: Monitoring reports must be requested from the proponent or obtained through an Access to Information request.

Monitoring reports

G.V.L. Environnement Inc. September 2003. Programme de suivi des populations de poissons (chenal ouest de l'île à Toinette) automne 2003 pour la Ville de Nicolet. 19 pages. [In French Only]

G.V.L. Environnement Inc. November 2003. Programme de suivi des populations de poissons (chenal ouest de l'île à Toinette) pour la Ville de Nicolet. 7 pages. [In French Only]

G.V.L. Environnement Inc. September 2003. Caractéristiques du chenal ouest de l'île à Toinette. pour la Ville de Nicolet. 19 pages. [In French Only]

G.V.L. Environnement Inc. February 2004. Programme de suivi des populations de poissons (chenal ouest de l'île à Toinette) hiver 2004 pour la Ville de Nicolet. 7 pages. [In French Only]

G.V.L. Environnement Inc. June 2004. Programme de suivi des populations de poissons (chenal ouest de l'île à Toinette) printemps 2004 pour la Ville de Nicolet. 10 pages. [In French Only]

G.V.L. Environnement Inc. August 2006. Programme de suivi des populations de poissons (chenal ouest de l'île à Toinette) été 2006 pour la Ville de Nicolet. 15 pages. [In French Only]

G.V.L. Environnement Inc. June 2006. Programme de suivi des populations de poissons (chenal ouest de l'île à Toinette) printemps 2006 pour la Ville de Nicolet. 13 pages. [In French Only]

G.V.L. Environnement Inc. June 2008. Programme de suivi des populations de poissons (chenal ouest de l'île à Toinette) printemps 2008 pour la Ville de Nicolet. 13 pages. [In French Only]

G.V.L. Environnement Inc. August 2009. Programme de suivi des populations de poissons (chenal ouest de l'île à Toinette) été 2009 pour la Ville de Nicolet. 24 pages. [In French Only]

Project title: Development of flood plain, Île du Milieu, Berthierville

Project: Installation of a control structure that guarantees a specific flood level (5.0 m rating) at all times in the western part of the Île du Milieu marsh to ensure some availability of breeding and rearing habitat in the spring and increase the availability of feeding habitat in the summer. This project will produce an estimated potential gain of 1.29 ha during the spring (April to June) and a gain of 2.15 ha during the summer (July to October). During the spring, the western portion of the Île du Milieu marsh is used by several species found in Lake St. Pierre, including perch, northern pike and brown bullhead, notably for breeding and rearing. During the summer, it is used by the same species mainly for shelter and feeding.

Project status: The project is considered a success. Results show that fish are able to reach the migratory route during both the flooding and low-water periods. Individuals of all sizes can clear the structures. The overall upstream migration rate for all species combined is estimated at 80%. Fish are able to clear structures while migrating both upstream and downstream. Fish of varying lengths cleared the structures, which indicates that they are not selective for a particular individual size range. At least 31 species of fish use the marsh for breeding, rearing the young-of-the-year and feeding. Through fisheries, it has been confirmed that the marsh is used for breeding and nursing by eight species: perch, northern pike, brown bullhead, sunfish, black crappie, silver minnow, and central mudminnow.

Indicators used:

- The control structure should, to the satisfaction of DFO, grant access to the western portion of the Île de Milieu marsh for adults of several fish species that are present, including perch, northern pike, sunfish and brown bullhead during their respective upstream migration periods.
- The control structure should, to the satisfaction of DFO, allow fish to leave the western portion of the Île du Milieu marsh after the water level drops.
- The development of the control structure should, to the satisfaction of DFO, help improve the breeding, rearing, feeding and shelter habitat, notably for perch, northern pike, sunfish and brown bullhead in the western portion of the Île du Milieu marsh.

Productivity criteria: It was requested that the harvested fish species be counted, measured (in length) and identified.

Monitoring period: Three monitoring periods over three years.

Documents accessible to the public: Monitoring reports must be requested from the proponent or obtained through an Access to Information request.

Monitoring reports

Ministère des Ressources naturelles et de la Faune, Direction de l'expertise Énergie-Faune-Forêt-Mines-Territoire de la Mauricie et du Centre-du-Québec, Directions des affaires régionales, Laval-Lanaudière-Laurentides – Estrie-Montréal-Montérégie. In collaboration with Terminal Maritime Sorel Tracy. March 2010. Aménagement d'une voie migratoire à l'Île du Milieu. 36 pages + appendices. [In French Only]

Simard, A., P. Brodeur and M. Théberge. 2011. Efficacité de la voie migratoire du marais de l'Île du Milieu, année 1. Ministère des Ressources naturelles et de la Faune, Direction de l'expertise Faune-Forêt-Mines-territoire-Énergie de la Mauricie et du Centre-du-Québec and Unité de gestion des Ressources naturelles et de la Faune de Laval-Lanaudière-Laurentides. 53 pages + appendices. [In French Only]

Project title: Development of multi-species spawning ground, St. Maurice River

Project: Development of a 9000 m^2 (120 m x 75 m) spawning ground that meets the needs of several species, specifically the smallmouth bass, white sucker and walleye. The purpose of the development was to compensate for the loss of a 150 m^2 smallmouth bass spawning ground, the loss of a shoal also used for spawning by the white sucker (1450 m^2), and the silting of another one of this species' spawning grounds (3000 m^2).

Project status: The project is considered a success. The number of smallmouth bass nests is higher than the number for baseline conditions.

Indicators used:

Regarding the integrity of the development:

- the surface area of the development must be a minimum of 4650 m^2;
- the characteristics of the spawning ground (e.g., depth, substrate and speed of current);
- the stability of the development.

Regarding biology:

- checks of the presence of spawners (bathyscope, angling), and counts of nests and the presence of smallmouth bass, walleye and sucker eggs (driftnet).

Productivity criteria: The Authorization indicates that the new spawning ground must be used at least as much as those destroyed to compensate for lost productivity. The number of bass (target species) nests increased from 4 to 16 after the development was carried out.

Monitoring period: The monitoring program was executed three times over five years. Seeing as the old generating station still in operation is scheduled to close in 2014, a second monitoring cycle will be carried out between 2015 and 2019 to determine whether the development is still effective under these new conditions of distribution of currents.

Documents accessible to the public: Monitoring reports must be requested from the proponent or obtained through an Access to Information request.

Improving results: Although the development is still functional, degradation has been observed in the bass spawning sites, which will eventually need to be reconfigured to ensure the durability of these structures.

Compensation projects not considered a success

Marine environment

Project title: Creation of an eelgrass bed

Project: The compensation project consisted of creating a marine eelgrass bed with a surface area of at least 1500 m^2 in the northwestern basin of the Bonaventure barachois. The work involved removing about 1900 eelgrass root balls from a natural bed in the bay of Saint-Siméon-Est (latitude 48º03’00’’N, longitude 65º31’00’’W) and transplanting the eelgrass sod in staggered rows one meter apart over a 1500 m^2 surface area in the northwestern basin of the Bonaventure barachois.

Project status: The project is not considered a success because the survival rate of the transplanted plants was less than 25% instead of the expected 80%, and the actual surface area of the created eelgrass bed is about 14 m^2 instead of 1500 m^2. However, given that naturally occurring eelgrass in the environment began to colonize the developed area, no additional corrective action was requested.

Indicators used:

Regarding the integrity of the development:

- the surface area of the habitat development must be at least 1500 m^2;
- the donor bank must has been left in its initial condition, i.e., the same state as prior to picking.

Regarding biology:

- the survival rate of the transplanted eelgrass root balls must be at least 80%;
- the plants must be evenly distributed over the entire developed surface.

Productivity criteria:

- Number and diameter of eelgrass root balls per m^2.

Monitoring period: Two monitoring periods over three years, i.e., one and three years after the work is completed.

Documents accessible to the public: Monitoring reports must be requested from the proponent or obtained through an Access to Information request.

Improving results:

Inadequate characterization along with picking from a donor bed with characteristics (salinity and temperature) that were too different probably sent the eelgrass plants into osmotic and temperature shock. Most of the plants died. Those that survived do not seem to have recovered from the shock and grew little in three years. This could have been avoided by taking plants from a donor bed with characteristics that were more similar to the receiving environment.

Monitoring reports

GENIVAR. 2005. Construction d'un mur de protection à l'ancien quai de Fauvel et extension du brise-lame à Sainte-Thérèse-de-Gaspé, Compensation d'habitat du poisson, Transplantation de zostère marine dans le barachois de Bonaventure, Rapport de suivi 2005. Report presented to Public Works and Government Services Canada by GENIVAR. 15 pages and appendices. [In French Only]

GENIVAR. 2007. Construction d'un mur de protection à l'ancien quai de Fauvel et extension du brise-lame à Sainte-Thérèse-de-Gaspé, Compensation d'habitat du poisson, Transplantation de zostère marine dans le barachois de Bonaventure, Rapport de suivi 2007. Report presented to Public Works and Government Services Canada. 16 pages and appendices. [In French Only]

Project title: Development of rearing habitat for northern pike, lake whitefish, walleye and fallfish at the mouth of the Manouane River.

Project: In 2004, a shallow bay was created, measuring 3.6 ha in surface area and containing islets, on the right bank of the Manouane River where it meets the Péribonka River, to act as a rearing ground for several species of fish in the area. This habitat, which should promote aquatic plant growth, is protected from potential variations in water levels caused by the nearby generating station's daily management of water flows, because of submerged weirs at the two access points at the ends of the bay. The project compensated for the loss of a 2.1 ha rearing ground destroyed by tailrace dredging.

Project status: The project's failure was related the design of the development itself: although the habitat was used well by fish at first, subsequent monitoring periods indicated that the new habitat was gradually being silted, which may have limited fry's access to the development (4500 fry to 310 fry) and prevented aquatic plants from establishing themselves. As a result, the portion of the development that could be used gradually decreased over time, and the entire structure will be filled within a few years.

Indicators used:

Regarding the integrity of the development:

- the surface area of the development must be a minimum 2.1 ha;
- the characteristics of the rearing habitat (e.g., slope, depth, substrate, vegetation, ice cover, temperature, dissolved oxygen, pH, conductivity, nitrogen and phosphorus);
- the stability of the development.

Regarding biology:

- checks to determine whether northern pike, lake whitefish, walleye and fallfish young are present (absolute and relative abundance based on purse seining and experimental net fishing);
- demonstration that fish are not trapped in the bay after water levels decrease in the spring.

Productivity criteria: The Authorization does not include abundance targets, as success is determined based on professional judgement of the number of fish observed in relation to those in nearby control stations, established vegetation, and the durability of the development.

Monitoring period: The monitoring period was initially a minimum of five years with data collected one, three and five years after the development work was completed. Such a monitoring period is deemed satisfactory because the stability of the development and whether aquatic plants establish themselves can be observed under various hydrological conditions. However, because of the development's silting problem, the monitoring period was extended to year seven and year eight, and a complementary study was conducted in 2013 to determine and take appropriate corrective action. This work should be carried out in 2014, and the development will be monitored twice: one and three years after this work is done.

Documents accessible to the public: Monitoring reports must be requested from the proponent or obtained through an Access to Information request.

Improving results: Better placement of the development based on hydrological sedimentological studies.

Monitoring reports

Burton, F., Gendron M and R. Lapalme., 2005. Aménagement hydroélectrique de ka Péribonka – Rapport technique sur les aménagements fauniques de 2004 – faune ichthyenne. Report prepared by Environnement Illimité inc. and presented to Hydro-Québec Équipement. Direction Environnement et service technique. 52 pages, 2 appendices and 1 map. [In French Only]

Environnement Illimité inc., 2008. Aménagement hydroélectrique de ka Péribonka – Suivis des mesures d’atténuation et de compensation pour la faune ichthyennes – Travaux 2007. Report prepared by Burton F., G. Tremblay and M. Gendron. Presented to Hydro-Québec Équipement. Unité Environnement. 62 pages, 11 appendices and 4 maps. [In French Only]

Environnement Illimité inc., 2009. Aménagement hydroélectrique de ka Péribonka – Suivis des mesures d’atténuation et de compensation pour la faune ichthyenne – Travaux 2008. Report prepared by Burton F. and G. Tremblay. Presented to Hydro-Québec Équipement. Unité Environnement. 69 pages, 8 appendices and 7 maps. [In French Only]

Environnement Illimité inc., 2010. Aménagement hydroélectrique de ka Péribonka – Suivis des mesures d’atténuation et de compensation pour la faune ichthyenne – Travaux 2009.

Report prepared by Burton F. and G. Tremblay. Presented to Hydro-Québec Production, Direction Production des Cascades. 75 pages, 12 appendices and 4 maps. [In French Only]

GENIVAR. 2013. Aménagement hydroélectrique de la Péribonka – étude du patron d'écoulement et du transport sédimentaire dans le secteur du bassin d'alevinage localisé au PK 0,5 de la rivière Manouane. Report prepared by François Hardy and Martin Bouchard Valentine. Presented to Hydro-Québec Production, Direction Production des Cascades. 62 pages, 6 appendices and 4 maps. [In French Only]

Project title: Moulin Creek, a tributary of the Petit Pabos River

Project: The purpose of the project was to improve free passage conditions for brook trout in that area by installing fish ladders or weirs at inactive beaver dams and creating brook trout spawning and rearing areas in the Moulin Creek.

Project status: During the first monitoring period, beavers were observed resuming their activities. They plugged all the openings made during the development work. They also built dams over the developed weirs. This created obstacles that the fish could not bypass. Corrective actions (trapping) and measures (wire fencing, openings) did not solve the problem. Under these circumstances and given the results, DFO closed the file.

Indicators used:

Regarding the integrity of the development:

- Check the stability of beaver dam E1 at the mouth of the pass;
- Check whether the physical characteristics (e.g., depth, substrate and flow) of the developed sites are still adequate and stable for brook trout reproduction and rearing. The general condition of developed habitats also needs to be documented.
- Assess whether brook trout passage conditions are adequate using physical variables (water level, weir height, depth of pit downstream of weir, presence of debris, runoff, etc.).
- Assess physical passage conditions for juvenile and adult brook trout at beaver dams during the active spring migration period and in the fall during the species' breeding season (upstream and downstream water level, water level in the structure, flows, area to attract fish, presence of debris, etc.).

Regarding biology:

- Determine, by capturing individuals, whether juvenile and adult brook trout can bypass the beaver dam through the passage structure from downstream towards upstream during the species' active migration period in the spring.
- Document fish distribution and the use of developed environments.

Monitoring period: Three monitoring periods over four years.

Documents accessible to the public: Monitoring reports must be requested from the proponent or obtained through an Access to Information request.

Monitoring reports

Ministère des Transports du Québec. 2005. Réalisation d'un projet de compensation pour l'habitat du poisson au ruisseau du moulin. Tributaire de la rivière du Petit Pabos. City of Chandler (Saint-François-de-Pabos). Réaménagement de la route 132 à Grande-Rivière (est de la baie du Petit Pabos). Work carried out in 2005. 6 pages and appendices. [In French Only]

Ministère des Transports du Québec. June 2006. Plan de travail déposé au ministère des Transports du Québec. Document prepared by PESCA Environnement. 46 pages and appendices. [In French Only]

Ministère des Transports du Québec. February 2007. Rapport de suivi d'aménagements aquatiques. Suivi annuel 2006. Projet de compensation de l'habitat du poisson au ruisseau du Moulin Chandler (Saint-François-de-Pabos).14 pages and appendices. [In French Only]

PESCA Environnement. February 2008. Rapport de suivi d'aménagements aquatiques. Suivi annuel 2007. Projet de compensation de l'habitat du poisson au ruisseau du Moulin presented to the MTQ. 17 pages and appendices. [In French Only]

PESCA Environnement. March 23, 2010. Rapport de suivi d'aménagements aquatiques. Suivi annuel 2009. Projet de compensation de l'habitat du poisson au ruisseau du Moulin (Chandler-Saint-François-de-Pabos) presented to Transports Québec. 21 pages and appendix. [In French Only]

Regroupement pour la restauration des trois rivières Pabos. June 2005. Identification des problématiques reliées à l'omble de fontaine sur trois tributaires de la rivière Petit-Pabos. 3 pages and appendices. [In French Only]

GULF REGION

Several compensation projects have been undertaken in the Gulf region over the years. In the marine environment, artificial reefs have been used, both for oysters and lobsters. Those projects are considered "successful" in 80% of the locations. Those projects were needed for authorizations issued to SCH mainly for infills in the marine environment. The compensation projects in freshwater habitat are mostly related to either erosion control (sedimentation) or fish passage (flow regime alteration, impediment to migration).

Freshwater Projects

- Removal of a log jam – Follow-up will be done by monitoring the abundance upstream of the former log jam (1 yrs after)
- ALUS – An initiative where farm land along streams/rivers is acquired and will act as a "buffer" to prevent the entrance of sediments in waterways. By doing so, it also reduces the nutriment load added in streams thus enhancing the water quality. This project was compensating habitat destruction by SCH (infill).
- Construction of a fishway in a "perched" culvert as compensation for destroying a portion of a stream; follow-up measured the presence of salmonids (DFO Science)
- Construction of a fishway in a natural waterfall to permit fish passage as a compensation project for SCH projects. Monitoring of success is being done by University (Dal.)
- In-Stream compensation for road construction to install vegetated "lunkers" and enhancing habitat features by installing boulders, root wads. Success was measured (abundance) for 3 yrs.

For projects related to fish passage, usually presence/abundance/observed migration of certain species (not only salmonids). Monitoring of the projects was between 1-3 years. No scientific papers were published but monitoring reports are available. The design of the various projects was essentially good but it appeared timing could have improved the performance in some instances.

Marine Projects

Nearshore Artificial Reefs in the Gulf Region

Since 2003, approximately 65,000 concrete structures were deployed in six sites to create nearshore artificial reefs to compensate for declared HADD in the southern Gulf of St. Lawrence. The general location and size in terms of area covered and number of structure for the artificial reefs were established by Habitat Management and the *in situ* site selection process and monitoring were coordinated or carried out by DFO Lobster Section, Moncton. The purpose of the artificial reefs was to enhance the complexity of rocky coastal habitat by increasing shelter availability for benthic species. Lobster was selected as the target species for investigating habitat productivity because of its commercial importance and availability of material in the scientific literature (i.e., the large number of studies on lobster).

The efficiency of an artificial reef will first depend on a proper site selection process and secondly on the type of structure deployed. We used a two step approach: exclusion mapping and visual transect surveys. The exclusion mapping consists of a multibeam mapping survey of a general location using the OLEX™ system. Areas with the incorrect depth, slope, and surficial benthic substrate were eliminated. The second step was to carry out a visual transect survey on a flat bottom in water < 10 m deep with gravel and small cobble substrate. During the visual transect survey, information was gathered on the abiotic (i.e., to corroborate the information from the remote multibeam technology) and biotic (i.e., density or presence of lobster and other benthic species) habitat characteristics for the final selection of the most appropriate site. The type of structures selected to create the artificial reef were standard 40 X 40 X 15 cm high-density concrete structures.

Between 2003 and 2011 twenty-four SCUBA surveys were done at 6 sites to determine the effectiveness of artificial nearshore reefs. The percentage of structure that sank into a soft substrate (sandy/muddy) was used as the site selection metric since lobster and other shelter digging species do not colonize these structures. The percentages of sunken structure were low ranging from 0% to 7%, indicating a suitable selection process had been followed for the deployment and creation of artificial reefs. The highest percentages of sunken structures were observed at sites with ledges forming small canyons with mud/sand substrate at the bottom.

The presence of lobster, and other benthic species, associated with the structures was used as the colonization metric. For lobsters, two indicators could be used; the percentage of structures with lobsters or lobster shelters. Lobsters colonized between 41% and 81% of artificial reefs. Following a marked increase in lobster abundance that occurred in most of the sGSL during the late 2000's, the percentage is now around 65%. Lobster shelters could be a better indicator because lobsters are mobile and could excavate and occupy multiple shelters. The percentage of lobster shelter within an artificial reef ranged between 78% and 100%. Once again, with the recent increase in lobster numbers, the percentage of structures with lobster shelters is now in the 90% range. Benthic fishes were observed on or within 90% of the artificial reefs that we examined. However, the situation was different for the Fox Harbour artificial reef located in central Northumberland Strait. Unlike the rest of the southern Gulf of St. Lawrence, the abundance of lobster in this part of the Strait is currently the lowest on record. Thus, between 2006 and 2010, the percentage of lobster and lobster shelter dropped by half from 4% to 2% and from 87% to 41%, respectively. This supports the hypothesis that the rate of artificial reef use is a function of lobster abundance.

Lobster densities associated with artificial reefs compared to natural lobster reefs was used as the productivity metric. The average lobster density estimated for artificial reefs (4.32 lobster/m^2) was 25-fold higher than the density estimated for natural lobster reefs (0.17 lobster/m^2) based on the 100-m transects. Another indicator for productivity metric was the density of 0-age lobster

(<18 mm of carapace length) because of their cryptic behavior and they are found near where they settle to the bottom (recruitment index). The average 0-age lobster density estimated for artificial reefs (0.67 lobster/m^2) was also 25-fold higher than the density estimated for natural lobster reefs (0.03 lobster/m^2) indicating that lobster recruits would take advantage of the artificial reef, i.e., increasing lobster recruitment and presumably population productivity. However, the density estimate from transects likely biased the outcome because of scaling factors (i.e., the effectiveness of an artificial reef will be positively biased). Instead of comparing densities estimated from artificial reef structures (0.16 m^2) with transects (400 m^2), we proposed to use density estimated from quadrats (0.25 m^2). Quadrats were only done in Caraquet and Fox Harbour. In Caraquet, the average lobster density estimated for artificial reefs (4.02 lobster/m^2) was 6-fold higher than the density estimated for natural lobster reefs (0.69 lobster/m^2). Similarly, the average 0-age lobster density estimated for artificial reefs (0.51 lobster/m^2) was 7.5-fold higher than the density estimated for natural lobster reefs (0.07 lobster/m^2). The situation was slightly different for the Fox Harbour reef as 0-age and overall lobster densities were very low (recruitment failure).

The site selection, colonization and productivity metrics all show that nearshore artificial reefs created in the proper habitat could enhance lobster, and coastal species, productivity.

MARITIMES REGION

Case Study 1

DFO Small Craft Harbours funded a DFO Science project involving the creation of artificial rock pile reefs. Infilling for breakwaters, dredging and other infrastructure-based work at several facilities in the Eastern Nova Scotia Area of the Maritimes Region had resulted in a deficit of habitat compensation. The proposed artificial reef study was accepted as compensation for these habitat losses and impacts. The scientific knowledge to be gained in this area was considered to be of great interest and value to the Habitat Management Program. The project was considered to be successful, though direct measurement of habitat compensation to habitat loss from the various Small Craft Harbour projects was not carried out to quantify the net loss or gain. The success lie in the knowledge gained from the research.

In August 2006 three rock pile reefs were constructed at Inner Sambro Island and also at Cook Head. Each reef module consisted of 20 rock piles set in a matrix of 4 by 5 each separated by 4 m. A rock pile consists of 200 kg to 250 kg of 15 cm (maximum dimension) beach stone (archaic) with a mean height of 27.8 cm above surrounding substrate and an average diameter of 1.3 m. Each rock pile is separated from the adjacent one by a minimum of 3 m.

The census of life on these rock piles in 2007 and 2008 described the development of a marine plant community that significantly changed the complexity of the habitat architecture.

In June 2008 we began a destructive sampling program at the reef modules at Cook Head and Inner Sambro Island and we completed it by September, 2008. A total of six rock piles were sampled on each artificial reef module. Three rock piles from the center of the matrix and three from the perimeter were haphazardly sampled. The entire rock pile was first encircled with a 1.5 cm mesh hoop net 1.5 m in diameter and 1 meter high to prevent the escape of mobile animals.

All overstory macrophytes were removed and placed in a net bag. An air lift suction with 3mm mesh collecting bag was used to capture mobile organisms, understory algae and meso-invertebrates. While suctioning the rock pile, we turned over the rocks to allow capture of the more cryptic fauna. Macrophytes were separated to genus and wet weighed to 0.1 g. All invertebrates were separated into taxonomic units and their wet weight was measured to 0.1 g. Three to four rocks were removed from each rock pile to identify sessile fauna and the undersides examined to find cryptic ones.

Adjacent to each artificial rock reef we sampled the epibenthos using the same net and suction technique. Six samples were chosen haphazardly but within 2m of the outer edge of the reef and all surface organisms (no digging) were suctioned to the net bag. At the Inner Sambro site the adjacent substrate was eelgrass (*Zostera marina L.*) and sand habitat while at Cook Head the substrate was sand/mud with some drift algal cover. Eelgrass was suctioned first to remove any attached or mobile organisms prior to removal of the shoots. Drift algae was suctioned from mud/sand with the main sample.

To examine the productivity of natural rock reefs in comparison to our artificial reefs we sampled three sites; two that were within 50 m of our reef modules and one that was within Sambro Harbour, Isle of Mann. The natural rock reef sites were sampled at the same 10 m depth zone (+ 1 m) as the location of the artificial reefs. Six samples were taken from parts of the reef with rocks that could be moved by the diver, equivalent to <30 cm maximum dimension. The overstory of macrophytes was removed and then the rocks were suction sampled within the hoop net.

Indicators for success were based upon the biomass of invertebrates, vertebrates and marco algae, though, as stated earlier, the science and practical knowledge for application by the Program, was the ultimate indicator.

Four major questions were addressed:

1) What is the level of annual productivity in rock pile reefs in comparison to adjacent habitat types and to natural rock reefs?
2) What are the principal subtidal habitats in Sambro Harbour and environs?
3) What is the spatial distribution and area of the principal habitats?
4) If we increased the area of rock pile reefs in Sambro Harbour and environs what would be the contribution to production from this area?

Production to biomass ratios were applied to each taxon based on P/B ratios derived from reviewed literature (references). The annual production per m^2 was calculated as an average of the sum and the standard error of the identified taxons and grouped into invertebrates, vertebrates and flora. These were compared for each habitat type.

Based upon the area of each habitat type from habitat mapping data, the contribution of local production was calculated with the habitat productivity. The area of each habitat was multiplied by the unit area production per year for each group of organisms.

Two years was the funding envelop and limited the duration of this particular study. It was acknowledged that more study was required and further questions identified for investigation. No significant funding source was obtained to continue, and the information gathered to date was useful for the Program. Nothing was published to date, though results and a draft was made available. It is believed that some publications may result from this work. It was determined that size of rock was crucial, as it related to stability and persistence of the structure.

Case Study 2: Cheverie Creek Salt Marsh

Back in 2005 the removal of an undersized box culvert that was replaced with a larger aluminum elliptical culvert (measuring 9.2 m by 5.5 m) in the tidal environment to restore tidal flow and fish passage to the upper watershed in Cheverie Creek, Hants County, Nova Scotia. This was a joint cost shared project between Nova Scotia Department of Transportation and Infrastructure

Renewal (NSTIR) and DFO-SCH. Partnerships were also formed for this project with the Ecology Action Centre and Ducks Unlimited Canada. Before the replacement of the culvert the total marsh area was 5.4 hectares and post-restoration the total amount restored was 43.08 hectares. The project was needed to compensate for some past highway projects and SCH projects that resulted in HADD's in that ecological unit of the province. It was considered successful based on the 5 years of monitoring data to show re-established salt marsh, which is known to be extremely productive habitat that would contribute to certain life stages of fish in the watershed. It was not only successful in terms of the biological community, but it was also a huge success for the community and residents in the area who worked hard to see the project happen. The community (from schools, residents and business owners) rallied around the project from its inception and now there is an interpretive hiking trail and community center adjacent to the re-established marsh. The land was provided by a local landowner for the establishment of the community center. This project was a win win for all involved.

Data was collected for geospatial attributes, hydrology (depth to water table; water quality), soils and sediments (pore water salinity; sediment accretion & elevation; soil characteristics), vegetation, nekton (fish) and benthic and aquatic invertebrates (reference condition approach; invertebrate activity traps) at both the salt marsh restoration site (Cheverie Creek) and a nearby reference site (Bass Creek).

Fish abundance was measured as a component of the monitoring, which showed a marked increase in the relative abundance of fish post-construction, mostly due to the increased Panne size, re-activated creek network and improved hydrological conditions. The pannes were formed as part of the flooding post-restoration. In 2010 did see a greater number of predatory species captured.

The abundance of benthic and aquatic invertebrates was also measured as a component of the monitoring program.

Initially as part of the Memorandum of Understanding the monitoring post-construction was going to take place for 5 years; however, following the third year (2008) of post-retoration monitoring it was decided that the schedule for the remainder of the monitoring program be adjusted from a consecutive 5 year post-restoration program to a year 5 (2010) and 7 (2012). The reduction of the 4th year of monitoring and the addition of monitoring activities 7 years post would enable the documentation of longer-term changes in the physical and biological components of the system as a result of the culvert replacement.

In my opinion I don't believe that the project could have improved through modification in design or timing. This was one of the first large scale salt marsh restorations related to fish habitat compensation (establishment of a habitat bank) that was completed in N.S. However, there have been other large scale salt marshes established after this project that have also been successful and it is likely that the monitoring program could be adapted as a result for future projects as we know now how quickly the salt marsh re-establishes back to or close to the original state. In saying that it should be noted that these are very dynamic environments and site maturation could be a factor in the success of Cheverie Creek and other salt marsh restoration projects.

References

Bowron, T., Neatt, N., van Proosdij, D., Lundholm, J., and Graham, J. 2009. Macro-Tidal Salt Marsh Ecosystem Response to Culvert Expansion. Restoration Ecology - The Journal of the Society for Ecological Restoration International.

Also as a result of a partnership with Saint Mary's University 6 student research projects from an Undergraduate Honours and Masters of Applied Science program have resulted from this project.

Case Study 3: Walton River Salt Marsh

In 2005 NSTIR in partnership with Ducks Unlimited Canada completed construction activities (water control structure removal and dyke breach) at a site along the Walton River, Hants County, Nova Scotia, to restore tidal flow to a 12 hectare former salt marsh. The project was required for fish habitat compensation related to prior HADDs from highway construction in the ecological unit of the restoration site. After 5 years of monitoring the project has been considered a success for the biological community as the restoration site continues to change from the pre- and post-construction conditions, becoming more like the reference site in certain indicators.

Data was collected for geospatial attributes, hydrology (hydroperiod & tidal signal; depth to water table; water quality), soils and sediments (pore water salinity; sediment accretion & elevation; soil characteristics), vegetation, nekton (fish) and benthic and other aquatic invertebrates (reference condition approach; invertebrate activity traps) at both the salt marsh restoration site (Walton River) and the nearby adjacent reference site.

Fish abundance was measured as a component of the monitoring, which showed a marked increase in the relative abundance of fish post-construction. Fish density was higher at the post-restoration site for all years with the exception of year 2 and year 5. Also the presence of higher order predators are accessing the site during high tide.

The abundance of benthic and aquatic invertebrates were also measured as a component of the monitoring program.

Initially as part of the Memorandum of Understanding the monitoring post-construction was going to take place for 5 years; however, following the 5th year as there is still potential for conditions to change it is advised that this site continue with annual monitoring through year 7.

In my opinion I don't believe that the project could have improved through modification in design or timing. This was the second large scale salt marsh restorations related to fish habitat compensation (establishment of a habitat bank) that was completed in N.S. However, there have been a few more large scale salt marshes established after this project that are still undergoing monitoring, but are proving to be successful. It is likely that the monitoring program could be adapted as a result for other future projects as we are finding that the salt marshes seem to re-establish back to or close to the original state. In saying that it should be noted that these re-established salt marshes are very dynamic environments and even after the 5th year of post-construction monitoring at Walton River changes are still occurring at the restoration site.

References

van Proosdij et al. 2010. Ecological Re-engineering of a Freshwater impoundment for Salt Marsh Restoration in a Hypertidal System. Ecological Engineering.

A book chapter titled "Chapter 14 – Salt Marsh Tidal Restoration in Canada's Maritimes Provinces" has been submitted for peer-reviewed publication in the book *Restoring Tidal Flow in Salt Marshes: A Synthesis of Science and Management.* (Roman and Burdick In Press).

Also in partnership with Saint Mary's University 6 student research projects from an Undergraduate Honours and Masters of Applied Science program have resulted from this project. Plans are also underway to produce additional peer-reviewed publications during the coming year in order to continue to share lessons from these two restoration projects.

Note: We did advocate for two dams to be removed in the province of N.B. with the New Brunswick Department of Transportation and Infrastructure at Barker Dam on the Nashwaak River and Moores Mills Lake Dam for fish habitat compensation; however, the monitoring data is expected to be collected this season with submission in the fall/ winter.

I would expect that the results of the upstream fish passage monitoring that will be undertaken this season will show evidence of success in these two large scale projects as well. I think there is much value in eliminating barriers to fish passage for fish habitat compensation projects as we know fragmentation of fish habitat is an important issue in our region and if we are strategic about where these projects occur, it could have a real positive impact on the productivity of the fisheries in our Region.

NEWFOUNDLAND AND LABRADOR REGION

Many fish habitat compensation projects in both marine and freshwater environments have been undertaken in the Newfoundland and Labrador region. Two case studies are described below.

Case Study 1: Rose Blanche Hydroelectric Development

In 1998 the Newfoundland Power Company Limited was issued a Section 35(2) *Fisheries Act* Authorization for the harmful alteration, disruption or destruction of fish habitat resulting from the construction and operation of a small hydroelectric development (6.1 MW) on Rose Blanche Brook on the southwest coast of Newfoundland. The project involved the construction of a forebay dam that caused the flooding of approximately 57000 m^2 of salmonid spawning and rearing habitat.

To compensate for the loss of fish habitat associated with the undertaking, a fish habitat compensation program was undertaken. The proponent created and enhanced spawning/rearing habitat in a channel located at the lower main stem of the brook (compensation channel) through:

- The placement of spawning gravels/boulders/logs at appropriate locations;
- Bank stabilization/revegetation;
- Maintaining consistent flows at an optimal level for salmonid spawning/rearing
    - excavating the northwest inflow and installing a concrete culvert to regulate flows;
    - constructing a control weir in the main stem to direct flows to the channel; and
    - constructing three dykes to prevent channel flooding and to ensure suitable.

The proponent also provided improved access to anadromous salmonids through:

- The reconstruction of an existing rustic fishway;
- The construction of two vertical slot fishways;
- Consistently maintaining flows below the tailrace at an optimal level for the enhanced spawning/rearing habitat and fishways operation.

A monitoring program was established in order to assess the effectiveness of the compensation measures by undertaking the following:

- Conducting visual inspections of the channel to ensure structural integrity, including substrate stability and bank stability;

- Conducting quantitative electrofishing surveys within the channel at representative sites and at sites in the lower main stem;
- Conducting visual inspections of each fishway to ensure structural integrity is maintained and evaluate the performance of each fishway;
- Assessing the effectiveness of each fishway during periods of peak migration at high, medium and low flows and monitor presence of anadromous salmonids above the fishways.

Results/Conclusions**:** Assessment of Habitat Utilization and Structural Integrity**:** Results indicate that the compensation channel appears to be operating as intended with suitable flows and velocities and is providing good quality fluvial spawning and rearing habitat. Redd surveys conducted in 2003 confirmed utilization of the spawning substrates within the channel; it was estimated that 168 redds existed in the compensation channel and some of these were likely to represent multiple brook trout or ouananiche redds (AMEC 2004).

Quantitative electrofishing indicated an increase in numbers of fish caught in both the main stem and compensation channel from 1999 to 2003. These increased numbers allowed for calculation of estimated biomass. In the compensation channel, total biomass was estimated to range between 535 and 670.6 grams per habitat unit and biomass in the main stem of Rose Blanche brook was estimated to range from 60.4 to 785.4 grams per habitat unit (AMEC 2004). To date no anadromous salmon have been recorded returning to Rose Blanche Brook.

Assessment of Fish Passage**:** Based on the final Rose Blanche Monitoring Report (AMEC 2004), all three fishways appeared to be operating effectively. Although the monitoring program is completed, the proponent is responsible to keep all fishways open, unobstructed, and supplied with sufficient water.

In addition to the monitoring program required under the *Fisheries Act,* DFO conducted a study on this project to determine the stability of the constructed habitat in the compensation channel and if fish production in the channel (measured as biomass) replaced that lost due to the habitat destruction caused by the project (Scruton et al. 2005). The amount of total biomass lost due to the project was determined from the area lost (57000 m^2) and the average fish biomass (brook trout only) in pre-development surveys. Compensation fish biomass was estimated based on the available habitat in the compensation channel (9960 m^2) and the average total fish biomass (Atlantic salmon and brook trout) in each year of sampling (2000-2002). The study found that the total fish biomass in the compensation channel increased throughout the three years of the study and biomass decreased in the mainstem habitat over the same time period but the changes were only significant ($p < 0.05$) in 2002. A net gain in fish production (i.e. no net loss) was achieved three years following the development, in 2002. This no net loss of fish production was achieved although the compensatory channel contained only 9960 m^2 of habitat versus 57000 m^2 that was destroyed.

References**:**

AMEC Earth and Environmental Limited. 2004. Rose Blanche Hydroelectric Development Fish Habitat Compensation Works Monitoring Program, 2003 (Year 5). Newfoundland Power. St. John’s, NL.

Scruton, D.A., K.D. Clarke, M.M. Roberge, J.F. Kelly, M.B. Dawe. 2005. A case study of habitat compensation to ameliorate the impacts of hydroelectric development: effectiveness of re-watering and habitat enhancement of an intermittent flood overflow channel. Journal of Fish Biology 67 (Supplement B): 244-260.

Case Study 2: Nugget Pond Gold Mine and Mill

On May 5, 1997 DFO issued an Authorization to Richmont Mines Inc. for the harmful alteration, disruption or destruction of fish habitat resulting from the construction and operation of a tailings management system associated with the development of a gold mine/mill in the Nugget Pond area located 17 km southwest of the town of La Scie on the Baie Verte Peninsula. Richmont Mines used Fly Pond, Nugget Pond, Jay Pond and Rocky Pond for a tailings management system utilizing Fly Pond as the tailings settling pond with Jay Pond, Nugget Pond and Rocky Pond comprising the polishing pond system. A dam and saddle dyke was constructed at the tailings pond and a dam constructed at the polishing pond to ensure settling and containment of tailings. Approximately 267,000 m^3 of tailings were deposited in Fly Pond during the 5 year life of the mine.

To compensate for the loss of productive fish habitat associated with the undertaking, Richmont Mines Inc. committed to replace the fish habitat productive capacity lost at the project site, by creating new habitat at a previously inaccessible site in Middle Arm Brook. More particularly, Richmont Mines provided fish passage above Camp 11 Falls through the construction of a rustic fish ladder on Middle Arm Brook during the period of fish migration thereby creating accessibility to fish rearing and spawning habitat in the Middle Arm Brook watershed above the Camp 11 Falls. Heavy rainfalls hampered progress in both the 1997 and 1998 construction seasons. All compensation works were completed by November 2001.

Monitoring: Richmont Mines established a monitoring program in order to assess the effectiveness of the compensation measures by undertaking the following:

- Conducting visual inspections in 2002 and 2004 to assess the effectiveness of the fishway, including safe fish migration past the falls and no congregating at either the base or immediately above the falls.
- Conducting hydrological evaluations to determine there is sufficient water flow in the fishway for safe fish passage.
- Providing DFO with a comprehensive report on the effectiveness of the compensation works for both monitoring years.

Monitoring began in 2002 and was completed in 2004.

Results/Conclusions: The monitoring results indicate that the fishway is operating effectively from a hydrological perspective (i.e. sufficient flows over the fishway are being maintained under low flow conditions). Salmon have been monitored in a pool approximately 100m below the falls however no salmon have been observed above the falls (Richmont Mines 2004). Since the original man-made obstruction was in place for a significant period of time (approximately thirty years), it is likely that fish would need to be transported above the falls before they begin using the fish ladder on their own.

Lessons learned from this project: As of the date of the final monitoring report, 2004, there was no evidence that fish were using the fish ladder. However, the *Fisheries Act* Authorization required only that fish passage be provided and did not require the proponent to ensure that fish utilized the ladder. For future offsetting of this type, DFO will likely require fish transfer of Atlantic salmon for at least 3 years to facilitate a timely re-establishment rather than just relying on salmon to find their way.

References:

Richmont Mines Inc. 2004. Fish Habitat Compensation Program Report. Richmont Mines Ltd. Baie Verte, NL.