Metrics for Assessing Fisheries Productivity and Offsetting Strategies under Canada's New *Fisheries Act*

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REPORT SUMMARY

The Alberta oil sands region contains one of the world's largest oil deposits, estimated at 1.7 trillion barrels. Development in this region can have negative effects for aquatic species, governed under Canada's *Fisheries Act*. The *Fisheries Act* allows the possibility for offsetting losses in fisheries productivity, e.g., through the creation of compensation lakes. Offsetting strategies are becoming increasingly important for large-scale developments such as mining operations in the oil sands region; they allow for development while ensuring that the project has 'no net loss' in fisheries productivity.

In 2012, omnibus Bill C-38 fundamentally changed large sections of the federal *Fisheries Act*. The focus of fisheries management was shifted from the protection of fish habitat in general to ensuring the ongoing productivity (FP) of fish important to commercial, recreational and aboriginal (CRA) fisheries. Further, the changes formalized the use of offsetting strategies to compensate for damage to fish caused by development.

The changes marked the move from the fisheries habitat management program (FHMP) as implemented prior to 2012, to the fisheries protection program (FPP). The goal of the FPP is to "provide for the sustainability and ongoing productivity of commercial, recreational and Aboriginal fisheries". Lack of standardized protocols and procedures following a shift of this magnitude could not only result in considerable additional expenses for industry, but also in less reproducible and so less reliable results. Rapid standardization of best practices and data collection methods would help ensure cost-efficient, meaningful and transferable data. Currently, these best management practices are being determined through an ongoing process involving Fisheries and Oceans Canada (DFO), industrial partners and government officials. The aim is to define a standard set of indicators for use under the FPP framework and assess which models may suitable for forming the link between data sets and long-term projections for whole-population productivity.

The interpretation of the changes to the *Fisheries Act* has been subject to controversy, making concise and publically available information important. Numerous scientific advisory reports have been published by DFO. However, there is currently a shortage of documents that give an overview over the scientific background necessary to understand how the changes may affect management practices, taking into account knowledge gaps and limitations in terms of data collection techniques. In this report, we will review existing monitoring tools as well as how the changes in policies associated with the shift from the FHMP to the FPP may affect management protocols.

Under the FHMP, the conceptual endpoint for assessing the impacts of development on fisheries was to achieve no net loss of the productive capacity of fish habitat (PC). Habitat was quantified mainly by area, and the success of an offsetting project was often determined mainly through acceptable installation. Methods in use under the FHMP provided only approximate values for PC.

For a meaningful planning, measurement and monitoring protocol that can help ensure fisheries productivity under the FPP, it may be necessary to move away from the previous practice of

managing fish habitat in Canada based on the use of FP as a theoretical concept only. As productivity in itself is difficult to measure directly, it is necessary to find appropriate indicators that can link changes in the components of productivity of individual fish or subsections of populations to changes in population-level fisheries productivity. We have compiled a list of indicators that may be used for estimating productivity of fisheries populations.

Solid measurements of fisheries productivity require repeated monitoring protocols extended over multiple years as well as a broadening of the definition of habitat affected by development. The financially and ecologically prohibitive nature of obtaining comprehensive, long-term data sets may make models an essential tool for linking limited data on subsets of populations with whole-population productivity and long-term projections. However, the trade-off between strength of model predictions and quality and quantity of data may make it a challenge to strike the balance between data needs for accurate predictions and financial feasibility.

In using knowledge-based standards for planning and executing compensation lake development, a key parameter to evaluate would be the carrying capacity of various compensation lake ecosystems. It may be a challenge to ensure an appropriate agreement between offsetting indicators and environmental assessment indicators, as established ecosystems are compared with populations in the process of establishing in a newly expanded habitat. On the other hand, lack of density dependence in the early establishment phase gives good possibilities for providing solid estimates of intrinsic growth rate of the populations within this specific habitat.

Future research should be conducted for areas characterized by intensive development to create models that allow for robust estimates of productivity based on limited and specific indicators that are manageable to measure. As factors limiting fisheries productivity vary between species, habitats and regions, it is likely that this would have to occur through the development of models specific for the given habitats and geographical areas.

If the drivers of the ecosystem in question are not well studied, the most cost-effective and ecologically sound way of implementing the FPP may be to adopt the management practices of the FHMP largely unaltered, but with the interpretive end goal shifted to FP. This would only require a mandatory inclusion of population level data in the monitoring protocols, and an extended monitoring period of several years. All of this constitutes protocols already in use under the FHMP. Though much work has been done on measuring and modelling the productivity of fish populations, it has proven difficult or impossible to find simple, reproducible techniques that can be applied across habitat types and ecosystems. In our opinion, the best predictors for fisheries productivity remain the quantity and quality of available fish habitat combined with abundance, size structure data and species composition within the given habitats.

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DISCLAIMER

Please be aware that these are the recommendations of the authors alone, and do not necessarily reflect the opinions and recommendations of OSRIN or any other sponsoring/funding agencies. This report largely constitutes a synthesis of current and past policies as well as knowledge pertinent to understanding how these were or may be implemented; and is current as of time of writing (late 2014). We note that there is current debate over offsetting strategies and that consultation on policy implementation with Fisheries and Oceans is ongoing and not yet finalized. This report is based on current peer reviewed and non-peer reviewed sources and includes official scientific advisory reports published by DFO, other government documents, journals, conference proceedings, articles and environmental assessment reports.

1 SCOPE

New and updated offsetting guidelines are currently being developed due to the need for determining best management practices and standardizing data collection methods with respect to the changes to the *Fisheries Act*. Such guidelines will act as tools for proponents responsible for assessing and offsetting the potential impacts of development projects. Further, the controversial nature of various interpretations of the Fish Productivity Protection (FPP) framework requires material that can serve as a base for a more comprehensive discussion of suitable project implementation procedures.

This report aims to provide an overview of policy changes as well as the scientific background relevant for assessing how to put the policies into practice. We aim to provide generally available information in a comprehensive but concise form that can be used as background information in the ongoing discussion on the appropriate interpretation and implementation of the changes. We do this by reviewing policies as well as procedures and protocols as applied to the Fish Habitat Management Program (FHMP). We evaluate how the updated policies will shift planning and monitoring needs under Fish Productivity Protection framework. The aim is not to provide a comprehensive analysis of currently used protocols and requirements, nor to dictate management practices. Instead, we aim for this report to serve as a document that can be used in evaluating our current state of scientific knowledge as it relates to present and past policies for ensuring the productivity and sustainability of freshwater fisheries in Canada. As such, it is our hope that it may be used by professionals as one of a number of tools available for assessing current scientific knowledge relevant for determining best management practices. Further, we hope that it may be of use to researchers as an aid in planning future research initiatives and to members of the public interested in the scientific background for the ongoing discussion on the changes to the *Fisheries Act* and offsetting strategies.

2 INTRODUCTION

The Alberta oil sands region contains one of the world's largest oil deposits with a total estimated volume of bitumen of 1.7 trillion barrels (Fung and Macyk 2000). This region is located in the boreal forests of Northern Alberta, an area rich in natural wetlands. As such, development of the oil sands region has the potential to destroy fish habitat and other wetland features that provide valuable ecosystem services.

Offsetting measures have become increasingly important over the past twenty years, as they allow for development while ensuring the no net loss in fish habitat productive capacity required by the Department of Fisheries and Oceans' (DFO) habitat protection policy (Department of Fisheries and Oceans 1986). The ongoing and expanding development of Canada's oil sands region, in particular, have benefitted from the possibility for offsetting losses through the creation of compensation lakes[1] as well as other habitat improvement measures.

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[1] See, for example, http://www.cnrl.com/corporate-responsibility/our-people/environmental-initiatives/arctic-grayling-habitat-enhancement-at-horizon-lake.html

Recently, the changes to the *Fisheries Act* due to the passage of the omnibus Bill C-38 shifted the end goal of fisheries management from no net loss of fish habitat productive capacity (PC) to no net loss of fisheries productivity (FP). The shift could potentially cause changes to best management practices related to off-setting measures, for instance with respect to creating and monitoring compensation lakes.

2.1 Bill C-38 Changes to the *Fisheries Act*

In 2012, the passage of the omnibus Bill C-38 legislated provisions that fundamentally changed large sections of the federal *Fisheries Act* (Government of Canada 2014)[2]. Box 1 presents the most important changes to key habitat protection provisions as applied to fisheries management through offsetting.

With the change in clause 35, the focus of fisheries management was shifted from the protection of fish habitat in general to ensuring the ongoing productivity of fish important to commercial, recreational and aboriginal (i.e., CRA) fisheries, as well as the fish that support such species. The removal of clause 32 reduced the severity of causing the death of fish; however, the definition of "serious harm" as used in clause 35 did include the killing of fish if this was not compensated for in other ways (Box 2). The addition of clause 6 formalized the use of offsetting strategies already widely employed in the industry to compensate for such serious damage caused to fish by development.

The changes to the *Fisheries Act* in part represent a formalization of management practices already in use throughout Canada, though the interpretation and implementation of the amendments have been subject to considerable controversy (Hutchings and Post 2013). Extracts of key policies outlining the official interpretation of the *Fisheries Act* as defined by DFO following the Bill C-38 changes are presented in Box 2 and Box 3. These policies mark a change from the fisheries habitat management program (FHMP) as implemented prior to 2012, to the fisheries protection program (FPP) to be implemented in the future (Department of Fisheries and Oceans 2013b, c)

[2] For more on the changes to the *Fisheries Act* and other federal legislation see Howlett, M. and J. Craft, 2013. Application of Federal Legislation to Alberta's Mineable Oil Sands. OSRIN Report No. TR-33. 94 pp. http://hdl.handle.net/10402/era.31627

Box 1

Amendments to the *Fisheries Act* as a result of Bill C-38:

Changed:

Prior to the amendment: 35 (1) No person shall carry on any work or undertaking that results in the harmful alteration, disruption or destruction of fish habitat.

After the amendment: 35 (1): No person shall carry on any work, undertaking or activity that results in serious harm to fish that are part of a commercial, recreational or Aboriginal fishery, or to fish that support such a fishery.

Removed:

Killing of fish

32. (1) No person shall kill fish by any means other than fishing.

Exception

(2) No person contravenes subsection (1) if the killing of fish […]

(b) is done in accordance with the regulations;[…]

(e) is done as a result of doing anything that is authorized, otherwise permitted or required under this Act.

Failure to comply with conditions

(3) Every person who fails to comply with a condition imposed under any of paragraphs (2)(a) to (d) […] a fine of not more than $100,000 […].

Added:

6. Before recommending to the Governor in Council that a regulation be made […] the Minister shall consider the following factors:

(*c*) whether there are measures and standards to avoid, mitigate or offset serious harm to fish that are part of a commercial, recreational or Aboriginal fishery, or that support such a fishery […]

6.1 The purpose of section 6, and of the provisions set out in that section, is to provide for the sustainability and ongoing productivity of commercial, recreational and Aboriginal fisheries.

Box 2

Selected excerpts of the Fisheries Protection Policy statement:

7.2 Goal
The goal of the Department in applying this Fisheries Protection Policy is to provide for the sustainability and ongoing productivity of commercial, recreational and Aboriginal fisheries.

8.1 Scope of application of the prohibition (Section 35)
The prohibition against *serious harm to fish* applies to fish and fish habitat that are part of or support commercial, recreational or Aboriginal fisheries.
Fish that support these fisheries are those fish that contribute to the productivity of a fishery (often, but not exclusively, as prey species).

8.2 *Serious harm to fish* (Section 35)
The Department interprets *serious harm to fish* as:

- the **death of fish**;
- a **permanent alteration** to fish habitat of a spatial scale, duration or intensity that limits or diminishes the ability of fish to use such habitats […] to carry out one or more of their life processes;
- the **destruction of fish habitat** of a spatial scale, duration, or intensity that fish can no longer rely upon such habitats […] to carry out one or more of their life processes.

8.4 Factors to be considered (Section 6)
For projects likely to cause large-scale impacts on the quantity or quality of fish habitat, metrics of productivity should be chosen based on the type of impact. These include metrics of productivity related to habitat area or metrics related to components of productivity that are linked to the life cycle of the fish.
Very large-scale impacts that are likely to result in ecosystem transformation will require the most detailed estimates of impacts to productivity, likely involving quantitative fish population models.
Proponents are responsible for documenting and providing information such that an analysis describing the contribution of relevant fish may be undertaken. This analysis will help inform how the project may affect the relevant fisheries management objectives (factor 6b) and the amount and type of avoidance, mitigation and offsetting measures required (factor 6c).

c) Measures or Standards to Avoid, Mitigate, or Offset Serious Harm to Fish
[..] When avoidance is not possible, then efforts should be made to minimize (mitigate) impacts caused by the project in question. After these actions, any residual impacts would normally require authorization and should then be addressed by offsetting.

Offsetting
[…] An offset measure is one that counterbalances unavoidable *serious harm to fish* resulting from a project with the goal of maintaining or improving the productivity of the commercial, recreational or Aboriginal fishery. Offset measures should support available fisheries management objectives and local restoration priorities.

Box 3

Selected excerpts of the Fisheries Productivity Investment Policy:

Offsetting Measures

[…]When determining the location for offsetting, offsets that occur within the vicinity of the project or within the same watershed are preferable. […]Offsetting measures could be undertaken in water bodies or for fish species other than those affected by the project, provided the measures are supported by clear fisheries management objectives […].

2.2 Guiding Principles

Principle 1: Offsetting measures must support fisheries management objectives or local restoration priorities.

Offsets should be designed so they contribute to the objectives identified in fisheries management plans, where such plans exist. […]

Principle 2: Benefits from offsetting measures must balance project impacts.

Offsets should be scaled such that they are proportional to the impacts caused by the project. Offsets are more likely to successfully balance losses when they benefit the specific fish populations in the geographic areas affected by a proposed development project or activity. With an "in-kind" approach to offsetting, the habitat that is destroyed or permanently altered is replaced by the same quantity and quality of the same type of habitat, with additional habitat offsetting required to account for uncertainty and time lags. […]With an "out-of-kind" approach to offsetting, offsetting measures target the factors limiting productivity in a given area by means other than replacing what has been lost. It can be more complicated to measure […]

Principle 3: Offsetting measures must provide additional benefits to the fishery.

[…] means that benefits to the fishery are caused by offset actions and not by other factors [...]

Principle 4: Offsetting measures must generate self-sustaining benefits over the long term.

[…] The offset benefits to the fisheries should last at least as long as the impacts from the development project.

Habitat Creation

When habitat creation is proposed to offset habitat losses, it must be reasonably expected that replacing the destroyed habitat with the same kind of habitat in the project area will maintain current productivity. Changing one habitat feature for another should be considered only when there is sufficient knowledge to be reasonably confident that the change in habitat will improve productivity.

Habitat Banking

A proponent-led habitat bank is a formalized approach for creating offsets […] in advance of a project's impact. […]The benefits accumulated in the habitat bank are counted as credits, while *serious harm to fish* caused by a project or projects are considered debits. A proponent that has established the bank may "*withdraw*" credits from the habitat bank to offset the *serious harm to fish* resulting from their project.

3 THE FISH HABITAT MANAGEMENT PROGRAM (FHMP)

One of the main purposes of the fish habitat management program was to lay out the principles that allowed DFO to review the extent to which development would cause adverse impacts to fish and fish habitat. When issuing an authorization, the FHMP allowed for a framework within which to negotiate a compensation plan designed to offset loss of fish habitat and fisheries productivity and monitor its implementation (Golder Associates 2004, 2012, 2013, Minns et al. 2011).

Under the FHMP, the conceptual endpoint for assessing the impacts of development on fisheries was the productive capacity (PC) of the fish habitat (Goodchild 2004). Already prior to the 2012 amendments to the *Fisheries Act*, it was a guiding principle in the policy for management of fish habitat (Department of Fisheries and Oceans 1986) that there should be no net loss (NNL) in the productive capacity of fish habitat and fish populations important to fisheries (Department of Fisheries and Oceans 1986, Golder Associates 2012, Minns et al. 2011). PC was defined as: "the maximum natural capability of habitats to produce healthy fish, safe for human consumption, or to support or produce aquatic organisms upon which the fish depend" (Department of Fisheries and Oceans 1986).

The importance assigned to productive capacity was due in part to its critical role when evaluating the maximum sustained harvest rates of fisheries species within a system (Barman et al. 2013, Holey and Trudeau 2005), and in part to its importance in ensuring long term stability in population dynamics (Lapointe et al. 2014, Minns et al. 2011). Hence, the concept of productive capacity was central to DFO's habitat management activities.

3.1 Methods for Monitoring Productive Capacity

In their 2011 synthesis on approaches for assessing PC, Minns et al. (2011) identified following general methods in use at the time:

- **Individual metrics and vital rates:** Were based on direct measurements of specific parameters for the relevant fish populations, obtained as outlined in Table 1. These were used as indicators to calculate PC, see section Table 2.
- **Habitat-based methods:** Measured physical habitat features that could be used to assess effects of habitat change. They did not directly measure PC, but were used extensively to guide fish habitat management decisions. They could broadly be divided in to four categories: hydrological methods, hydraulic rating curves, habitat simulation models and defensible methods. They have all been used to some degree to assess impacts of human development of fish habitat in Canada. Defensible methods (Minns and Nairn 1999) is the only habitat simulation model (see Table 3) that was specifically created to provide a scientifically robust approach to FHMP.

Table 1. Techniques commonly employed in obtaining data for fish population monitoring and assessment.

Technique	Application	Advantages	Disadvantages	References
Passive Capture Methods				
Gill net	Analyze community structure Monitor and assess populations Determine fish distributions in lakes and reservoirs Fish depth distribution studies Individual metrics	Easy to use, requires little training Simple in design and construction Can be used in most habitats with sufficient unobstructed water depth, and low current Can be used in multiple depths Widely used in monitoring programs, has standard methods developed and linked to factors of interest to managers (e.g., recruitment, fish density, population structure)	High mortality rate Highly selective Efficiency decreases over time (gear saturation) Efficiency will vary with time of day, and target species Not effective for catching sedentary fish Standardizing catches from multiple net set with different mesh sizes and set times can be complex Capture and mortality of non-target fish species (bycatch) likely	Fisheries Techniques Standardization 1992 Hubert and Oshea 1992 Portt et al. 2006 Spangler and Collins 1992
Trammel net	Similar to gill net	Similar to gill netting advantages Can provide reliable estimates of total harvest of commercial species from a water body	Similar to gill net disadvantages, less size selective, lower mortality Lower precision in calculated catch-per-unit-effort relative to gill net Not widely used for population estimates	Coggins et al. 2006 Collins et al. 2002 Fabi et al. 2002 Fisheries Techniques Standardization 1992 Guy et al. 2009 Portt et al. 2006
Hoop, fyke or trap nets	Targets fish attracted to cover, bait and other fish Monitor and assess fish populations Studies of habitat use Individual metrics Often used in conjunction with mark-recapture methods	Little or no harm to fish; bycatch can be released unharmed Can be used in a variety of habitat types (lentic, lotic)	Species and size selective based on net dimensions and location Catch per unit effort is influenced by factors such as water temperature, turbidity and water velocity, etc. Lower catch rates compared to gill netting Catches can have high variability It is possible for fish to escape	Coggins et al. 2006 Gerhardt and Hubert 1991 Portt et al. 2006 Smith and Hubert 1989

Technique	Application	Advantages	Disadvantages	References
Minnow traps	Monitor and assess fish populations Community assemblage assessments Studies of habitat use Individual metrics	Traps are typically small and easily transportable Where diversity of small bodied fish is high, minnow traps can be more effective than gill nets and trap nets Can be set in dense cover Little or no harm to fish	Typically limited to small bodied fish It is possible for fish to escape	Bryant 2000 Fisheries Techniques Standardization 1992 Portt et al. 2006
Active Capture Methods				
Electrofishing	Population density and structure assessments Community structure analyses Life history studies Can be used with mark-recapture methods and removal/depletion methods Individual metrics	Can sample a wide range of habitats (varies with type of electrofisher – backpack, boat, etc.) Highly efficient Can sample a wide range of species Does not require fish to be moving Low mortality rates Widely used in fisheries management	Requires training and certification Could pose risk to operators and fish if not operated properly Somewhat size and species selective Efficiency is dependent on netting ability of crew Backpack, and shore unit electrofishers are limited to use in wadeable areas	Fisheries Techniques Standardization 1992 Portt et al. 2006
Angling	Procuring live specimens for radiotelemetry studies Obtaining tissue samples Relative abundance and size structure analyses Can be used with mark-recapture methods Individual metrics	Gear is portable and activity is not labour intensive Can take advantage of efforts by recreational anglers	Efficiency is highly variable and dependent on fish behaviour and skill of angler Difficult to standardize sampling effort	Campana et al. 2006 Fisheries Techniques Standardization 1992 Gabelhouse Jr and Willis 1986
Seining	Estimate fish assemblage composition and species richness Population density and structure assessments Individual metrics	Little or no harm to fish Simple method to sample large area in short time	Can be challenging in presence of obstructions (rocks, woody debris, macrophytes) More likely to catch mid-water species rather than benthic High variability between hauls can exist	Fisheries Techniques Standardization 1992 Portt et al. 2006

Technique	Application	Advantages	Disadvantages	References
Trawls	Most common sampling gear in marine/estuarine habitats Quantitative indices of population estimates Used to obtain fish for age, growth, diet and tissue studies, as well as in combination with mark-recapture techniques	Samples a discrete area or volume over specified time	Cannot be used with obstructions present Requires powerful boats to tow	Fisheries Techniques Standardization 1992
Population Estimate Methods				
Mark-recapture	Population estimates Survival	Widely used Provides accurate and robust estimates	Time intensive Requires resampling Depends on efficiency of fish capture techniques (e.g., electrofishing, seining, trapping)	Gresswell et al. 1997 Peterson and Cederholm 1984
Removal /depletion	Population estimates	Widely used Provides accurate and robust estimates	Time intensive Depends on efficiency of fish capture techniques (e.g., electrofishing, seining, trapping)	Bryant 2000 Peterson and Cederholm 1984 Zippin 1958
Observational Methods				
Videography	Relative abundance Species composition Fish length (individual)	Non-destructive/invasive Can access extreme depths that would not be accessible by a diver Provides a permanent record Fairly accurate fish measurements can be determined using stereo-video	Impacted by visibility (turbidity, cover, light) Absolute density is not possible to measure because of possible recounts Selectivity towards fish that do not rely on cover Inclusion of bait introduces more bias	Fisheries Techniques Standardization 1992 Harvey et al. 2002

Technique	Application	Advantages	Disadvantages	References
Observation by snorkeling or scuba diving	Determine specific habitat relationships Abundance, length (individual) and species composition data	Requires less time than removal methods used with electrofishing No harm to fish	Not possible in extremely shallow environments or extremely high velocity water Impacted by visibility (turbidity, cover, light) Observer must be able to identify species visually Accuracy declines in high densities Fish behaviour may be influenced by presence of diver Large room for human error and variability between divers Measurements of fish are not direct	Cunjak and Power 1986 Fisheries Techniques Standardization 1992
Hydroacoustics	Presence/Absence Stock assessments Fish biomass and size Spatial distribution	Non-destructive/invasive Large area can be covered Does not rely on or influence fish behavior Non-selective in data collection	Echogram interpretation may vary between analysts High error associated with high densities of fish, or fish located near substrate Does not provide reliable species-specific data No individual metrics	Fisheries Techniques Standardization 1992 Sutherland 2000 Thorne 1983

- **Population-based approaches:** Traditionally used to measure fish responses to habitat changes. They could be anything from simple estimates of change in abundance to stock-recruitment relationships to complex habitat-population models (see Table 3). Abundance methods largely represented partial or surrogate indicators, whereas rate-adjusted methods were thought to be more complete. As the complexity of approach increased, the need to rely on assumptions and so the uncertainty decreased, but at the cost of increased data requirements.
- **Community- and ecosystem-based approaches.** Were based on fish community measures such as species richness, community biomass and productivity, composition (e.g., fish trophic composition) and interspecies distribution, as well as sometimes measurements of ecosystem characteristics (Minns et al. 1996, Quigley and Harper 2006).

Although habitat based methods were listed as one of several approaches in the above list, they were in reality the foundation for most analyses and management practices under the FHMP. Assessments of loss or gain in the productive capacity of fish habitat and fisheries populations were often largely based on quantifications of habitat area and indicators for quality. In large-scale developments such as those that occur in the oil sands region, however, requirements were often more comprehensive. In cases such as these, individual metrics and population-level approaches were drawn in as a secondary measure for quantifying the productivity of fish per unit habitat area (Golder Associates 2004, 2012, 2013, Minns et al. 2011).

The productive capacity of the fish populations contained within the habitats was estimated based on individual metrics and population based approaches. The fish populations were sampled using standard collection methods (see Table 1), and were done on a seasonal basis. The assessment of the data was based on a catch per unit effort analysis. From this, an estimate was made of the productivity of each population, multiplied up to relevant scale (Golder Associates 2004, 2012, 2013). Seasonal migrants that relied on the given habitat for only part of their life cycle were included in the considerations.

The monitoring protocols required for assessing the key components related to the productive capacity of fish populations and habitats could roughly be divided into four tasks (Minns et al. 2011):

1. Establish a frame of reference by identifying the key characteristics of the ecosystem and the habitat, quantifying the relative extent of each habitat type identified within the ecosystem and assigning weights and life stages to fish present in the habitat.
2. Apply specified measurement to obtain an estimate of the productive capacity of the ecosystem. The sum of all data obtained on e.g., fish abundance, size and life stages (see Table 1) as well as on habitat types and quality can be used to gain an estimate of total PC.
3. Use data gained above to analyze how best to execute a specific development project so that loss in PC is minimized or avoided. This can be done through a net change

assessment applied to various scenarios as part of the design process, something that should lead to a preferred option that prevents net loss or minimizes losses when unavoidable.

4. Identify sources of uncertainty and variation with respect to the net change assessment due to e.g., cofactors related to the habitat characteristics or interactions and feedback mechanisms among organisms of the ecosystem.

Because of the inherent errors associated with available sampling protocols (Table 1) as well as issues related to the link between indicators and productivity (Section 4.1.5, Table 2), methods in use under the FHMP provided only approximate values for PC. Sources of error were less of a concern because of the general practice of quantifying habitat mainly by area. Indicators were required to a lesser extent because post-monitoring programs often judged the effectiveness of a compensation project on whether it had been properly installed and currently contained viable fish populations. The more difficult to obtain projections of long-term sustainability of the fish habitat were rarely included in the required considerations.

3.2 Requirements of PC Measurements in the Authorization Process

Once development had been approved, conditions of the Authorization provided specific directions regarding the measures to be used for assessing the extent of fish habitat productive capacity loss. The purpose of this was to determine the required offset (i.e., compensation) with respect to fish habitat productive capacity.

With respect to large-scale developments such as those undertaken in the oil sands region, however, requirements can often be more comprehensive. For example, in the case of the Horizon Lake – a compensation lake project in the oil sands area – requirements for compensation habitat were based on the following assessment of the loss in net PC (Golder Associates 2012):

> *"The fish habitat losses will be calculated as surface areas of fish habitat presented in Article 8.0 multiplied by expected annual biomass production. The fish habitat gains will be calculated as surface areas of constructed compensation habitat multiplied by expected annual biomass production. Areas defined as lost are defined in Article 8.0."*

Article 18.3.1 of the Authorization further specified that:

> *"The average annual fish biomass production per unit area for all species in the water bodies being sampled shall be determined by measuring biomass and growth rates and undertaking population estimates for each species".*

The concrete data required for these estimates included long-term monitoring of abundance and species composition of fish at different times of the year, measured through the sampling strategies outlined in Table 1. By determining the quantity and quality of the habitats as well as key population characteristics of the species present, it was possible to provide an estimate of the productivity of each population and multiply up to the applicable scale (Golder Associates 2004, 2012, 2013). Hence, though the focus of FHMP was on fish habitat protection, fish population productivity formed an integral part of the management process in the oil sands region.

3.3 Challenges in Measuring PC

The majority of habitat assessment models in use under the FHMP could be parameterized with a relatively small set of biophysical data and fisheries survey information. The most common minimum survey requirements included standard physical features, site-specific assemblages, BACI (before after control impact) sampling design, population size estimates and individual fish morphometrics (Minns et al. 2011). Though studies tended to show a good correlation between habitat quality or quantity and productivity (Lapointe et al. 2014), the assumption of a linear relationship may at least in some cases be invalid (e.g., Rose 2000).

4 INDICATORS FOR MEASURING PRODUCTIVITY

Fisheries productivity was defined by Randall et al. (2013) as "the sustained yield of all component populations and species and habitats which support and contribute to a fishery." As productivity in itself is difficult to measure directly, it is necessary to find appropriate indicators that can link changes in the components of productivity of individual fish or subsections of populations to changes in population-level fisheries productivity (Table 1 and Table 2). Determining appropriate indicators is difficult due to inherent errors associated with any of the data collection methods (Table 1) as well as the complex causative factors governing productivity rates of various species co-existing within a habitat (Bradford et al. 2014, Holey and Trudeau 2005, Mills et al. 2005).

Though simple metrics such as abundance, biomass and fish size tend to be assumed to provide robust estimates of FP, the link to fish productivity may not necessarily be straight forward (Shin et al. 2010). It is important to determine the extent to which indicators have assistive or synergistic relationships, or alternatively could overwhelm the effect of others. Direct density to productivity correlations are often confounded by factors such as the change in environmental parameters, e.g., temperature (Botsford et al. 2014, Fulton et al. 2014, Kielbassa et al. 2010), or by complex and unpredictable community interactions (Blanchard et al. 2014, Hammar 2014, Ingels et al. 2014). Further, these approaches rarely account for differences in how various environmental parameters affect the components of productivity of all life stages of different species.

Prior to the 2012 amendment, most fish habitat management in Canada was more often based on the use of FP as an abstract concept than a concrete, measurable quantity. Indicators were not necessarily required under the FHMP; it was in many cases considered an acceptable practice to judge post-monitoring programs based on appropriate installation combined with basic abundance estimates (Minns et al. 2011). It was generally assumed that there was a direct link between abundance and habitat quality (e.g., generalized linear models, Table 23, Minns et al. 2011), or between abundance and habitat quantity. Sources of error related to productivity estimates were less of a concern since fish habitat was quantified mainly by area.

Table 2. Indicators used for estimating components of fisheries productivity.

Indicator	Used to estimate	Relevance for compensation lake systems	Potential issues	References
Abundance and biomass	Population growth rates through P:B or time series analysis; particularly effective during the recovery/establishment phase. Population productivity.	Provides good data for relative growth rates and productivities of different fish species in recovering or recently expanded/created wetlands where population sizes are increasing.	Difficult measure; data often imprecise. Density dependence and environmental fluctuations can make it a poor indicator for population productivity in established populations.	Fulton et al. 2004 Lambert 2011 Randall et al. 2013
Spawner density	Egg production. Population productivity.	May be a more robust indicator for population productivity than general abundance, especially when using ecosystem-based models.	Difficult to measure. May not be directly correlated with population productivity due to density dependence at other life stages.	Fulton et al. 2004, 2005
Growth rate	Quality of the environment as it pertains to the individual species.	Aids in determining the productivity of the specific CRA species within the given environment.	Data difficult to obtain: requires mark-recapture techniques. Can give unrealistic estimates.	Botsford 1981 Gilliers et al. 2006 Wenger et al. 2012
Body size	Biomass, fish condition, parameters to use in the van Bertalanffy growth model and life stage models.	Moderately robust indicator when thresholds include age-specific sizes, or when used as part of a suite of indicators.	Natural variation and density dependence can lead to unpredictable relationships. Monitoring time ≤5 years typically too short to detect significant changes.	Fulton et al. 2004 Thorson et al. 2012 Woodward et al. 2010
Body condition	Health and potential productive capacity of individual fish.	If temperature is included when using this metric, it may be useful when comparing populations of one species among different sites within the same year.	In many studies, it has been shown to be a poor or inconsistent indicator in field evaluations. More successful in laboratory settings.	Hering et al. 2006 Lambert 2011 Uusi-Heikkila et al. 2011
Age structure	Year-class variability in recruitment.	Gives very robust data for population assessments.	Requires lethal and work-intensive sampling techniques.	Everhart and Youngs 1981 Isely and Grabowski 2007 Pope et al. 2010

Indicator	Used to estimate	Relevance for compensation lake systems	Potential issues	References
Gonadal somatic index	Effect of habitat change on a population's reproductive investment.	Can be used to assess the potential reproductive capacity of individual fish in the given habitat.	Require lethal sampling. Is associated with a high coefficient of variation, so potentially imprecise. Species- and sex specific.	Dutil et al. 2006 Faller et al. 2003 Lester et al. 2004
Mortality	Growth and potential harvest rates, as it forms the basis of most harvest models. Key parameter in the Leslie Matrix model.	Useful indicator when calculating population-level productivity if obtained with adequate accuracy.	Difficult to measure. Typically requires comprehensive mark-recapture procedures.	Arnason and Mills 1987 Dunlop et al. 2007
Egg, larval and juvenile mortality	Population productivity and growth.	Generally shown to be a robust indicator of population growth.	Difficult and labor intensive to measure, requires intensive surveying through cohorts and years.	Dunlop et al. 2007 Fulton et al. 2004 Velez-Espino and Koops 2009a,b
Change in trophic level	Change in prey availability. Habitat quality for the specific species.	Can be used to assess whether the productivity of forage species is in line with the needs of the CRA fish. Useful in large, ecosystem-level developments.	Unclear how change in trophic level is reflected in change in productivity.	Fulton et al. 2004 Patrick et al. 2010 Perez-Dominguez et al. 2012
Tissue and blood chemistry	Stress response. Environmental toxicity levels.	Can be used to check for toxicity issues in newly established and/or potentially polluted environments.	Stressors may not contribute significantly to reduction in productivity due to influence of confounding parameters, e.g., density dependence and fecundity.	Adams 2002 Adams et al. 1993 Segner 2011
Disease	Declining water quality. Potential contamination.	Though difficult to interpret in itself, disease is a red flag showing that other indicators and habitat parameters need to be assessed.	Difficult to identify the specific problem since it is often a result of cumulative effects. Difficult to scale up to population productivity.	Blazer et al. 2010 Wedekind et al. 2010

In large-scale developments, however, the evaluation of PC was in reality often based on an additional assessment of the productive capacity of the individual species sustained by the habitat, similarly to what is needed to assess FP (Barman et al. 2013, Department of Fisheries and Oceans 1986, Golder Associates 2004, 2012, 2013, Minns et al. 2011). The use of a number of specific indicators were developed and required for approval of the project under the authorization process (see section 3.2). The indicators for productivity that were used either frequently or occasionally under the FHMP are summarized in Table 2.

With the shift to the FPP, an increased and more consistent use of indicators might be required to provide long-term projections for the project's ability to ensure no net loss in fisheries productivity. As such, it may be critical to understand potential sources of uncertainty associated with the given indicators (Bradford et al. 2014, Department of Fisheries and Oceans 2014a,b, Randall et al. 2013). Currently, no standard set of indicators has been defined for use under the Fish Productivity Protection (FPP) framework (Bradford et al. 2014, Department of Fisheries and Oceans 2013a, 2014b, Fulton et al. 2005, Minns et al. 2011, Pope et al. 2010, Randall et al. 1995, 2013). Best management practices related to the selection and use of indicators are being determined by Industry and Government Agencies. In these deliberations, it will be critical to evaluate potential sources of uncertainty (Department of Fisheries and Oceans 2014a, Minns et al. 2011).

Minns et al (2011) suggested that productive capacity in general should be measured on a minimum of four different levels: habitat, individual, population, and community / ecosystem (see section 3 and Minns et al. (2011)). Because of this, it is necessary to use multiple indicators when characterizing aquatic environments. As a minimum, sampling protocols should include non-target species with fast turn-over (e.g., plankton), fish species targeted by commercial or recreational fisheries, habitat defining groups, and environmentally sensitive groups (e.g., upper trophic level species with slow population dynamics) (Fulton et al. 2004, 2005, Minns et al. 2011).

Habitat-based methods have been extensively used in management decisions in the past due to the nature of the FHMP, but may not in themselves provide an adequately precise measure of productive capacity as needed to ensure no net loss as required by the FPP (Bradford et al. 2014, Randall et al. 2013). Population-based methods for assessing fisheries productivity are the most practical in terms of data requirements and were often included in management programs in the past(Golder Associates 2004, 2012, 2013, Minns et al. 2011). However, they are mainly effective in ecosystems dominated by relatively few species (Lindstrom et al. 2009), and potentially insufficient in species-rich areas where community approaches may be needed.

Unless the biology and ecology of the relevant species are very well understood, it may be challenging to determine appropriate indicators (see Table 2) to include in addition to those measured under the FHMP. Such indicators would have to be relevant for the specific project, yet allow for consistency across locations and spatial scales (Bradford et al. 2014, Fulton et al. 2005, Koops et al. 2013). They should simultaneously allow for a scaling up from small, local impacts to general effects on fisheries productivity. Further, they should be based on sound ecological theory, be conservative under uncertain conditions, be based on data that are possible to obtain, and allow for a quantitative evaluation of errors (Bradford et al. 2014, Randall et al. 2013).

Population productivity is largely determined by the growth, survival and recruitment of the individual fish that make up the population. Each of these vital rates varies with habitat heterogeneity and quality (Minns et al. 2011). To determine appropriate indicators to use for a given system, it is necessary to understand which environmental- and ecosystem-based parameters limit survival and/or reproductive rates at various life stages. Further, it must be determined which life stages constitute the bottleneck to overall recruitment rates. High fecundity, for instance, does not necessarily add to stock recruitment (Magnusson and Hilborn 2007), among other things because a strong density-dependent mortality of juveniles is common in limnic ecosystems (Rogers and Allen 2010, Teichert et al. 2013). This may obscure effects of adult abundance or spawning rates. Density dependent effects such as those related to limited food resources or predation are stronger in freshwater than marine systems.

Even in natural systems that have reached their carrying capacity, high natural variability means that large population changes often go unnoticed, and impacts on top predators may show substantial delays compared to time of habitat quality change (Budy et al. 2007, Maxwell and Jennings 2005). Therefore, abundance and biomass should only be seen as suitable indicators in themselves when conducted over long time periods and including multiple species.

Fulton et al (2005) concluded that the best and/or most robust indicators for fisheries productivity include total biomass across multiple groups, size at maturity of top predators, efficiency of consumption in various trophic levels, catch estimates of bottom feeding fish and total production and respiration. Most of these indicators are highly correlated. A set of indicators chosen to conform to the requirements and limitations within specific habitat types have been shown to be much more useful than a one-size-fits-all model (Fulton et al 2005).

Even with an appropriate selection of indicators to be used in a specific situation involving known species, the indicators are only as robust as their sampling protocol (Table 1). Differences in sampling protocols may cause large variations in the estimates produced. In studies based on up to a decade of sampling, relatively small variations were shown to be sufficient to ensure that significant changes in the given indicators went unnoticed (Jones and Petreman 2012).

Assessing the indicators best suited for a given species in a specific habitat and community structure requires extensive knowledge on the biology and ecology of the species and habitat in question. Where this knowledge does not exist prior to the planning phase of a development project, obtaining it will cause significant delays and be associated with additional expenses for the developer. Since these data tend to be linked with substantial errors and the interpretation may be subject to a degree of uncertainty, it is probable that such approaches do not justify the additional time and expense. Where no specific knowledge on the system exists, fish habitat quantity and quality, fish abundance, species composition and size classes remain the most solid general indicators of productivity. Further, as these were the indicators already in use under the FHMP, protocols for obtaining usable data already exists.

5 THE FISHERIES PROTECTION PROGRAM (FPP)

In 2013, DFO developed two policies outlining the government's official position as to the appropriate interpretation of the *Fisheries Act* following the C-38 amendments:

- The *Fisheries Protection Policy Statement*, published October 2013 (Box 2), which provides general guidance on the application of the amended *Fisheries Act* to decision processes in management and industry (Department of Fisheries and Oceans 2013b).
- The *Fisheries Productivity Investment Policy: A Proponents Guide to Offsetting* (Box 3), which provides specific guidance for industrial purposes where development required the use of offsetting strategies (Department of Fisheries and Oceans 2013c).

Together, these policies marked the change from the Fish Habitat Management Program (FHMP) to the Fisheries Protection Program (FPP).

As stated in these policies (see Box 2 and 3), the goal of the FPP is to "provide for the sustainability and ongoing productivity of commercial, recreational and Aboriginal fisheries". Ongoing sustainability is defined as "the potential sustained yield of all fish populations and their habitat that are part of or support commercial, recreational and Aboriginal fisheries" (Department of Fisheries and Oceans 2013a).

5.1 Challenges in Moving from Productive Capacity to Fisheries Productivity

By shifting from a habitat-based focus (bottom-up analysis) to CRA fisheries productivity focus (scaling down approach or top-down) we move away from a management practice that was based on fifty years of knowledge and expertise. It signifies a shift from management based on a large body of knowledge to a practice that may be based on a comparatively smaller knowledge base. Implementing such strategies is associated with substantial opportunities for improvement. However, given the considerable uncertainty associated with these changes, there are several challenges that need to be addressed. These can be divided into six key areas:

- Determining what constitutes a waterbody
- Determining how ephemeral or indirect fish habitats are considered
- Determining which fish species act to support the productivity of CRA fisheries.
- Determining indicators to add to current management practices as well as best measurement protocols for quantifying these.
- Determining the appropriate spatial and temporal scales for monitoring
- Determining how modelling approaches can be used as a tool for estimating fisheries productivity

In this section, we will evaluate how the above challenges may affect best practices for implementing a shift from a PC-based assessment to an FP-based assessment in a cost-efficient manner that may be of concrete use for management purposes.

5.1.1 *What Constitutes a Waterbody?*

In planning offsetting strategies and compensation lake management, an essential first step is to evaluate the loss of productive capacity to the fisheries caused by a development project. As such, it is important to define which waterbodies must be considered in the estimate. Waterbodies covered by the decree for the protection of CRA fisheries under the amended *Fisheries Act* include "areas of fishing for food, social, or ceremonial purposes or under land claims agreements by Aboriginal peoples; and […] areas covered by federal or provincial fisheries regulations".

Recently, DFO have interpreted CRA fisheries as all areas in which you need a license to fish since these are all covered by federal or provincial fisheries regulations. Hence, the above decree should encompass the majority of the wetlands in Canada that act as fish habitat, whether currently accessible or not. This ensures that the overall productivity of freshwater fisheries is not reduced, as required by the federal *Fisheries Act*, by protecting currently realized as well as all potential future fisheries areas.

5.1.2 *How are Ephemeral or Indirect Fish Habitats Considered?*

Most riverine systems are inherently linear, linked from source water to their destination. In many cases, linkages within a riverscape (from source to mouth) may provide important ephemeral or indirect habitat. For example, tributaries that contain no fish may act as refuge during catastrophic events, such as floods or chemical spills (Morrissey and de Kerckhove 2009). Further, many headwater or riparian areas provide necessary allochthonous material for freshwater fishes (Richardson et al. 2010). The degree to which these ephemeral or indirect habitats are considered under the new FPP remains unknown.

Already under the FHMP protection was required for any habitat that contained fish, even if it did so only seasonally. However, ephemeral or indirect habitats, such as wetlands that contained aquatic life but no current permanent or seasonal fish populations were not included in the estimate of damage caused to fish habitat by development (Department of Fisheries and Oceans 1986, Golder Associates 2004). Hence, habitats that no longer require protection due to the change from the FHMP to the FPP should be limited to habitats that do contain fish but not any species of direct or indirect value to the CRA fisheries. Since even seasonal use should be considered in this context, most habitats that were protected under the FHMP should also be protected under the FPP according to the above definition.

The shift from the FHMP to the FPP would increase the importance of regional concerns, e.g., the headwater or tributary importance of the habitats present upstream of the development area with respect to other habitats in the region. However, determining the headwater/tributary effect of a habitat with respect to adjacent connected lakes and rivers would be extremely data intensive and complex, and so prohibitively expensive. General defined ecological overheads that take this source of uncertainty into account might provide a more cost-efficient approach that can be implemented rapidly.

5.1.3 *Which Fish Support a CRA Fishery?*

One of the key shifts in the *Fisheries Act* surrounds the inclusion of fish that *support* a CRA fishery. The Fisheries Protection Policy (Department of Fisheries and Oceans 2013b) states that "*fish that support these fisheries are those fish that contribute to the productivity of a fishery (often, but not exclusively, as prey species)*" (see Box 2).

For a fish species to be considered in support of a fishery, they must perform a support function that is essential for sustaining the productivity of CRA fishery species (Department of Fisheries and Oceans 2013a). Further, the species in question must satisfy two requirements (Department of Fisheries and Oceans 2013a):

1. that changes in the status of the support fish must result in changes in productivity of the CRA fishery fish in a consistent manner.
2. that the ecological function provided by the support species can be filled by few or no other species with more resilience to the work/activity/undertaking.

In cases where multiple species exist that may fill a particular ecological function, decisions must be made regarding which species should be classified as support species based on ecological linkages among species (Kenchington et al. 2013). Such species include those that provide direct support functions, e.g., key prey species and structure-providing species, as well as those that provide indirect support functions, e.g., keystone species, apex predators, highly connected species, and environment modifiers.

Section 6.1a of the *Fisheries Act* states that the Minister will consider "*the contribution of the relevant fish to the ongoing productivity of commercial, recreational or Aboriginal fisheries*." The contribution of the relevant fish to the ongoing productivity of CRA fisheries would be measured by the impact on productivity of CRA fishery species expected to occur given a change to the potentially affected species or habitat (Department of Fisheries and Oceans 2013a). The science advice to support development of a fisheries protection policy for Canada (Department of Fisheries and Oceans 2013a) outlines the key information required to characterize the contribution of the relevant fish to ongoing productivity as follows:

1. "understanding how overall productivity depends on the affected species or habitats,
2. the "current" state (i.e., the state before the work, undertaking or activity commences) of the potentially affected species or habitats,
3. resilience of fish productivity to perturbations of the affected species or habitats,
4. how the proposed work, undertaking or activity may alter the state of affected species or habitats, and

5. uncertainties about the relationship, the current state of affected species or habitats, the potential impacts of the work, undertaking or activity, and, when applied, the effectiveness of avoidance and mitigation measures."

Comprehensive data sets are required to understand which species are relevant to ongoing productivity and to quantify their contribution to CRA fisheries. The relevant support species and their ecological roles are likely to vary between geographic areas. As such, it is likely that intensive monitoring prior to any work, undertaking or activity (w/u/a) will be necessary to establish ecological links and identify relevant support fish species. Over time, a database comprising support species, their distributions, habitat use, and functional roles may be built based on knowledge acquired from application (Kenchington et al. 2013). In addition to productivity analyses that will be necessary for evaluating the status of support fish once they have been identified, additional quantitative analyses would be necessary to establish ecological links and contributions to CRA fisheries productivity. Although the productivity metrics to assess support fish would be the same as those required for CRA fishery fish, the limited life-history and population dynamics information on non-fishery species may result greater uncertainties in estimating support fish productivity.

5.1.4 *What are the Appropriate Spatial and Temporal Scales for Monitoring?*

The change in focus from protecting the productive capacity of habitats that sustain fish populations (PC) to ensuring sustainable fisheries productivity (FP) opens up the possibility that total fisheries habitat can be reduced if the quality is improved with respect to CRA fishes. Whereas fish habitat is relatively easy to quantify, reliable estimates of the productivity of selected species can only be obtained through data intensive monitoring. Further, to justify a sustainable increase in productivity as opposed to a short-term spike (Box 3), the population would have to be monitored over prolonged time periods. Therefore, the change in focus from protecting habitat to ensuring the long-term sustainability and productivity of CRA fisheries may cause fundamental shifts in planning and monitoring requirements for offsetting industrial impacts.

Measurements of fisheries productivity require repeated monitoring protocols extended over multiple years so that changes in population sizes can be noted and quantified. Since management practices under the FHMP had the conceptual end-goal of ensuring no net loss in fish habitat productivity, long term monitoring procedures were not necessarily required for all projects, though in the oil sands region they generally constituted the standard. Once the habitat had been restored or created and fish populations were present, the project was judged to be successfully completed.

In general, given the complexities in determining long-term sustainability of CRA fisheries, a shift from the FHMP to the FPP will likely require an extension of the monitoring period required to determine the success of the offsetting strategy. It will be important to identify appropriate indicators of productivity to include in the monitoring protocol. Further, to ensure cost-effective monitoring protocols that provide meaningful data for the use of ensuring long-term sustainability of the fisheries populations, an increased use of models may be necessary.

5.1.5 *Models for Estimating Fisheries Productivity*

Due to the financially and ecologically prohibitive nature of obtaining all relevant data for a given system, models are essential for linking limited data on subsets of populations with whole-population productivity and long-term projections. A shift to long-term sustainability practices based solely on experimental data and monitoring would require such extensive and potentially ecologically damaging data sampling protocols that management would become economically and ecologically prohibitive. Models could form an essential link between relatively limited data sets on subsets of populations and long-term projections for whole-population productivity (Blanchard et al. 2014). Hence, fisheries management under the FPP may require more extensive use of models as a predictive tool (Carr and Heyman 2014, Jennings et al. 2014, Minns et al. 2011, Velez-Espino and Koops 2012).

Numerous models have been created in the past to aid fisheries management decisions. It is beyond the scope of this report to review all of these in detail. Instead, we provide an overview over the basic principles used throughout many of the existing models, and how they may be applied with respect to compensation lake management under the FPP (Table 3). Most models currently in use are variations or expansions of these basic approaches (Andersen and Beyer 2013, Wan et al. 1999).

Models are essential in balancing data requirements with the need for long-term predictions of fisheries productivity and maximum sustainable harvest rates. This is particularly important in newly created or expanded ecosystems such as compensation lakes and end pit lakes where there are no pre-existing or baseline data. The main challenge lies in striking the balance between data needs for accurate predictions and financial feasibility; any model is only as good as the data it is based on and the assumptions on which it is made.

Stock-recruitment rates, for instance, are arguably the most important of the rate functions governing fish population dynamics (Quist 2007). Together with logistic growth curves, they form the basis for many models (e.g., Zhang 2013). Through the steepness coefficient (h) of the recruit/spawner curve, these rate functions can be used to estimate maximum sustainable yield as well as to conduct stock projections, and so is particularly useful for offsetting approaches and for predicting the long-term consequences of a project. However, these types of models require data on abundance, reproduction or reproductive capacity of adult fish and survival (or mortality) rates of juvenile fish. Acquiring sufficient data for the proper use of these models is labor intensive, cost prohibitive and potentially damaging to the fish populations; adequate data are difficult to obtain with the required degree of accuracy (Quist 2007).

Further, all models are based on assumptions, most of which require further research for validation and all of which will vary in accuracy between different ecosystems and habitat types. The assumptions of most models, when tested, very often turn out to be imprecise at best (Hoshino et al. 2014, Pardo et al. 2013) and fundamentally wrong in some cases (Minns et al. 2011, Railsback et al. 2003, Rose 2000). For instance, a number of models (e.g., HSM and GLM, see Table 3) assume that there is a linear relationship between parameters, e.g., productivity and prey availability or species abundance and specific habitat features. These assumptions are typically proved false when tested due to effects of spatial heterogeneity within the habitat, complex community interactions and the cumulative effects of multiple stressors (Railsback et al. 2003, Rose 2000). There is a strong trade-off between the amount of available data and the number of assumptions that must be made in the modelling process.

Table 3. Basic modelling approaches relevant for linking population level data with fisheries productivity.

Model or modelling tool	**Used to**	**Data required (see also Table 1)**	**References**
Allometric relationships	Provide quantitative generalizations on how various parameters change with size, to be used in growth and productivity models.	Data on how the relevant parameters (e.g., mortality rates, spawning rates, metabolic coefficients) change with size for the given species.	Boukal et al. 2014 Hossain et al. 2012
Logistic population growth models	Quantify how the population growth rate changes with population size. Estimate carrying capacity and intrinsic growth rate.	Estimates for growth rate and abundance for a given species in a given environment. Typically though time-series investigation and mark-recapture.	Chakraborty et al. 2013 Erhardt and Scarnecchia 2014
Von Bertalanffy growth models	Provide an allometric curve of length as a function of age. Used to estimate e.g., max. length, coefficients of growth and mortality. Modifications allow habitat change to influence the shape of the curve.	Measurement of how length varies with age for the relevant species in the relevant habitats.	Boukal et al. 2014 Lester et al. 2004 Vincenzi et al. 2014
Stock-recruitment models	Calculate the number of new recruits that arise from a particular number of spawning fish. Quantify area-based survival. Used to estimate factors affecting the carrying capacity of a system, maximum sustainable yield and long-term projections of productivity.	Abundance of adult fish, fecundity/reproductive capacity of adult fish, survival/mortality rates of eggs and juvenile fish.	Cadigan 2013 Honea et al. 2009 Minns et al. 2011 Sharma and Hilborn 2001

Model or modelling tool	Used to	Data required (see also Table 1)	References
Stock-assessment models	Inform quotes for maximum sustainable yield for fisheries.	Scale of fishery, age composition of catch and abundance-index data. Typically based on biomass caught under the effort of commercial fisheries. In addition, require data for a plausible model of the ecology of the particular species.	Cotter et al. 2004 Wang et al. 2014
Stage-structured models	Calculate growth or decline in a population based on the probability of surviving from one life stage to the next. Estimate the functional dependence of population growth rate on e.g., stage specific habitat requirements, fecundity or mortality rates.	Number of fish as a fraction of total abundance that survive from one life stage to the next. Quantitative estimates of dependence of relevant parameters on life stage.	Botsford et al. 2014 McAllister et al. 2001 Minns and Moore 2003 Velez-Espino and Koops 2009b
Individual-based bioenergetics model	Determine the relative effects of different parameters (metrics) on the growth and reproduction of an individual fish based on energy input/output calculations. Possible to scale up to population level.	Energy consumption, energy expenditure and energy investment in reproduction for the relevant species. How relevant parameters (e.g., prey species availability) affect these figures.	Hartman and Kitchell 2008 Pethybridge et al. 2013 Rinke and Petzoldt 2003 Steele 2012 van Winkle et al. 1993
Ecosystem-based fisheries management models (EBFM)	Calculate fish/fisheries productivity or production based on environmental parameters, e.g., a triad of drivers: exploitation, tropodynamics and biophysical environment.	Developing field, the search for appropriate reference points and metrics to measure is ongoing. Include data on habitat quality as it pertains to the relevant species, community interactions and population level indicators for productivity (see Table 2)	Fulton et al. 2005 Link et al. 2012 Rice and Rochet 2005
Population - habitat models	Determine causal relationships between changes in habitat gain or loss and fish production. A type of ecosystem-based approach. May or may not be based on stage-structures population models.	Data on habitat preferences of all life stages and functional relationships between habitat variables and vital rates for all relevant species of fish.	Hayes et al. 2009 Minns et al. 2011 Velez-Espino and Koops 2009a

Model or modelling tool	Used to	Data required (see also Table 1)	References
Habitat simulation models (HSM)	Predict change in habitat availability resulting from incremental changes in flow; linked to the habitat suitability index (HSI) based on habitat preferences for fish species of interest. Can be used to calculate NNL but very data intensive.	Change in habitat area with change in flow. Relationship between habitat area and population biomass of relevant species. Data required to calculate habitat suitability index for relevant fish species.	Ahmadi-Nedushan et al. 2006 Anderson et al. 2006 Minns et al. 2011
Defensible methods	Version of habitat simulation model specifically created to calculate change in productive capacity as a result of development. Created for habitat management under the FHMP.	Area affected by development (pre- and post-development, including any compensation habitat). Suitability of affected habitat with respect to relevant fish species. Relationship between amounts of suitable habitat and productive capacity.	Minns and Nairn 1999 Minns et al. 2001
Generalized linear model (GLM)	Used to fit data on species abundance to habitat features. Assumes that habitat-abundance relationships are linear over a range of habitat features, something that tends to be proven false when tested.	Habitat types present in the ecosystem in question. Abundance of fish in the relevant habitat types.	Minns et al. 2011 Railsback et al. 2003

With increasing availability of information on a given ecosystem and habitat type, it is possible to reduce the impact of many of the uncertainties and errors related to data sampling and assumptions. Hence effective models specific for given habitat types and community structures may be the most promising tool for improving out monitoring protocols with respect to FPP.

The defensible methods version of the habitat simulation model was specifically created to aid management decisions under the FHMP. Because the end goal of habitat management already prior to 2012 was to assure that fish, particularly species relevant for fisheries, suffered no net loss in productivity, the defensible methods were based on the relationship between amount of suitable habitat and productive capacity. As such, it provides a promising starting point for developing models specifically tailored towards efficient management of the FPP.

6 SPECIFIC CONSIDERATIONS FOR OFFSETTING APPROACHES

The Fisheries Protection Policy (Department of Fisheries and Oceans 2013b) specifies that whenever possible, efforts should be made to prevent impacts first or, if this is not possible, to minimize (mitigate) impacts caused by the project in question. However, if projects have sufficient residual impacts, compensation is needed to ensure the “ongoing productivity of commercial, recreational or Aboriginal fisheries (CRA)” (Figure 1). Ongoing may here be defined as “sustained productivity, as experienced by participants in the fishery at and just before the time of interest” (Randall et al. 2013).

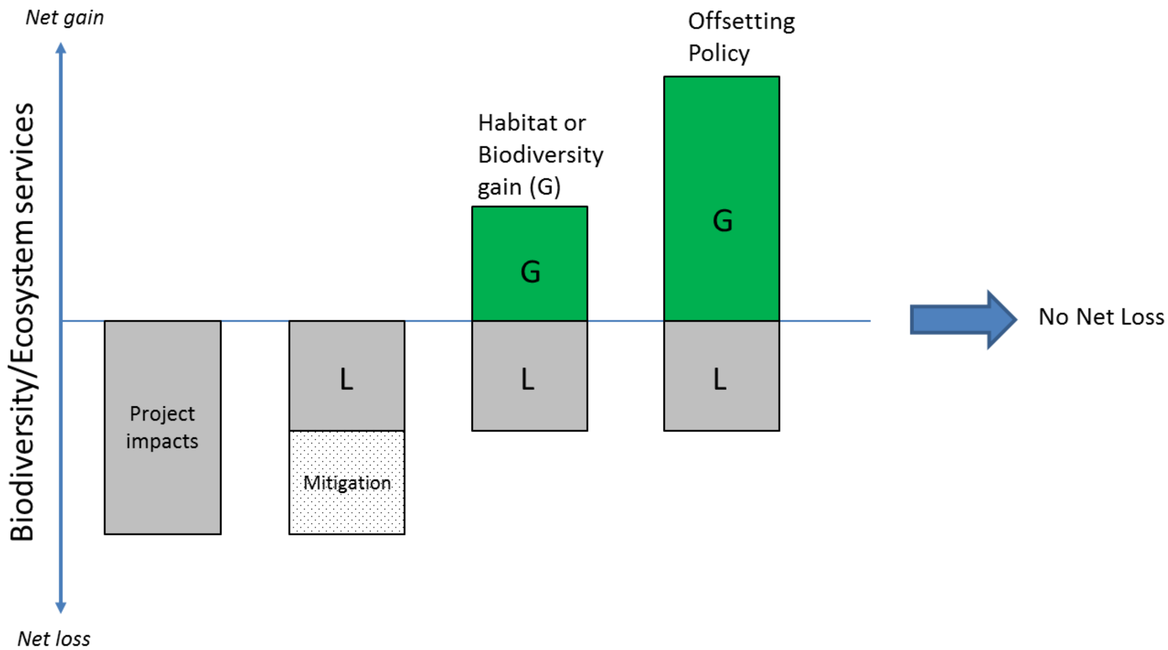

Figure 1. Conceptual diagram of offsetting strategies.
L = Loss; G = Gain.
Adapted from Quetier and Lavorel (2011).

An offset measure is one that counterbalances unavoidable *serious harm to fish* resulting from a project with the goal of maintaining or improving the productivity of the commercial, recreational or Aboriginal fishery. Due to the problems faced in providing accurate measurements and predictions of current and future productivity of a fisheries population, offsetting approaches will have to make effective use of available resources and make knowledge-based decisions. The guiding principles listed in the Fisheries Protection Policy Statement (Department of Fisheries and Oceans 2013b) for meeting the goal of the fisheries protection program (Box 2) is:

1. to avoid harm whenever possible,
2. to use science, technical information and traditional knowledge to promote sound decision making
3. to collaborate with partners well-placed to deliver the objectives of the Fisheries Protection Program,
4. to develop and support the use of standards to provide clarity and certainty, and
5. to consider cumulative effects on the ecosystem.

These factors should be considered in determining the best practice for approaching offsetting management. Offsetting indicators should agree with the environmental assessment indicators to ensure that changes in population productivity are equivalent across projects. Currently, more information is needed to determine best management practices for ensuring the long-term sustainability of the productive capacity of fisheries in the oil sands region.

6.1.1 *Compensation Lake Management*

The development of compensation lakes has been important for a number of projects both in the oil sands region itself and in the development of infrastructure such as roads necessary for operations in the oil sands area. They provide a means of compensating for loss in productive capacity due to a destruction of fish-bearing wetlands that cannot be avoided or mitigated. Knowledge-based standards for planning and executing compensation lake development may ensure ecologically robust solutions that can be implemented within a predictable budget. In the process of determining best standards, a key parameter to evaluate is the carrying capacity of various compensation lake ecosystems (the shift away from the intrinsic population growth rate when not influenced by density dependence). This could be based on e.g., density-dependent limitations to population growth within all relevant species and how they interact (Winemiller 2005).

With compensation lakes, ensuring an appropriate agreement between offsetting indicators and environmental assessment indicators may be challenging; it constitutes a comparison between established ecosystems and populations in the process of establishing in a newly created or expanded habitat. To ensure that changes in population productivity are equivalent across projects, it may be particularly important to take juvenile indicators into account (including mortality, growth rates, etc.), as these could demonstrate noticeable change much faster (Jones et al. 2003).

Since compensation lakes constitute systems in which fish species are establishing, it possible to obtain good estimates of intrinsic growth rate of the populations within this specific habitat. This is particularly important in stock assessment models (Table 3), which are critical to understanding the current state of a fishery and to estimating the effect of future harvest on the ongoing productivity of the fish populations within it. These estimates will be valuable in evaluating the success of the compensation lake. The main difference between models is in how they address fish recruitment, fish growth and natural mortalities (Magnusson and Hilborn 2007).

Stock assessment models (Table 3) are typically based on a plausible demographic model of the fish's ecology (e.g., Sparre et al. 1989). Data sets for these models are traditionally obtained from catch rates from commercial fisheries. In most freshwater systems, commercial fisheries are limited or non-existent, making data sets harder and more expensive to obtain. In compensation lake systems, where fisheries are initially prohibited (Golder 2012, 2013), all data will need to come from site specific sampling with the explicit purpose of ensuring adequate monitoring. However, since the best estimates of these population characteristics, as mentioned above, come from recovery periods (Magnusson and Hilborn 2007), compensation lakes form ideal systems in which to perform this type of analysis.

The issues faced in ensuring the appropriate agreement between offsetting indicators and environmental assessment indicators could in part be mitigated through the newly established possibility for habitat banking, initiated through the Fisheries Productivity Investment Policy (See Box 3). Such a proponent-led habitat bank is an approach for creating offsets in advance, hence allowing for actual measurements of the productivity of the fisheries populations in the newly created habitat. In this way, gain in productivity could be measured prior to the destruction of habitat in the development area, providing more accurate estimates of acceptable levels of loss in fisheries productivity. The benefits accumulated in the habitat bank would be counted as credits, while serious harm to fish caused by a project or projects would be considered as debits.

6.1.2 *Evaluating the Need for Technical Assessment*

There are two phases that will require a proponent to conduct a technical assessment to determine if offsetting approaches are required, and if so to determine the magnitude of the necessary offsetting (Department of Fisheries and Oceans 2014b):

1. A serious harm evaluation (Figure 2)
2. A productivity assessment (Figure 3).

During the serious harm evaluation, the proponent will need to consider potential impacts to fish and fish habitat using Pathway of Effects (POE) models developed by DFO. This includes evaluations of expected duration and spatial scale of impacts, availability and condition of nearby fish habitat, the impact on relevant fish, and proposed avoidance and mitigation measures (Department of Fisheries and Oceans 2013b).

Figure 2 illustrates application of the fundamentals of “avoid, mitigate and offset” to implement the hierarchy that is internationally recognized as a best practice to reduce impacts on biodiversity. This hierarchy has not been altered from the previous FHMP. However, implementation of the hierarchy of preferences (avoid, mitigate, offset) is now applied only to serious harm to fish that are part of a commercial, recreational or Aboriginal fishery or to fish that support such a fishery. If serious harm cannot be avoided, or mitigated, residual serious harm is established an authorization from DFO is required for the work, undertaking or activity proposed (Department of Fisheries and Oceans 2013b).

Once residual serious harm is predicted to occur as a result of a proposed work, undertaking or activity, a productivity assessment is recommended to assist decision making (Department of Fisheries and Oceans 2014b). Figure 3 illustrates the procedure required of such productivity assessments. The two main factors to consider are the type and scale of the impact, which will determine the level of detail required for the productivity assessment (Bradford et al. 2014, Department of Fisheries and Oceans 2013a,b, 2014b).

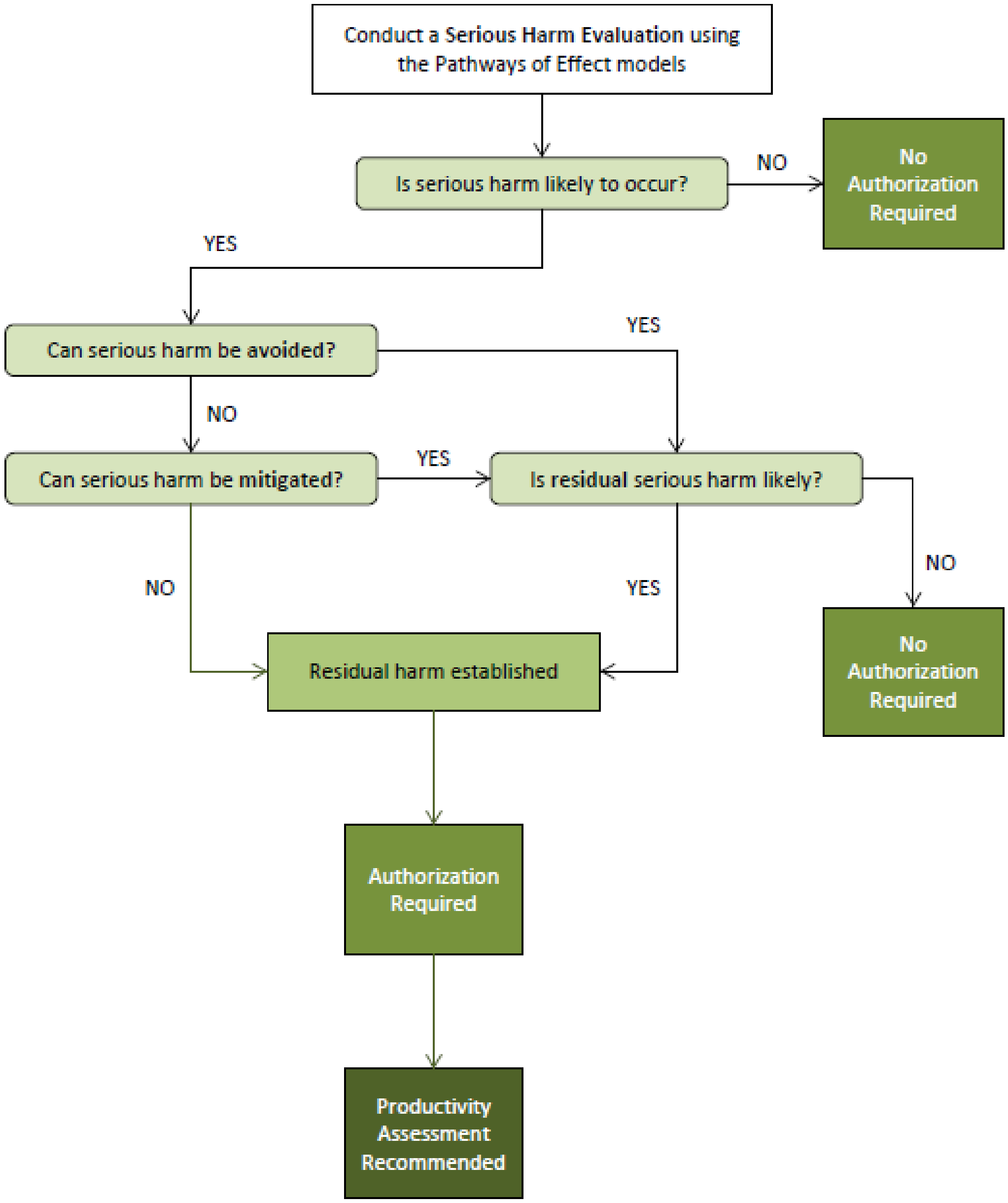

Figure 2. Flowchart summarizing the decision making process employed in a serious harm evaluation used to determine if DFO Authorization is required, and whether it is necessary to conduct a productivity assessment.
(Bradford et al. 2014, Department of Fisheries and Oceans 2013a, 2014b).

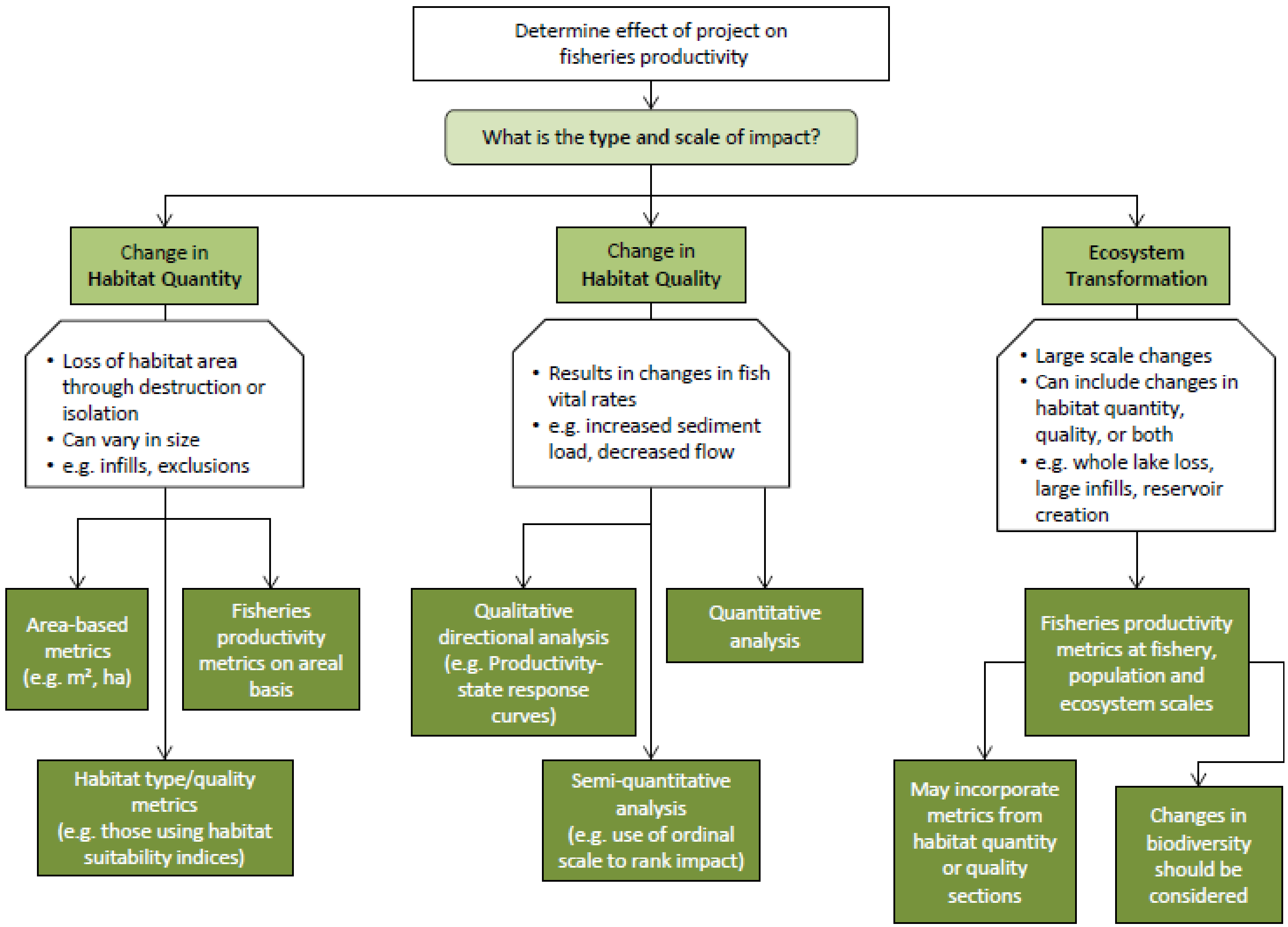

Figure 3. Flowchart summarizing fisheries productivity assessment by outlining categories of metrics based on predicted impact. (Bradford et al. 2014, Department of Fisheries and Oceans 2013a,b, 2014b,c).

The type of metrics that are required to assess FP impacts will be determined by an evaluation of whether anticipated impacts involve changes in habitat quantity, habitat quality, or will result in ecosystem transformations. The scale of the potential impact will also factor in to the metrics chosen for analysis, with larger scale impacts requiring more complex estimates of productivity. For example, for projects that are expected to result in serious harm as a result of a small scale change in habitat quantity, it may be appropriate to use simple area-based metrics or metrics based on habitat suitability indices. A large-scale version of the same impact, however, may require more intensive fisheries productivity estimates (Department of Fisheries and Oceans 2014b).

Productivity-state response curves have been developed by DFO for assessing the impact of changes to habitat quality (Department of Fisheries and Oceans 2014c). More complex quantitative productivity-state analyses would be necessary to assess the impacts of large-scale changes in habitat quality. Requirements to conduct quantitative productivity-state analyses would include quantitatively derived productivity-state relationships, accurate predictions of project impacts, and baseline information on habitat and relevant fish. The ecosystem transformation category of impact would require more direct assessment of fisheries productivity at the population or ecosystem scale. Further, biodiversity metrics should be incorporated to account for associated losses in productivity that may not be identified using typical fisheries productivity metrics (Bradford et al. 2013).

7 CONCLUSIONS

Though much work has been done on measuring the productivity of fish populations, it has proven difficult or impossible to find simple, reproducible techniques that can be applied across habitat types and ecosystems. Current methods for providing assessments of the productivity of fisheries require comprehensive, long-term data sampling techniques. Typically these are done to quantify indicators related to physiological features and abundances of fish within the populations. Adequately intensive sampling is associated with costs that may be considered prohibitive to developers. Interpretation of data has been associated with significant errors due to sampling protocols and modelling assumptions. Further, data sampling techniques may include sampling methods that are lethal or damaging to the fish or eggs of the populations that the FPP aims to protect.

Habitat-based methods do not in themselves provide an adequately precise measure of productive capacity as needed to ensure no net loss required by the Fish Productivity Protection framework. However, the goal of the Fish Habitat Management Program was already, prior to the 2012 amendments, to ensure no net loss of the productive capacity of fish within a habitat. Because of this, established management practices included the monitoring of fish diversity, abundance and size distributions, and through this estimates of annual average fish biomass produced per unit area. Habitat-based approaches coupled with population-based estimates as used under the FHMP may provide the best compromise between financial feasibility, avoiding additional damage to the fisheries, and ensuring ecologically robust results.

Models are essential in balancing data requirements with the need for long-term predictions of fisheries productivity and maximum sustainable harvest rates. However, it may be difficult to strike the balance between data needs for accurate predictions and financial feasibility. Any model is only as good as the data it is based on and the assumptions on which it is made.

Future research may enable more accurate estimates of fisheries productivity based on key fish and habitat indicators. As the governing factors that limit the productivity of fish populations vary between species, habitats and regions, it is likely that this would have to occur through the development of models specific for the given habitats and geographical areas. Similarities between indicator development in the Ecosystem-based Fisheries Management field (e.g., Fulton et al. 2004) and the emerging Fish Productivity Protection framework (Bradford et al. 2013) are promising in terms of a knowledge base for developing such models. Though the top data needs for Ecosystem-based Fisheries Management include primary biomass and abundance with a secondary set related to diet/consumption and mortality and the Fish Productivity Protection framework may have more varied requirements, the two are fundamentally similar.

8 RECOMMENDATIONS

Future research should be conducted for areas characterized by intensive development, such as the oil sands region, to develop habitat-specific models. The purpose of these models should be to allow for robust estimates of productivity based on limited and specific indicators that are manageable to measure.

If the drivers of the ecosystem in question are not well studied, the most cost-effective and ecologically sound way of implementing the FPP would be to adopt the management practices of the FHMP largely unaltered, but with the interpretive end goal shifted to fisheries productivity. The main additional requirement for achieving this would be to make it mandatory to include abundance, species composition and size structure data in the monitoring protocols. Further, the monitoring period should be extended so that it is required to occur over a time-span of several years. These management practices are already commonly used in many developments in the oil sands region, which should ease the shift to management under the FPP.

At our current state of knowledge, it may be detrimental to the goal of the FPP to pursue productivity assessments beyond these practices employed under the more comprehensive of the monitoring protocols used under the FHMP. The most precise indicator for fisheries productivity remains the quantity and quality of available habitat and the abundance, species distribution and size structure of the fish populations that inhabit it.

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10 GLOSSARY

10.1 Terms

Carrying Capacity (CC)

The maximum abundance of a population that can be maintained at an equilibrium in the absence of exploitation for a given habitat.
Unit: Biomass or abundance.

Commercial, Recreational and Aboriginal (CRA) Fisheries

Fish that are harvested under the authority of a license for the purpose of sale, trade or barter, fish that are harvested under the authority of a license for personal use, and fish that are harvested by members of aboriginal organizations for food, social- or ceremonial purposes.

Density Dependence

Limits to the growth of a population caused by factors that are dependent on the existing population density, e.g., competition from other individuals within the same species or competition from other species.

Fish Habitat Management Program (FHMP)

The program for managing the habitat that sustains fish populations that was used before 2013 based on the iteration of the *Fisheries Act* valid at the time and the DFO policy of 1986.

Fisheries Protection Program

The program for managing the ongoing productivity of commercial, recreational and aboriginal (CRA) fisheries, applicable after 2013 in accordance with the current iteration of the *Fisheries Act* and the DFO 2013 Fisheries Protection Policy Statement and the Fisheries Productivity Investment Policy.

Growth Rate (G_r)

Increase in the size of a population per unit time per unit biomass or abundance. Expressed in terms of biomass or abundance.
Unit: $Time^{-1}$, e.g., $Kg \cdot Kg^{-1} \cdot year^{-1} = year^{-1}$

Intrinsic Growth Rate (r)

The maximum rate a population will grow at, which is only achievable in small populations, e.g., when populations are establishing or recovering.
Unit: $Time^{-1}$, e.g., $Number \cdot Number^{-1} \cdot year^{-1} = year^{-1}$

Maximum Sustained Yield (MSY)

The yield taken at the maximum rate of production. Represents the annual and repeated harvest rate that yields the most return without negatively impacting stock productivity. It is often taken to be a function of G_r and CC.
Unit: $Biomass \cdot time^{-1}$

Production

Population characteristic; it is the total increase in amount of fish tissue during a unit of time, regardless of whether or not fish survive during the time interval.
Units of measurement are usually weight per unit area per unit time (e.g., $kg \cdot ha^{-1} \cdot year^{-1}$).
Production rate is the product of specific growth rate (G) and average biomass (B) for a specified duration (usually one year).

Productivity
Population characteristic that relates to the birth, growth and death rates of a stock. A highly productive stock is characterized by high birth, growth and mortality rates and exhibits a high production to biomass (P/B) ratio. Productivity is typically defined as the maximum survival rate at low density (i.e., when survival is density-independent).

Fisheries Productivity (FP)

The sustained yield of all CRA species, equivalent to the amount of new biomass produced per population per unit time summed up over all populations for the given species and all CRA species present in the relevant area.

Ongoing Sustainability

The potential sustained yield of all fish populations and their habitat that are part of or support commercial, recreational and Aboriginal fisheries.

Productive Capacity (PC)

Habitat characteristic. For individual fish populations, the productive capacity of a given habitat is the equilibrium density of fish that a particular habitat can support indefinitely by the resources available in that particular habitat. For communities, productive capacity can be defined as the sum of the maximum production of all species co-habiting within the habitat. The DFO policy for management of fish habitat defines productive capacity as: "The maximum natural capability of habitats to produce healthy fish, safe for human consumption, or to support or produce aquatic organisms on which fish depend" (DFO 1986).
Unit: Fish biomass·land-area^{-1}·time^{-1}, e.g., kg·ha^{-1}·year^{-1}

10.2 Acronyms

BACI	Before After Control Impact
CC	Carrying Capacity
CRA	Commercial, Recreational, and Aboriginal
DFO	Fisheries and Oceans, Canada
EBFM	Ecosystem-based Fisheries Management
FHMP	Fish Habitat Management Program
FP	Fisheries Productivity
FPP	Fisheries Protection Program
GLM	Generalized Linear Model
HSI	Habitat Suitability Index
HSM	Habitat Simulation Model
MSY	Maximum Sustained Yield

NNL	No Net Loss
OSRIN	Oil Sands Research and Information Network
P:B	Productivity: Biomass
PC	Productive Capacity
POE	Pathway of Effects
SEE	School of Energy and the Environment
w/u/a	Work, Undertaking or Activity

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