Fisheries and Oceans Canada
Science

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Canadian Science Advisory Secretariat (CSAS)

Research Document 2014/112

National Capital Region

Science advice on a decision framework for managing residual impacts to fish and fish habitat

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January 2015

Foreword

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

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

Published by:

Fisheries and Oceans Canada
Canadian Science Advisory Secretariat
200 Kent Street
Ottawa ON K1A 0E6

http://www.dfo-mpo.gc.ca/csas-sccs/
csas-sccs@dfo-mpo.gc.ca

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ISSN 1919-5044

Correct citation for this publication:

Bradford, MJ, Koops, MA and Randall RG. 2015. Science advice on a decision framework for managing residual impacts to fish and fish habitat. DFO Can. Sci. Advis. Sec. Res. Doc. 2014/112. v + 31 p.

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ABSTRACT

In 2012, legislative amendments were made to Canada's *Fisheries Act*, including the Fisheries Protection Provisions that apply to activities or works (projects) that have the potential to adversely affect fish or fish habitat, potentially resulting in a loss of productivity of Canada's fisheries. The Fisheries Protection Program (FPP) sought advice from Science regarding approaches and methods for the evaluation of the adverse effects of projects, particularly for the initial screening of smaller projects where the information available for making regulatory decisions is limited. Risk assessment and management process are discussed, and a review of the application of DFO's 2005 Habitat Risk Management framework is presented. Recommendations are made on attributes that could be used to evaluate project impacts. The concept of equivalent adults is proposed as a common metric that permits diverse impacts to be computed in the units of fish potentially lost to the fishery, expressed as either abundance or production. It is recommended that regional benchmarks for fish abundance and production be developed to assist decision making when project-specific information is lacking.

Avis scientifique sur un cadre décisionnel relatif à la gestion des incidences résiduelles sur le poisson et l'habitat du poisson

RÉSUMÉ

En 2012, des modifications législatives ont été apportées à la *Loi sur les pêches* du Canada, y compris les dispositions relatives à la protection des pêches qui s'appliquent aux activités ou aux travaux réalisés (projets) qui peuvent avoir des effets néfastes sur le poisson ou l'habitat du poisson, ce qui pourrait entraîner une perte de productivité des pêches du Canada. Le Programme de protection des pêches (PPP) a demandé l'avis du secteur des Sciences concernant les approches et les méthodes servant à l'évaluation des effets néfastes des projets, en particulier pour l'évaluation préalable des petits projets dans le cadre desquels les renseignements disponibles pour prendre des décisions en matière de réglementation sont limités. Le processus d'évaluation et de gestion des risques fait l'objet d'une discussion, et un examen de l'application du cadre de gestion du risque lié à la gestion de l'habitat du MPO (2005) est présenté. On formule des recommandations sur des paramètres qui pourraient être utilisés pour évaluer les répercussions du projet. On propose le concept d'équivalents adultes comme mesure commune permettant de calculer les diverses incidences dans les unités de poissons représentant potentiellement une perte pour la pêche, exprimé sous forme d'un taux d'abondance ou de production. On recommande d'établir des points de référence régionaux pour la production et l'abondance du poisson afin de faciliter la prise de décisions lorsqu'il y a un manque de renseignements propres au projet.

INTRODUCTION

In 2012, legislative amendments were made to Canada's *Fisheries Act*, including new terminology and the addition of new sections to the Act. The Fisheries Protection Provisions are sections of the act that apply to activities or works that have the potential to adversely affect fish or fish habitat, possibly resulting in a loss of productivity of Canada's fisheries. Serious harm to fish is defined as the "death of fish or any permanent alteration to, or destruction of, fish habitat". The management of serious harm is guided by section 6.1, which states the purpose of decision-making under the Provisions is to "provide for the sustainability and ongoing productivity of commercial, recreational and Aboriginal fisheries". Science advice on these terms is provided by DFO (2013b, 2014a) and supporting documents.

The Fisheries Protection Program (FPP) is currently developing a project review and decision making process that has the goals of providing a consistent, transparent and efficient approach to the application of the Provisions. A two-stage process is being considered utilizing a combination of guided self-assessment by proponents, and advice and direction from FPP staff.

Initially the proponent is to consider the project and the proposed avoidance and mitigation measures to determine if there is a residual effect on fish and fish habitat. Residual effects are impacts to fish and fish habitat that cannot be avoided in the project design, and they become the object of review under the Fisheries Protection Provisions.

The goal of the first review stage is to determine if the residual effect is likely to cause a localized effect on fish or fish habitat (DFO 2013a). In this phase relatively basic information about the project, potential residual effects, and the habitats and fish that may be affected are used. If a localized effect is determined to be unlikely due to the nature of the project and the proposed avoidance and mitigation measures, further regulatory review may not be required. If a localized effect is likely, then proponents will move to the second phase of review.

In the second phase proponents may be required to make an application for authorization under section 35 of the *Act*. In this case a more detailed description of the impact of the project on fisheries productivity, proposed mitigation and offsetting activities, and monitoring programs will be specified and will inform the Minister in making a decision using the factors listed in section 6 of the *Act*. These requirements are specified in the regulation "Applications for Authorization under Paragraph 35(2)(b) of the Fisheries Act", SOR/2013-191.

GOALS OF THIS PAPER

FPP seeks Science advice to inform the operational implementation of these legislative changes, particularly in the first review stage where the consideration of serious harm to fish is being made. Advice is requested on possible tools and approaches to inform regulatory decisions related to serious harm to fish. It is requested that such advice should consider the magnitude and likelihood of potential impacts to fish and fish habitat likely to result from development projects (works/undertakings/activities), particularly the influence of spatial and temporal scale, and the magnitude of potential impact to fisheries productivity.

Previously, regulatory decisions under the habitat protection provisions of the Act were guided by the Risk Management Framework (RMF), a tool developed in the mid-2000s to structure information and provide a consistent approach to decision making. Here we review the notions of risk, the RMF, and regional variations of the RMF for insights that might inform the development of a new approach for the serious harm determination. We also consider risk frameworks that have been developed in other sectors of DFO and elsewhere. Having established the context we then make specific suggestions on approaches and considerations that may be of use during the development of the decision tool required by FPP for the first phase of the regulatory review.

This advice is primarily intended for the Fisheries Protection Program, to assist them in developing a scientifically defensible process for evaluating the potential of projects to cause serious harm, as defined in the *Act.* The advice is directed towards the assessment of smaller projects (in terms of extent, duration or intensity) where the potential to cause serious harm is uncertain. The procedures we develop are not intended for individual proponents, but rather for FPP to use to classify works or to develop regionally-based simplified protocols for project evaluation.

CONCEPTS OF RISK, RISK ASSESSMENT AND RISK MANAGEMENT

Risk analysis, as an aid to decision-making is a relatively young field, having origins in Operations Research of the Second World War, and subsequent analyses of nuclear and atomic safety in the Cold War Era. The development of the US Environmental Protection Agency's (USEPA) Environmental Risk Analysis in the 1970s for toxic chemicals ushered in the use of risk analysis for environmental issues.

Because risk analysis is a new field that has crossed many disciplines, there are a variety of definitions of risk that can lead to confusion regarding the appropriate approaches to analysis and assessment. Common to all of them is the concept of decision-making in the face of future uncertainty, however, the definitions of risk differ, largely due to discipline-specific differences in the nature of risks. Aven and Renn (2009) list 10 definitions for risk; these fall into 2 general categories:

1. Definitions that involve probabilities and consequences
2. Definitions based on uncertainties about future events.

The first definition is commonly used for random or stochastic events that can have negative consequences, where the threat is a combination of the probability or likelihood of the event, and the magnitude or consequences of that event when it occurs. Examples include natural catastrophes such as floods, or earthquakes, spills or accidents, or malfunctions in manufacturing processes or safety systems. Risk is often expressed as (Yoe 2012):

$$\textit{Risk} = \textit{Probability} \times \textit{Consequence}.$$

It should be noted that this equation is a risk-neutral calculation of risk, where frequent small events are considered of equal risk to rare large events. This approach may be appropriate for financial management, for example, but may not be relevant for other types of threats. Consequently, other definitions of risk in this category consider only one of these attributes, or consider risk to be multidimensional, comprising both probability and consequence rather than the simple product form. For example, DFO (2014b) defined risk as *exposure*consequence* to account for variation in the spatial extent of threats to marine ecosystems.

The second category of risk definitions are usually expressed as the uncertainty in an outcome, for an event that could be a threat to something of value. These types of definitions are appropriate for events or actions that are very likely to occur, but the magnitude of the consequence or impact is uncertain. Uncertainty in this case is not due to whether or not the event will occur but due to variation in the magnitude of the consequences plus the uncertainty in our ability to estimate the magnitude of the consequences. This definition of risk is appropriate to most projects being reviewed by FPP, as the uncertainty largely lies in the magnitude of the impact of the project on fish and fish habitat (and fisheries productivity).

RISK ASSESSMENT AND RISK MANAGEMENT

The distinction between these terms was sharpened during the development of the USEPA's risk assessment and management frameworks. Those frameworks distinguished between the technical analyses of the risk assessment phase (based on models and analyses to predict the effects of a hazardous chemical) that would be conducted by specialists, and risk management, where the results of the analysis are handed off to "managers" for decision making. Power and McCarty (2002) review these frameworks.

In recent years the delineation between risk assessment and risk management is breaking down as a result of an increasing recognition of the need to integrate technical information and values (including policies and legislation). Usually many policy- or value-based decisions are needed to implement a risk assessment and the notion that the risk assessment phase is a value-free science-based exercise is erroneous and sometimes disingenuous (Wagner 1995). Determining exactly what is at risk and what aspects of risk are the most important to manage are usually value-based analyses, and these tasks are equally important to the science-based technical analyses required to estimate risk (Gregory et al. 2006).

Cognitive psychologists have long recognized that there can be large differences in perceived risk vs real (statistical) risk and have investigated the factors that influence how individuals evaluate risks (Tversky and Kahneman 1974, Kahnemann 2011). A full treatment is beyond the scope of this report but it is important to note that the question of the "risk of what to whom" is important and needs to be identified when developing a decision framework. Secondly, the perception of risk is influenced by factors such as recent experience and emotion (Slovic 1999; Wilson, 2008). For the FPP these findings suggest that in the absence of anchors provided by regional and national guidance, internal or personal factors will dominate risk-based decision making. Undoubtedly this has contributed to inconsistencies in decision making in the habitat program (Minns 2015).

THE 2005 HABITAT RISK MANAGEMENT FRAMEWORK

The Risk Management Framework (RMF) was developed in the mid-2000s to provide a structured approach to decision making in the habitat management program, building on the 1986 Policy. The Practitioners Guide to the Risk Management Framework (DFO undated) provides the most readily available description of this tool. The approach introduced the use of pathways of effects (POE) diagrams to assess the effects of projects on fish and fish habitat. POEs are used to identify the pathways that could result in a residual effect after mitigation and best practices are applied. In the "risk assessment" phase, the impact of the project's residual effects on fisheries resources is estimated based on 2 primary scales of measurement. These attributes are displayed in a 2-dimensional risk matrix. The attributes are:

1. "Scale of negative effect": this is a rating of the magnitude of the impact of the project on fish habitat, and can be assessed on the basis of extent, duration and intensity of the effect. Other descriptors may be used. Constructed scales have been proposed for the use of these attributes, but ultimately the attributes and scores have to be combined to form a 3-point scale (L/M/H) for the scale of negative effect axis.
2. "Sensitivity of fish and fish habitat": This generally refers to the type of fish and fish habitat that is being affected by the project. Regional fish habitat or species priorities are expected to be used. Additional considerations include the sensitivity of key species to the change, the dependency of the species on the habitat and any unique characteristics of the exposed habitats. Information is used to position the project into one of 4 categories (H/M/L/Rare).

Ratings from these 2 attributes map the project's impacts on to the risk matrix (Figure 1). Four categories of "risk" are identified (DFO undated) and are described by their corresponding management response:

1. Low: Projects that are unlikely to result in a HADD (harmful alteration, disruption or destruction) if appropriate practices and mitigations are used. Project impacts are well described and uncertainty is low.
2. Medium: Projects that are likely to cause a HADD but the scale is relatively small and the outcomes are predictable. These may be routine projects for which class or streamlined authorizations can be employed.
3. High: Projects that cause larger HADDS and/or may occur in important habitats will require a site-specific review and authorization. Compensation will likely be required.
4. Significant Negative Effects: In this case the scale of the impact or the importance of the habitats or species affected cannot be adequately compensated for. Such projects may be deemed unacceptable.

The use of the risk ratings is summarized in the guidelines (DFO undated, p. 19): "Once the risk to fish and fish habitat has been characterized, practitioners can use the results to support and guide their decision on how to best manage the risk. The Risk Assessment Framework provides an effective means through which to communicate those decisions to proponents and other stakeholders".

REGIONAL APPLICATIONS OF THE RMF

In this section we summarize some common features of the regional tools that may be useful for the development of the new framework.

Insight into the use and utility of the RMF was gained by a review of aids and tools for the RMF as well as variations of the RMF that have been developed in DFO's regions. These were solicited from Regional FPP staff in early 2013, however, no attempt was made to be exhaustive.

Worksheets/checklists: RMF worksheets or checklists were developed by some regions. Those worksheets followed the approach and attributes of Table 4 and 5 of the *Practitioners Guide*. Here the *x* and *y* axes of the RMF are broken down into a number of attributes, and each individual attribute is assigned a L/M/H rating. There is some guidance on how to assign rankings for each attribute, and how to summarize the attribute scores into an overall rating for placement on the RMF matrix diagram, however, these decisions appear to be largely at the discretion of the reviewer. Some have commented that the absence of anchor points on these axes defeats the goal of consistency as the definitions of these categories or the determination of the final risk rating is largely a subjective process of the individual reviewer, despite the organizing structure provided by the RMF.

RMF Variants: A number of regional risk management tools were obtained and key features of them are cataloged in Table 1. In some cases variants were developed for common activities for which the regulatory approach could be standardized and applied repeatedly. Many of the examples are not well documented or are intended for internal use so the entries in Table 1 are generalized to allow the development of common themes. Those themes are described in the following sections.

Changes to Scale of Negative Effects axis (Vertical axis of the RMF): In a number of cases the assessment of project impacts using the attributes and the L/M/H scale has been replaced by a ranking of project type itself. The BC large lakes, Manitoba drains and Alberta pipeline crossing schemes take this approach. In these cases the magnitude of the project's effects are sufficiently well understood and relatively consistent from site to site so that analysts were able to rank projects according to their impact. An assessment of the actual impacts may not be needed if the range of management actions can be deployed across the project types such that the outcomes are deemed satisfactory.

There were no examples where the scale of negative effects was quantified in terms of a loss of productive capacity, fish abundance or production.

Modifications of the Sensitivity of Fish and Fish Habitat axis (Horizontal axis of the RMF): This axis is used to characterize the type of fish or habitat that may be impacted, or the sensitivity of those habitats to impacts. In many of the regional processes a direct habitat classification scheme was used based on fish use, sometimes modified by habitat attributes. Fish species were usually prioritized and range from single target species (e.g., salmon), groups (salmonids), or uses (all fish species that are part of fisheries). Other categories include those for forage fish, or non-target species. In some cases habitats were classified by their attributes, usually on the basis of physical complexity (channel form, cover, bed grain size) on the assumption that more complex habitats were more likely to be important or productive. In some schemes previous history of development or alteration resulted in a downgrading of the habitat ranking. Watercourse classification was conducted by direct fish sampling, habitat survey, or GIS analysis, based on spatial data.

There was considerable variation in the "grain size" of categories among regions and schemes. For example, for rivers in Alberta there are 4 categories that assessed streams could be placed in. At the other extreme, the BC Lakes tool classifies shorelines of individual lakes into one of 7 categories based on fish use or physical attributes. All of these classes would probably fit within one or 2 categories of the broader schemes.

Ranking procedures based on scoring of a suite of attributes for fish and fish habitat conditions were used by the BC large lakes and Mackenzie River tools. In these cases constructed scales for different attributes of the fish or habitat were devised and each habitat unit was rated on the basis of those attributes. Attribute scores were added or multiplied together for an aggregate score, and cut-offs were set to bin the scores into categories along an L/M/H or similar scale. In general, the fish habitat classification schemes in the regional tools were simpler, and more directly linked to fish use, than the list of attributes (sensitivity, dependence, rarity, resiliency) proposed in the RMF *Practitioners Guide*.

Risk ratings and management actions: the goal of the risk analysis and decision support tools is to assist decision making by providing a structured and consistent approach to reaching a regulatory decision (DFO undated).

A risk matrix most similar to the RMF was used by the Mackenzie River risk assessment tool to categorize the 167 stream crossings with respect to relative risk. The purpose of this ranking was for the allocation of regulatory and environmental effort but no details on that effort is supplied in the preliminary documentation of the tool.

In other cases a regulatory "grid" or table was used instead of the matrix. The two dimensions of the table are the type of activity, and the type of habitat being affected. Table entries are regulatory responses for each activity*habitat combination. The regulatory approaches are generally similar to the 4 classes identified earlier for the RMF. In the case of the BC large lakes tool, the risk grid has entries based on a VH/H/M/L scheme, but a regulatory approach is explicitly linked to each risk rating in the documentation.

In the most prescriptive approaches the mitigation measures for each activity are linked to the habitat classifications. For example, for the Yukon Placer Authorization, there are suspended sediment and riparian disturbance standards for placer mining operations that vary depending on the stream classification. Similarly, the Alberta stream crossing code of practise specifies the preferred methodologies for stream pipeline crossings as a function of stream type. In these cases the nature of the impacts of the activities is well known and the degree of protection (or risk tolerance) is conditional on the value of the affected habitats to fish or fisheries production.

An alternative approach using a decision key: Québec Region has developed a decision key approach to sort projects into L/M/H risk categories. The first Low-Medium Risk bifurcation is based on an assessment of the project against 10 criteria; if the project meets one or more of those criteria it is elevated from a Low to M/H risk categories. The 10 criteria are a mixture of habitat or species-based considerations, and as well as those associated with project impacts. A similar but less specific set of criteria are described to be used to determine if a project would be ranked as Medium or High if it was elevated from the Low category by the initial screening. Again, these criteria are a combination of the extent and intensity of project impacts, the habitats exposed, and uncertainty surrounding impacts and mitigation measures.

KEY MESSAGES FROM THE REVIEW OF REGIONAL RMF TOOLS

A few generalizations are possible from the review of regional RMF tools. First, the sensitivity of fish and fish habitat axis is often replaced with regional fish and habitat priorities. The suggested attributes for the sensitivity axes in the *Practitioners guide* are difficult to quantify, and more difficult to combine into a L/M/H score. Consequently, for many regional tools the axes is replaced with a hierarchy of fish habitat types based on locally important species and the habitat they use, and other local values.

Direct estimates of the scope of the residual effect are not commonly made. For situations with routine, repetitive projects, no attempt is made to estimate the impact on habitat using the “scale of negative effect” axis and the attributes identified in the *guide*. Rather project types, mitigative measures or regulatory actions are ranked and aligned with the scale of negative effects axis. It is likely that this alignment was achieved as part of interactions with proponents or associations, the risk tolerance of the parties, and professional judgment regarding the significance of the impacts.

Subjective risk ratings (i.e., L/M/H) vary among tools and regions as there is no standardized description of these categories. Many applications use information on the activity type and habitats exposed to generate the L/M/H-type risk rating. A cursory examination of these ratings suggests considerable variation among tools in the likely level of impact on fisheries productivity for each risk category. Unless the risk categories are anchored on a scale of impact to fisheries, they may be influenced by the risk preferences of the parties that created the tools. Risk ratings are largely meaningless if they are defined by the regulatory response (the risk management step) rather than the actual effects on fish or fish habitat.

OTHER RISK ASSESSMENT/MANAGEMENT FRAMEWORKS

In recent years there has been a proliferation of “risk assessment” tools across a wide range of natural resource applications both within DFO and other organizations. Most are designed to evaluate relative risks of threats or stressors to some component of the environment that may be of use to managers in the allocation of resources, mitigation measures or other actions. These tools have a definition of risk deemed appropriate for the situation, and usually have a scoring scheme to yield a risk rating or risk score. If risk is defined by two major dimensions (e.g., probability and consequence) then the scores can be displayed in a risk matrix or heat diagram similar to the RMF. When there are more than 2 dimensions an overall risk score is computed by an algorithm that might involve the addition and/or multiplication of scores. Often the major attributes or dimensions are the result of scoring on a number of sub-attributes, all of which need to be combined to generate the overall rating.

These scoring approaches are also popular in business and informatics applications, and have been criticized on a number of grounds (Hubbard 2009, Cox 2009). First, the scores are usually unitless and ambiguous, and the risk ratings that result from these approaches are equally difficult to quantify or explain outside the specific frame in which they were developed. In some cases quantitative information is reduced or collapsed to scores (e.g., 1-4, or L/M/H), causing a loss of information in the process (e.g., Faber-Langendoen 2009). The second major criticism is the way that scores are aggregated or combined to produce risk ratings. There is little consistency in the approaches used, nor any testing against known outcomes. Combined scores usually cluster near the average due to both scoring bias and as a result of averaging poorly estimated scores. Other schemes are biased by the use of the worst case individual rating to characterize the aggregate. Cox (2008) shows that some algorithms can produce inconsistent and sometimes very biased results. Critics of scoring schemes generally promote fully quantitative methods as an alternative noting that properly structured expert assessment of probabilities and impacts are preferable to qualitative ratings (Hubbard 2010). At a minimum, quantitative analyses should be used to evaluate the utility of scoring schemes to ensure they are robust.

Some of these issues may not be critical if the goal of the risk assessment tool is to organize and summarize general information about the relative importance of stressors or threats and to rank them relative to each other. Because many of the ratings are based on expert elicitation, the effort required to complete an assessment is relatively low. However, the shortcomings of qualitative approaches can become critical when the outputs are used to make management decision that could have significant economic and ecological consequences.

A variety of screening tools have been developed for the assessment of potentially invasive species (Mandrak et al. 2014) and these provide a useful contrasting example. Invasive species screening tools differ from the general risk ranking tools as they are designed to inform specific management decisions regarding the importation of certain species. A variety of techniques have been used to assess risk, from 2-dimension risk matrices based on expert opinion, questionnaires, decision flow charts, and empirically-based statistical methods. Here risk is the potential for a given species to become a harmful invader. A distinction of the invasive species tools is that there are (unfortunately) datasets of invasive and non-invasive species that facilitate model development and testing. Thus the error rates of classification of potential invaders can be assessed prior to their widespread use (Mandrak et al. 2014). Many of the decision tools have been demonstrated to have reasonably high discriminatory ability despite being relatively simple in structure (e.g. Keller et al. 2007).

Concluding points: Most risk assessment tools currently being used in other sectors are designed for broad-scale relative risk ranking, rather than decision making on specific issues. Their qualitative nature precludes comparisons across sectors or disciplines and makes them difficult to use when other factors (costs, lost opportunities etc.) are part of the trade-offs that are invariably involved.

Tools that have the greatest relevance to FPP decision needs are those designed to make site-specific regulatory decisions, such as the AIS screening methods noted above. Features of these could be examined in greater detail in future work. The ability to test proposed algorithms with case history information is an important advancement in the development and adoption of these tools, and a similar step could be taken for the development of FPP tools if a database sufficiently monitored projects was assembled to allow an assessment of outcomes relative to the regulatory tool that was used.

A DECISION-BASED PERSPECTIVE

Gregory et al. (2006) suggest resource managers are largely trained and work in a “study culture” such that when faced with a new problem, the initial reaction is to collect additional information in the hope the problem can be resolved. They suggest problems become more tractable in a “decision culture” where the decision being reached is the entry point to the analysis. There are 3 pillars of the decision culture- the objectives, the alternatives, and the consequences. In this section we analyze the FPP decision framework from the perspective of the decision.

The primary focus of this report is the decision regarding the evaluation of initial regulatory triage within the FPP decision framework. Although the decision is most easily considered in terms of impacts to fish and fish habitat, these are not the only factors that are affected by the decision. To assist in developing the framework, and guidelines or thresholds it is worth exploring these factors further. At a minimum there are three “entities” that are affected by the decision framework:

1. societal expectation for environmental protection,
2. DFO,
3. project proponent.

Each entity has or is associated with different objectives and values. Thus the consequences of a decision can be measured as effects on each party’s relevant values. The following are example for discussion only and should be refined by a deliberative process (Gregory et al. 2006):

1. Environmental protection: The goal of the FPP provisions is maintaining the ongoing productivity of CRA fisheries. This is a biologically-based value that will be expressed in a change in fisheries productivity or a proxy (e.g., fish abundance, habitat quantity) caused by a project’s residual impacts (Randall et al. 2013).
2. DFO: The efficient use of DFO’s regulatory resources. Decisions that cause DFO to use extensive resources for regulatory review may result in trade-offs with other aspects of its activities, creating risk with respect to achieving its overall policies or strategic goals.
3. Proponent: Efficient environmental management. Inappropriate or excessive regulatory burden will cause expense and time; insufficient measures for environmental protection may pose a legal risk, or diminish the social license or mandate to operate.

The key uncertainties that affect decision making are:

1. Lack of knowledge or inability to predict residual impacts on fisheries productivity.
2. Natural variation that causes impacts to vary from place to place or in time.
3. Implementation uncertainty cause by proponents not meeting expectations for best practices, engineering requirements or mitigative measures, or unplanned events during construction and operation that cause impacts on fish and fish habitat to be different than forecast by the initial assessment.

The “alternatives” are the different management responses to be considered and are defined by FPPs decision framework. The consequences are the potential impact of the management response to the 3 entities, given the uncertainties listed above.

Analyzing the problem from a decision perspective in the context of objectives, alternatives and consequences can change the way the information required, process and decision points are viewed and is likely a more efficient way to developing a framework. Further development of a decision framework should include a decision-focussed analysis along these lines.

ATTRIBUTES OF A FRAMEWORK FOR DECISION MAKING

The review and analysis of the preceding sections and supporting information suggests principles that can guide the development of the framework.

1. The Policy Statement states “Proponents are responsible for avoiding and mitigating serious harm to fish” (DFO 2013a). Irrespective of the regulatory pathway used as a consequence of the decision framework, goal of minimizing impacts to fish and fish habitat by using avoidance and mitigation strategies that are “practically and technically and economically feasible” will be fundamental in the design of all projects (DFO 2013a p.14).
2. The review of existing frameworks reveals that in the past risk was defined in terms of both the impacts to fish and fish habitat, and the relative value or importance of the fish or habitats that are affected. We conclude there is merit in a framework that results in greater regulatory engagement for projects that impact key habitats and fish species, and that have larger impacts.
3. Thus two major attributes will be needed for a decision within the framework:
    (i) The nature of the impact of the project on fish and fish habitat. Impact is assessed by temporal and spatial scales and intensity (including mortality).
    (ii) The type of habitat or species that will be exposed to the project’s residual impacts. Some form of classification scheme utilizing habitats and potentially species could be used to reflect regional priorities.
4. Other management objectives can be incorporated into the decision framework, and these can extend the attributes of #3. Examples include the background condition or state of the ecosystem where the project is situated, and risks associated with the implementation of the project or its mitigative measures.
5. The objective of the decision tool is to direct DFO’s regulatory efforts to situations where there is a legal requirement and to cases where policy objectives may not be achieved without oversight or regulatory tools. This can likely be achieved without precise estimates of project impacts or the magnitude of serious harm, because the consequences of misclassifying a project on impacts to fish and fish habitat may not be significant. Some level of quantification will be required for consistent and transparent decision making. More precise estimates of impacts are likely to be needed if the project proceeds to the “request for Authorization” pathway and a process is developed for calculating offset requirements based on the magnitude of project impacts.
6. To understand the implications of regulatory decisions and to compare decisions across project types we propose project impacts be quantified in terms of metrics relevant to fisheries productivity. We introduce the use of “Equivalent adults” as one potential metric. We use existing life tables, inventory information and other sources to convert losses in habitat or mortality to their approximate equivalent in terms of adult fish (that would be available for human use) as abundance or biomass. This analysis will inform the development of thresholds in the decision framework. Explicit quantification increases the transparency and consistency of decisions by reducing some of the shortcomings of subjective decision making.

CONSIDERATIONS FOR A DECISION FRAMEWORK

A framework or tool for the initial evaluation of project proposals must respect the parameters set out by the *Fisheries Act*, and incorporate additional values or considerations required to satisfy additional objectives as indicated in the previous section. To meet this requirement we propose a 2-step process with the first step based on the analysis of the potential for serious harm to occur; the second step allows for incorporation of other factors when choosing a regulatory pathway for a project proposal. This approach enhances the transparency and defensibility of decisions as the requirements to satisfy the legal elements are distinguished from those that reflect regional or other priorities or considerations.

Step 1: Section 35(1) and the definition of serious harm to fish specify that the death of fish or the destruction or alteration of fish habitat that support CRA fish will constitute serious harm. There is no apparent discretion for consideration of the type of fish, habitat or antecedent conditions although we infer that those changes to habitat are of a nature that a reduction in fisheries productivity is likely.

The FPP policy statement states that projects likely to cause a localized effect on fish and fish habitat may require an authorization (DFO 2013a). These requirements mean that the assessment of a project's residual effects should be based on the prediction or calculation of the project's residual impacts on fisheries productivity as measured by changes in habitat or the mortality of fish. To standardize the evaluation of localized effects across project types we propose methods that translate project impacts into either adult fish, production or biomass that would be foregone (*sensu* Rago 1984) as a result of the project's residual effects.

Project impacts are described by 4 attributes and the calculus is described in the following sections. The 4 attributes are the temporal scale, spatial scale and intensity of habitat impacts, and the death of fish. We propose that the Department develop regional datasets and methodologies to assist in the evaluation of these attributes. The calculations could be enhanced if site-specific information was available.

The outputs of these calculations are to be used in to determine the magnitude of the impact of the project on the productivity of affected CRA species. The output of this process is passed to Step 2 for the determination of the management response.

Step 2: There is a suite of options available as a management response to the results of Step 1. We propose "risk management factors" that may be considered at this stage in determining the management response. Those factors may reflect regional priorities for habitats or species, the background or antecedent condition of the habitat or ecosystem that the project is located in. Consideration could also be given to the complexity of the project and mitigation measures if there is potential for a greater impact on fish and fish habitat if there is a risk of a failure of the project's design or mitigation measures.

As a preliminary example of the use of the risk management factors we identify 3 example regulatory pathways in step 2 of the process. These are identified as lettered boxes in Figure 2:

(a) Projects that have small impacts and are simple in nature and are in locations such that the risks to fisheries productivity are considered minor. No additional risk management factors are invoked.

(b) Projects that may have a small impact if they are successfully implemented, but a combination of the habitat and species impacted and the potential for an implementation failure creates a risk that warrants a greater regulatory response.

(c) Projects that have residual effects that cause a localized effect such that an application for Authorization under s(35) is required. In this case most of the likely risk management factors will be incorporated into the s(6) considerations in the application for authorization process and will not be considered further here.

Other categories for the management response are possible and can be added to the suite identified.

EVALUATING RESIDUAL EFFECTS

In the following sections we describe a process for estimating the magnitude of residual effects on fish and fish habitat on the basis of impacts to fish abundance, biomass or production. This information is required in step 1 of the proposed decision framework. This analysis will consider the 4 attributes: spatial and temporal scale, intensity, and mortality and the results will be used when considering the potential for serious harm.

EQUIVALENT ADULTS

The goal of the FPP is to provide for the sustainability and ongoing productivity of CRA fisheries. It is a natural extension of this goal to view impacts of projects on fish and fish habitat in terms of their effects on fisheries productivity (See DFO 2013b; Randall et al. 2013). Since fisheries generally occur on the adult stages, that stage can serve as a common metric for considering the effect of a large suite of development projects with varying types of impacts. Having a common currency can assist in the development of regulatory thresholds that are consistent across activity types. Converting ecosystem damages to a common life stage of key species is also central to some applications of the Habitat Equivalency Analysis (HEA; Allen et al. 2005) that can be used to calculate offset requirements (Clarke and Bradford 2014).

The simplest method to convert impacts on habitat or a diversity of life stages of fish to a common metric is the equivalent adult approach, first introduced by Horst (1977) for the analysis of power plant entrainment impacts. Equivalent adults are calculated as the product of the number of fish killed in the larval or juvenile stage and the average survival rate from larval to adult stages. This approach can be elaborated to account for lost biomass, production, or loss of reproductive potential (Boreman 1997). French McCay et al. (2003) provide an example of the use of a population model to evaluate losses and equivalent restoration options.

A life table can be used to assist the calculation of adult equivalency. A life table summarizes a population’s mortality (death) and natality (birth) schedule. Here we will follow the form and structure described by Power (2007), where:

x = age

s_x = annual survival of individuals of age-x

l_x = proportion of individuals surviving from age-0 to age-x (survivorship)

b_x = number of female offspring produced by a female at age-x

C_x = proportion of individuals in age class x

r = intrinsic rate of population increase

λ = population growth rate = e^{-r}

R_0 = net reproductive rate

G = generation time

If the survival and birth schedules are known (or estimated) then the Euler-Lotka equation can be used to solve for *r*:

$$1 = \sum_{x=0}^{\infty} e^{-rx} l_x b_x$$

The proportion of the population in any age-class (C_x) can be calculated as:

$$C_x = \frac{\lambda^{-x} l_x}{\sum_{i=0}^{\infty} \lambda^{-i} l_i}$$

An example is provided in Table 2 for a population of Black Redhorse (*Moxostoma duquesnei*) at equilibrium with a stage distribution of 99.85% young of the year (YOY), 0.11% juveniles (ages 1-3), and 0.03% adults (ages 4-10). This stage distribution can be used to calculate the number of YOY or juveniles per adult, which in this case are 3,328 (= 99.85/0.03) and 3.76 (= 0.11/0.03) respectively. These values can be used to directly quantify the effects on fisheries productivity for a project that causes mortality.

For projects that impact habitat empirical information on typical densities or area per individual calculations can then be used to estimate the habitat required to support larval or juvenile fish, thus provided the means to convert habitat losses to equivalent adult fish.

For anadromous species, habitat impacts often occur in juvenile rearing areas and a similar but simpler calculation can be used to estimate the loss of adult production from a reduction in juvenile habitat supply. For coho salmon, populations are sustainable when the smolt-adult survival rate is about 3%; 33 smolts are needed to yield one adult fish (Bradford et al. 2000). Coho streams typically produce about 1500 smolts/km of stream, inferring that one adult is produced for each 22 m of stream (corresponding to about 100 m^2 for a typical stream; Bradford et al. 1997).

Equivalent adult appoaches can also be used to standardize impacts across species through a food web. While the prohibition against serious harm includes fish that support CRA fisheries, impacts to prey can be converted into equivalent adults of a fishery species by assuming a trophic transfer efficiency. It is common to assume 10% transfer efficiency per trophic level when considering the productivity of fishes and fisheries (e.g. Pauly & Christensen 1995, McGarvey et al. 2010). A simple calculation for the equivalent number of a fishery species per individual of a prey species is:

$$N_F = W_F / (W_p \varepsilon)$$

where N_F is the equivalent number of the fishery species, W_F and W_P is the weight of an individual of the fishery or prey species respectively, and ε is the trophic transfer efficiency (often assumed to be 10%). For example, a 1 g prey fish predated by a 1 kg (1000 g) fishery species would have a 10,000:1 equivalency.

Although these calculations involve many simplifying assumptions they illustrate the potential of the method to generate an approximate estimate of the loss of production from projects that alter habitat. Additional assumptions or alternative approaches will be needed to calculate losses from more complex situations such as migratory corridors, food production areas and riparian alterations.

ATTRIBUTES FOR ASSESSING IMPACT

TEMPORAL SCALE

Increased regulatory measures are likely to be needed when the duration (along with the spatial scale and intensity) of a project's impacts are sufficient to diminish the ability of fish in the project vicinity to carry out one or more of their life processes (DFO 2013a, section 8.2). The assessment of temporal scale can proceed by a series of test questions to determine if the project satisfies criteria implied by the policy statement. These criteria are ranked in decreasing duration:

1. Is the alteration physically permanent? (e.g., hard structure, maintained riparian removal) or is it reversible or transient?
2. Is the impact repeated with sufficient frequency such that the effect should be considered cumulatively, rather than single sporadic events?
3. Is the duration longer than a life stage of CRA fish in the local area? (e.g., lasting many months or years)
4. If the duration is shorter than (3), is the timing is coincident with that of life processes of CRA fish? (e.g., noise production during spawning).
5. Is the duration of the impact sufficient to cause a meaningful impact on a life processes above that fish may experience as a result of natural variation in environmental conditions. (e.g., a flow change or sediment pulse).

Listing the criteria sequentially results in an increasingly precise test of this attribute's potential to contribute to an impact on fisheries productivity. Criteria 3 and 4 impacts may be mitigated through the use of timing windows.

The magnitude of residual impact from a project will, in part, be determined by the duration of the impact relative to the life process(es) being affected. For fishes, many physiological and life history traits are related to body size. Larger fishes tend to exhibit life history traits with slower rates or longer durations including: slower growth, longer juvenile stages (i.e., later age at maturity), longer adult lifespans, and longer generation times. Physiological traits vary among and within species with body size, so that larger species and individuals tend to exhibit faster swimming speeds, higher metabolic rates with greater oxygen demands and lower tolerance of anoxic conditions, greater energy reserves and lower specific metabolic rates allowing longer survival times to starvation. Table 3 provides a sample of allometric relationships that demonstrate the known influence of body size on various physiological and life history traits.

Coker et al. (2001) compiled information about the life history traits of freshwater fishes in Canada. Using these data and allometric relationships, a distribution of the duration of some life processes can be obtained. Most freshwater fishes in Canada mature before age 3 (i.e. duration of the juvenile stage is less than 3 years) and have an adult lifespan (i.e. maximum age minus age at maturity) less than 5 years. The longest-lived fishes (representing 25% of all species) do not mature before 5 years of age and have an adult lifespan at least 10 years long. Using weight at maturity available from Coker et al. (2001; a subset of 20 fishes) along with the time to starvation allometry, 25% of this subset can survive starvation times in excess of nine months and 25% have times to starvation less than 2 months. Average starvation survival times for a 0.1 g fish is up to one month, 2 months for a 1 g fish, and 3 months for a 10 g fish. While body size can provide an indication of when an alteration (in this case restricted access to food) becomes permanent (fish die), there will be sub-lethal effects over shorter time frames.

The magnitude of an impact will be influenced by the scale of the impact as well as its duration. Population modelling of species at risk (e.g., Young and Koops 2013) has demonstrated that the level of allowable harm will depend on whether that harm is chronic (permanent) or transient. A single perturbation can be of larger magnitude of effect than a permanent perturbation. In general, we can expect that if a threshold were identified (e.g., an acceptable decline in abundance, productivity, etc.), that duration and scale of impact would be negatively related (Fig. 3). That is, we can expect that as the scale of effect increases, the tolerable duration of the impact will decrease exponentially.

Overall, smaller-bodied fishes will exhibit shorter life-stages (e.g., juvenile or adult stages) and faster rates (e.g., growth) suggesting that smaller-bodied fishes will experience a greater consequence from a residual impact of a given duration.

Information on the temporal scale canbe combined with that of the other attributes (see below) for the overall assessment of the project type on fisheries productivity.

SPATIAL SCALE

The FPP policy statement states that projects that will require authorization are those that are likely to cause a “localized effect” on a fish population (DFO 2013a). This suggests the spatial scale of project effects should be assessed not only for the project’s footprint but also include larger, diffuse impacts that may occur. The **destruction** of habitat results in the complete loss of habitat for fisheries productivity (i.e., infills), while a **permanent alteration** will cause a diminishment of that habitat’s capability to provide for the life processes of fish in that areas. These categories (destruction, alteration) are analogous to the changes in habitat quantity and quality classification scheme developed in Randall et al. (2013).

Change in habitat quantity (destruction)

The first stage for assessing residual impacts of projects involving infill or isolation is to record the area being lost (m^2 or ha), along with specific attributes of the habitat. Information on ecosystem and fishing area, target species (CRA fisheries), habitat requirements, fishery objectives, habitat threats, body size, and site specific mesohabitat-scale characteristics (depth, substrate, structure and riparian attributes) are likely to be required. This information is needed to assess the quantity (and quality) of habitat being lost in order to evaluate its potential for fisheries production.

Change in habitat quality (alteration)

Again, the spatial scale of project effects will be assessed using area. For project types that cause a physical change in habitat quality (e.g., structure simplification, shoreline modification) the project plan can be used to define the impact area. For projects that cause diffuse changes in habitat quality (ie, changes in sediment, temperature, noise, flow) some judgement will be needed to bound the project’s impact area to that where the changes are likely to have impact on fisheries productivity. If the change in conditions is below defined thresholds for impacts (such as flow; DFO 2013c), spatial boundaries for the impacted area are not critical to the assessment.

INTENSITY

Intensity refers to the magnitude of the residual effect to fish habitat that occurs within the temporal and spatial bounds defined earlier. Intensity in relation to mortality is dealt with separately in a later section. Intensity can be defined as the proportional reduction in the capability of the habitat to contribute to fisheries production through project effects on one more life processes. This is similar to the concept of “service loss” used in HEA analysis (Penn and

Tomasi 2002). Service loss evaluates the relative loss of function of an ecosystem that has been damaged. Service loss estimates are often semi-quantitative, and are expressed as a proportion of the baseline or undamaged services. For example, in an analysis of oil spill damages, Penn and Tomasi (2002) used 4 categories (10, 40, 75, 100% loss) to calculate total damages. Here we introduce a parameter I, that we call an impact factor that will be used in a manner analogous to service loss coefficients as a proxy for the loss of production associated with a habitat alteration.

Change in habitat quantity (destruction)

Projects that cause the destruction of fish habitat either by infilling, blocking access, or rendering it otherwise unusable have an impact factor of 1.0 as all potential for fisheries productivity is lost. For assessing impact, the number of potentially vulnerable fish for the project area is calculated as the product of the area and the number of fish per square metres (density). Fish density is dependent on the ecosystem, regional productivity, body size and detailed mesohabitat scale attributes. Fish density for the area can be estimated in one of three ways:

1. Regional estimates of habitat carrying capacity (Bradford et al. 1997; Cote et al. 2011; Randall et al. 2013);
2. Empirical relationships that relate fish abundance to habitat area, often species specific (e.g., Table 4 of Bradford et al. 2013)
3. Literature values of density as a function of body size for either salmonids (for which much information is available) or fishes in general (Table 4).

If an inventory of mesohabitats is available, then habitat suitability indices and a relative weighted suitable area could be generated for the project area using science-based habitat models (e.g., Habitat Alteration and Assessment Tool (HAAT) or equivalent; Minns et al. 2011). If regional benchmarks of habitat capacity (expected numbers or biomass of fish that the habitat can support) are also known, the absolute numbers of fish of target species can then be predicted based on the habitat supply and suitability for different life stages in the project area (Randall et al. 2013).

When multiple CRA species are present, similar calculations could be made for each individual species, or simple models that predict community biomass or abundance for the project area could be employed, and then apportioned by species.

Equivalent adults for infill area:

Equivalent adult methods may be required when the habitats being affected by the project are those used by egg, larvae or juvenile stages, or are habitats that contribute resources to support fisheries productivity. Calculation of equivalent adults depends on the CRA fishes inhabiting the project area. For anadromous salmonids, the number of adult equivalents potentially lost could be calculated from the density of eggs or juveniles (including smolts) using life stage tables. For CRA species that inhabit and mature in the area (or vicinity) being impacted, size at maturity would be known, or could be obtained from FishBase. Area per individual, density and the number of adult equivalents for the project area could then be calculated based on the body size of the adults.

Productivity:

In addition to using adults as the currency for determining magnitude of impact, production, productivity, or biomass surrogates are also useful. Rago (1984) correctly pointed out that production is more relevant for population bioassessment than numbers lost because it includes consideration of the energy potentially transferable to other trophic levels and thus to ecosystem processes. The numbers of fish by equivalent adult methods could readily be expressed as biomass (including regional benchmarks), and fish production could be estimated from biomass and literature P/B ratios (Randall and Minns 2000; Randall et al. 2013). P/B ratios are inversely and predictably related to fish body size, both within and between populations.

Change in habitat quality (permanent alteration)

Permanent alterations have the potential to reduce fisheries productivity and thus have an impact factor, I, such that $0 \leq I < 1.0$ for habitats effected by the project. The relation between some alterations and productivity is non-linear and may have thresholds or inflection points below which the stressor is unikely to have any change on productivity (Koops et al. 2013). For example, a flow reduction of <10% of the natural flow is considered unlikely to cause an impact on fisheries productivity (DFO 2013c); in this case $I \approx 0$, and no further consideration is needed. For the other productivity-state relations of DFO (2014a) more detailed review and analysis may be required to develop a suite of threshold values for common stressors that can be used to evaluate project impacts.

For situations where thresholds cannot be readily defined, or known thresholds are exceeded, impact factors can be developed to pro-rate losses in productivity. In many cases it may be adequate to use broad bins or categories for I, rather than seeking precise values. For example, a 3-category scheme could use the ranges like 0-0.3, 0.3-0.7 and 0.7-1.0. Reviews of existing information and expert experience could be used to classify typical project impacts into one of these categories. The categorization of impacts and the requirement for precision of impact scores will depend on the decision context, and in particular the determination of thresholds for serious harm. Some iteration will likely be needed using test-case examples to determine the minimum level of precision that will result in satisfactory outcomes.

The mid-points of the bin ranges are then used as scalars to pro-rate potential fisheries productivity that would remain. Estimates of potential productivity detailed above are multiplied by I to estimate the loss of productivity or abundance, or $1-I$ to estimate the remaining productivity.

MORTALITY

Impact from mortality events will depend on both the magnitude and frequency of the mortality events. The tolerable magnitude and frequency will be inversely related such that rare events can be much larger (potentially catastrophic, e.g. Reed et al. 2003, Vélez-Espino & Koops 2012) because they are infrequent and populations have the potential to recover. As the frequency increases, the tolerable magnitude is expected to decline exponentially (Fig. 3).

Mortality rates are commonly related to body size (e.g., Pauly 1980, Peterson & Wroblewski 1984, Lorenzen 1996, McGurk 1999; see Kenchington 2013 for a review of mortality estimators) with larger-bodied fishes experiencing lower mortality rates than smaller-bodied fishes. Within species, smaller size-classes also experience higher mortality rates, and mortality is expected to decline as fish get larger (e.g. Lorenzen 2000). Other population level rates that are related to body size include production, P/B, and maximum population growth rate (Table 5).

Pope et al. (2006) used a size-based model to examine how sensitive fishes of different sizes were to fishing mortality. Their results indicate that large-bodied fishes are more sensitive to fishing mortality because these mortality increases represent a greater proportion of their natural mortality rates (Jennings & Reynolds 2007). Others have demonstrated that larger-bodied fishes are less able to withstand mortality than smaller-bodied fishes (e.g. Jennings et al. 1998). For North American freshwater fishes, Vélez-Espino et al. (2006) found that longer-lived fishes (which tend to be larger-bodied) exhibited greater sensitivity to changes in adult survival.

Consideration of a brook trout population (Table 6) indicates a stage distribution for this population of 94.7% YOY, 3.7% juveniles, and 1.6% adults. The YOY and juvenile stages have an equivalent adult ratio of 59.73 and 2.34, respectively. Thus, a mortality event that killed 10,000 YOY brook trout would be equivalent to 167.4 adults.

Overall, large-bodied fishes will be more sensitive to additional sources of mortality that reduce survival rates. Furthermore, a mortality event that kills a certain number of individuals will represent a proportionally larger mortality event for large-bodied fishes than small-bodied fishes. Thus, large-bodied fishes will experience a greater consequence from a residual impact of a given mortality event.

These observations that are grounded in population dynamics and life history theory are generally consistent with the predictions of using a simple equivalent adult approach to the assessment of losses from direct mortality. More analysis comparing the two approaches is needed to ensure that the equivalent adult approach and the accounting framework proposed here using discount rates is generally consistent with results from detailed population models, at least for the purposes of the managing different forms and rate of mortality on fisheries productivity.

RISK MANAGEMENT FACTORS

In the proposed decision framework we consider the evaluation of project residual impacts will be largely based on a biophysical analysis that takes into account the biology of the fish and habitats and the nature of the impacts. Other factors that could be important in the decision process are reserved for the “risk management” step; these could influence the management response and regulatory pathway chosen. The application of risk management factors should be guided by the analysis of the decision context as outlined in the earlier section to ensure the measures being included meet legal requirement, policy goals and meet the objectives of the three entities as outlined in that section.

HABITAT OR SPECIES AFFECTED

In the review of regional tools we observed that there is a general pattern that the extent of regulatory review or regional oversight is in proportion to the importance of the species or habitats that are potentially impacted. In most cases some form of habitat or species classification was employed to assist in the allocation of regulatory effort.

If it is decided that a species-based approach it to be used, then a hierarchy of species (either individual, or in taxonomic or functional groups) can be employed in the decision framework. The ranking of the species may be based on stakeholder or agency preferences, or fisheries management objectives.

Alternatively, greater weight could be put on habitat types affected. The guiding principle is importance or significance of the habitat type in the project area to the fisheries productivity potential of the local area. Consideration may be given to the sensitivity of the habitat (in terms of its potential for fisheries productivity) to perturbations. Under this approach some of the attributes used in the Practitioners Guide for the RMF (e.g., species dependence on the habitat, rarity relative to species needs, resilience) may be appropriate.

As the number of regulatory choices in the decision framework are few, the number of categories needed for this attribute are likely small, probably in the range of 3-5 habitat types or species groups within a region. Most of the schemes used in Table 1 had 5 categories for the fish/habitat attribute. Existing regional or provincial classifications may prove useful as-is or with slight modifications to meet FPP needs.

Using EBSA tools

For Canada's marine ecosystems, the identification of Ecologically and Biologically Significant Areas (EBSA) is based on knowledge of the properties of a particular area, and a process-based understanding of these properties in terms of ecosystem function and structure (DFO 2004). Some EBSA criteria may have utility for FPP application. Specific criteria to aid the assessment of each of the EBSA properties have five dimensions: uniqueness, aggregation, fitness consequences, resilience and naturalness (Table 7); all are briefly described below. Marine ecosystems are often large, but these properties and criteria could be useful for rating fish habitat (determining relative suitability) at localized sites in freshwater ecosystems as well.

Ecological functions of fish habitat (properties and row labels of Table 7) are to sustain or enhance the reproduction, growth and survival of fishes. Consistent with the definition of fish habitat in the *Fisheries Act*, the function of fish habitat is life-stage dependent; i.e., the habitat required for spawning, nursery, feeding, migration and seasonal refugia. The structural features of habitat can be physical structure (strong topography, oceanographic or limnological features, convergence zones), biological structure (eel grass, macrophytes, sponges) or, collectively, a combination of features that are strongly related to biodiversity (i.e., areas providing exceptionally high productivity and biodiversity). For a Fishery Protection decision framework, functional and structural habitat would be identified in the context of CRA fisheries and their habitat, or species and habitat that support or contribute to the productivity of CRA fisheries.

The five dimensions of the criteria (columns of Table 7) for evaluating the components of ecosystem structure and function are rated on a relative scale from high to low. Unique habitat is important fish habitat that does not occur or is rare elsewhere (e.g., only one suitable spawning or nursery area for a particular species). Aggregation (of fishes, prey or nutrients) refers to habitat that is used by a high percentage of a population, or by a large number of species, or by some ecological process which occurs at exceptionally high density. Fitness consequences refer to habitat areas where components of productivity (e.g., survivorship) are demonstrably enhanced compared to other areas, and that can be mechanistically linked to the habitat in that area. Resilience of habitat ranges from highly sensitive and easily perturbed, to habitat or species that are robust and resistant to anthropogenic activities. Naturalness is ranked from pristine areas used by native species to perturbed areas, sometimes inhabited by introduced species. Assessment of these five dimensions as criteria requires geographic knowledge of the fishing area, threats to fisheries productivity, and the fishery management objectives for the area (explicit or implicit).

Although by design the EBSA criteria apply at a large marine spatial scale, the descriptive language and structure can be adopted and scaled down for use at a localized spatial scale, to aid FPP regulation. The criteria would help guide the first order rating of fish habitat as a component of a decision framework designed to manage residual impacts.

PROJECT COMPLEXITY

Some projects may have small residual impacts if the works are successfully executed and the mitigations perform as expected but could have much large impacts may if there is a failure. For example, a stream crossing may have small impacts due to its footprint but if the crossing results in a blockage to fish passage due to improper construction, the effects could be much more significant. Regulatory measures to reduce these risks could be applied in Phase 2 of the regulatory scheme.

ANTECEDANT CONDITIONS

The abundance, state or condition of the habitat that the project is situated in may also be used in the risk management stage. Development of guidance for this stage is beyond the scope of this work.

COMBINING ATTRIBUTES WITHIN THE FRAMEWORK FOR DECISION MAKING

For an assessment of a project's residual impacts the attributes outlined in the previous sections need to be combined so that an estimate of the loss or fisheries productivity can be obtained. This section summarized a possible approach; the details differ for the type of project effects.

CHANGE IN HABITAT QUANTITY (DESTRUCTION)

For permanent losses of habitat the annual loss in fisheries productivity is the product of the area affected and the number, biomass or production that the habitat is predicted to support.

CHANGE IN HABITAT QUALITY (PERMANENT ALTERATION).

Permanent changes in habitat quality are evaluated in a 2-stage process. If the predicted change in habitat conditions is less than that identified to have an impact based on analysis of the productivity-state relation, then no effects on fisheries productivity are anticipated and no further analysis is required. This applies to those stressors for which a non-linear relation exists between productivity and the stressor.

If the residual effects are greater than the thresholds for impacts, annual fisheries productivity losses are calculated as the product of the area affected, the productivity potential of the habitat, and I, the impact factor that characterizes the intensity of the impact.

The temporal extent of the impact or stressor can be used to modify the impact factor. If the duration of an effect is such that fish may not be able to complete one of its life processes will have a much larger impact than an event that has a duration less than one of the life stages. Duration and intensity will interact to determine the overall impact factor I.

Mortality

Direct mortality to adult stages can be summarized as an annual loss of numbers, biomass or productivity. For impacts on younger stages, the equivalent adult approach can be used to estimate lost foregone adults, biomass or production. Mortality of prey fish may be considered directly as an impact to fish that support a CRA fishery or a trophic transfer efficiency can be used to estimate the equivalent loss of CRA fishery individuals.

THE TIME DIMENSION

Some projects may result in impacts that are truly permanent, while others may be of more limited duration. Some may occur immediately, while others may take some time to manifest themselves as the project is developed. If there is a desire to put all projects on a similar scale for the determination of serious harm or management responses the timing and duration of impacts should be incorporated into the assessment.

In habitat equivalency analysis and other resource valuation procedures a discount rate is applied to time-dependent effects or activities; discount rates put greater weight on more recent events than those distant into the future (e.g., Allen et al. 2005). The current-day value, *V*, of a single unit of a resource *t* years in the future is calculated as

$$V = (1+r)^{-t},$$

where r is the discount rate. Values of 0.03 are used in commonly used in HEA analysis. Using this discount rate the value of the permanent loss of habitat is valued at approximately 30 times the annual rate of loss. This value is obtained by summing over time the future diminishing value of a single unit of the resource (i.e., a fixed quantity of fish).

This approach is the most extreme simplification of long-term value of habitat or fish as it ignores the population dynamic perspective aspects habitat loss or fish mortality. That approach (using population models or analysis) will provide more biologically correct estimates of the short- and long-term implications of the effects of project impacts, but further investigation is needed to determine whether a fuller analysis will result in significant differences in the overall comparisons of impacts of differing durations for the decision framework being developed.

THRESHOLDS FOR DECSION MAKING

In the preceding methodologies for assessment we have attempted to define the effects of residual impacts in terms of metrics or proxies of fisheries productivity. For some impacts threshold for effects emerge from non-linear relations between the stressors and fisheries productivity. However, in many cases no obvious threshold emerges from the impact assessment, and the setting of thresholds will be policy-based. If policy guidance is based in terms of fisheries productivity, then the methods described in this report can be used to determine whether residual impacts are likely to exceed the thresholds.

DISCUSSION

In this document we outline a process for the assessment of the residual impacts of smaller development projects on fish and fish habitat. Our protocol estimates those effects as changes to fisheries productivity, either directly or using proxy metrics. We have attempted to strike a balance between simplicity (and the use of many simplifying assumptions), and sufficient structure and rigour such that the outputs contribute to a transparent and consistent decision process.

Estimates of lost productivity made using the protocols we described will be coarse, but we take the view that any attempt to quantify impacts is an improvement over qualitative or judgement-based approaches (see Hubbard 2010 for a similar call in business applications). Although our approach is much simpler than those suggested by Minns (2013) for the quantification of habitat alterations, we believe our methods will be sufficient for the particular task at hand, and provide a starting point for more detailed approaches that may be needed for the determination of offset requirements.

There is significant preparatory work required to operationalize our approach. Information needs include:

1. A defined list of regions and ecosystems is needed to structure spatial variation in fish communities and productivities at a national level.
2. Standards for estimating fish abundance, productivity and biomass are required, either from data compilations or predictive models for each region and ecosystem
3. Life table and other algorithms need to be developed (along with regional variants) for the equivalent adult approach.
4. Regional or national impact factors or service loss coefficients are required for estimating losses due to changes in habitat quality.

5. If the risk management factors are due to be used in assigning regulatory approaches, guidance on priority habitats, or species, or other considerations is needed.

If this information is assembled for a few regions or ecosystems, the approach can be trialled using some standardized projects. An iterative approach using inputs from the policy and legal sectors may be a useful approach for defining the thresholds needed for the full implementation of the decision framework.

The performance of the framework can be assessed using the approach developed in the “Decision Context” section, i.e., by analyzing the results of a proposed approach and thresholds in terms of consequences to the three sets of objectives implied by the decision context.

Some deliberation and experimentation will be needed to determine the approach to be used to deal with comparisons of permanent and shorter duration impacts. We have proposed the use of discount rates as is common in resource valuation, but other approaches could be used.

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Table 1. Summary of regional risk management tools, tabularized to identify the context, schemes for classifying habitats or fish species exposed, and the impact of development activities. The habitat/fish rating is analogous to the horizontal sensitivity of fish and fish habitat axis of DFOs risk management matrix (Figure 1), while the impact/activity rating usually substitutes for the vertical scale of negative effects axis. QP refers to qualified professionals and OS is operational statement.

Region	**Habitat**	**Activity**	**Habitat/Fish Rating**	**Habitat Categories**	**Impact/Activity Rating**	**Impact Categories**	**"Risk" ratings**	**Mgmt Decision**
Pacific	Interior large lakes	Recreational property development	Score based on fish use and physical features	6 categories Spawning-Vhi-VLow	Shoreline activities	Activities ranked by impact	VH-L	Regulatory pathway, compensation, use of QP linked to risk rating.
Pacific	Yukon streams/rivers	Gold placer mining	Suitability and use for chinook salmon	5	Mitigation measures based on habitat classification	Conditions for sediment input, riparian clearing, works in water etc.	None	Conditions of authorization based on habitat type
Gov't AB	Alberta streams/rivers	Pipeline crossings	Categories based on sport fish use, stream width	4 classes, streams > or < 5m in wetted width	Method of pipeline crossing	4 types of crossing differing in potential impact	None	Preferred construction method matched to habitat type. Use of OS for certain combinations
C&A	Manitoba streams and drains	Drain clearing	Fish use- Key species, forage, and not used. Habitat complexity subcategory	5 in total. 3 types based on fish, 2 on complexity	Based on area proposed for clearing/dredging	5 categories on logarithmic scale: 10^1 to 10^5 m^2 of wetted area to be maintained	Unclear	Regulatory response based on activity type and fish habitat classification
C&A	Mackenzie basin streams/rivers	Sediment inputs from pipeline crossings	Species composition and habitat use scores	5 categories of sensitivity	Geomorphological rating of sediment inputs	6 categories of likelihood of sediment input	7 categories, VL to VH	For allocation of effort among sites
Quebec	All	Any	Presence of Atlantic salmon, scarce habitats, spawning or aquatic vegetation, others	10 criteria used to determine if project is medium or high risk. 4-5 are habitat or fish based.	Criteria for medium and high risks based on project impacts.	5 project impact criteria	Initial triage for low vs. med/high risk	Determination of med/high risk based on a mixture of habitat characteristics and project impacts.

Table 2. A life table for the Black Redhorse (Moxostoma duquesnei) based on parameter estimates as reported by Vélez-Espino & Koops (2009).

x	s_x	l_x	b_x	l_xb_x	r = 0.009 $e^{-rx}l_xb_x$	λ = 1.01 $\lambda^{-x}l_x$	C_x
0	0.00058	1	0	0	0	1	0.9985
1	0.675	0.00058	0	0	0	0.000575	0.000574
2	0.5	0.000392	0	0	0	0.000385	0.000384
3	0.813	0.000196	0	0	0	0.000191	0.00019
4	0.622	0.000159	2,223	0.354	0.341	0.000154	0.000153
5	0.585	9.9 x10^{-5}	3,102	0.307	0.294	9.46 x10^{-5}	9.45 x10^{-5}
6	0.485	5.79 x10^{-5}	3,935	0.228	0.216	5.49 x10^{-5}	5.48 x10^{-5}
7	0.18	2.81 x10^{-5}	4,681	0.131	0.123	2.64 x10^{-5}	2.63 x10^{-5}
8	0.025	5.06 x10^{-6}	5,323	0.0269	0.025	4.7 x10^{-6}	4.7 x10^{-6}
9	0.015	1.26 x10^{-7}	5,861	0.000741	0.000683	1.17 x10^{-7}	1.16 x10^{-7}
10	0.01	1.9 x10^{-9}	6,301	1.19 x10^{-5}	1.09 x10^{-5}	1.73 x10^{-9}	1.73 x10^{-9}
Sum				$R_0 = 1.05$	1	1.0015	

Table 3. Examples of allometric relationships for fish relating mortality and other parameters to body size.

Response	**Equation**	**Reference**
Mortality (y^{-1})	$\mathit{log}M = -0.0066 - 0.279\mathit{log}L_\infty + 0.6543\log k + 0.4634\mathit{log}T$	Pauly (1980)
Production	$\mathit{log}P = 0.38 + 0.18\mathit{log}W$	Boudreau & Dickie (1989)
	$\mathit{log}P = 0.32 + 0.94\mathit{log}B - 0.17\mathit{log}W$	Downing & Plante (1993)
P/B	$P/B = 0.074W^{-0.28}$	Banse & Mosher (1980)
	$\mathit{log}P/B = 0.46 - 0.33\mathit{log}W$	Boudreau & Dickie (1989)
	$P/B = 2.64W^{-0.35}$	Randall & Minns (2000)
Intrinsic rate of population increase	$r_{max} = 0.025W^{0.26}$	Blueweiss et al. (1978)

Table 4. Allometric relations between territory size, density and biomass and fish body size.

Dependent	Equation	Reference
Salmonids (rivers)		
Territory per fish	$\log_{10}$ area(m^2) = 2.61$\log_{10}$length(cm) – 2.83	Grant and Kramer 1990
Territory per fish	$\log_{10}$ area(m^2) = 0.86$\log_{10}$W(g) – 1.17	Grant and Kramer 1990
Density	$\log_{10}$ density(m^{-2}) = -2.61$\log_{10}$length(cm) + 2.83	Grant and Kramer 1990
Biomass	$\log_{10}$ biomass(g m^{-2}) = 0.42$\log_{10}$length(cm) + 0.90	Grant and Kramer 1990
Biomass	$\log_{10}$ biomass(g m^{-2}) = 1.35 – 1.16$\log_{10}$density(m^{-2})	Grant and Kramer 1990
All species		
Area per individual	Area (m^2) = -2.07 + 1.13habitat = 0.96$\log_e$W (habitat is 0 for rivers, 1 for lakes)	Randall et al. 1995; Minns 1995.

Table 5. Four categories of productivity of fish populations depending on life history traits all of which are related to body size (population growth rate (r), growth parameter (k), fecundity, and age at maturity (T, years) (from Musick 1999).

Parameter	**Productivity**			
	High	**Medium**	**Low**	**Very low**
$r^{\text{yr-1}}$	>0.5	0.16-0.5	0.05-0.15	<0.05
von Bertalandy k	>0.3	0.16-0.3	0.05-0.15	<0.05
fecundity $^{\text{yr-1}}$	$>10^4$	10^2-10^3	$10^1<10^2$	$<10^1$
Tmat	<1yr	2-4 yr	5-10 yr	> 10 yr
Tmax	1-3 yr	4-10 yr	11-30 yr	> 30 yr
Body size at maturity	small	medium	med-large	large
Adult equivalents	many	medium	few	very few

Table 6. A life table for Brook Trout (Salvelinus fontinalis) based on parameter estimates as reported by McFadden et al. (1967) and Power (2007).

X	s_x	l_x	b_x	l_xb_x	r = 0.04 $e^{-rx}l_xb_x$	λ = 1.04 $\lambda^{-x}l_x$	C_x
0	0.0407	1	0	0	0	1	0.947
1	0.368	0.0407	0	0	0	0.0391	0.037
2	0.204	0.0150	43	0.644	0.594	0.0138	0.013
3	0.0818	0.00306	122.6	0.375	0.332	0.00271	0.0026
4	0	0.00025	346.2	0.0866	0.0736	0.000213	0.0002
Sum				R_0 = 1.11	1	1.056	

Table 7. Criteria for identifying Ecologically and Biologically Significant Areas (EBSA) in marine areas of Canada (modified from DFO 2004). Scaled down, these criteria can be used for rating habitat at localized areas in freshwater ecosystems as well. A few examples are given of habitat that would be rated as high for ecological significance (see text for details).

Properties	**Dimensions**				
Ecological Function	**Uniqueness**	**Aggregation**	**Fitness consequences**	**Resilience**	**Naturalness**
Spawning		fluvial spawning area for lake sturgeon below a natural barrier			
Nursery			areas where larvae/ juveniles have increased survivorship compared to other areas		
Feeding					
Migration	obligatory passage for a species (e.g., estuary)			disruption to migration pathway would cause population decline	
Seasonal refugia			macrophytes		refuge exists independent of human intervention
Structural Features					
Physical		convergence zone, concentration of prey and nutrients			benthic habitat not impacted by fishing or oil exploration
Biological			eel grass; macrophytes	marine sponges	
Biodiversity	coastal wetlands in an otherwise expanse of exposed shoreline				national or provincial conservation areas

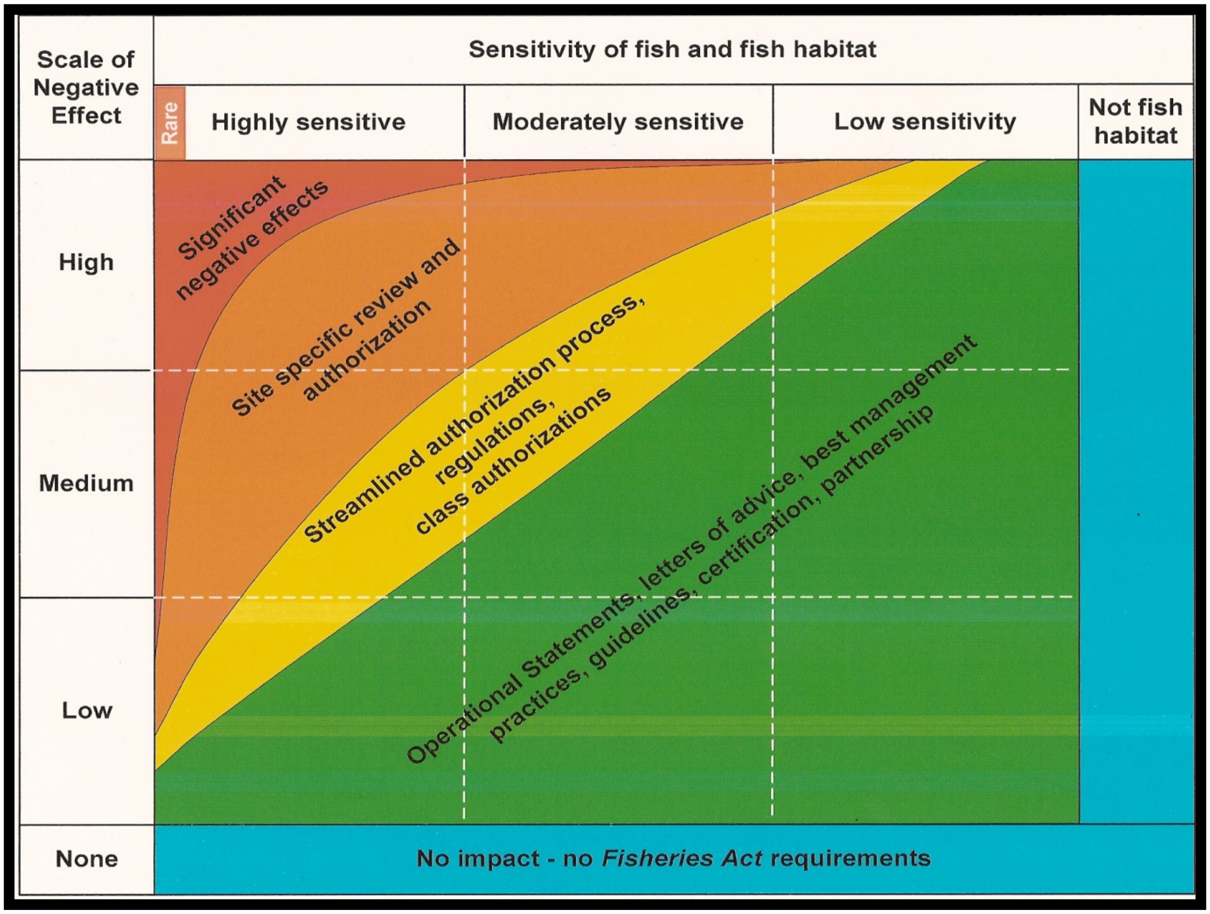

Figure 1. The original DFO Risk Management Matrix developed by the Habitat Management Program in the mid-2000s (DFO no date).

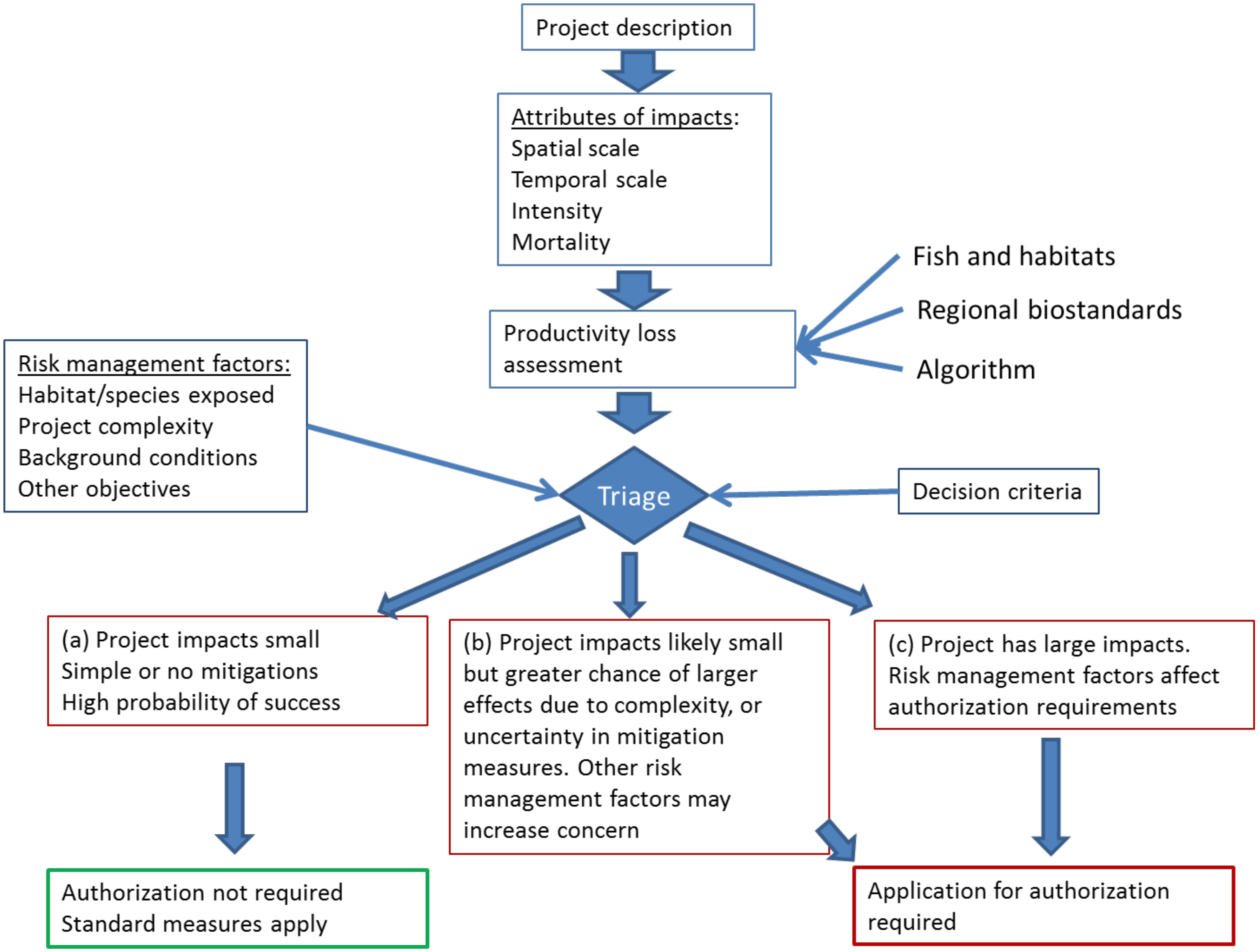

Figure 2. Example of a decision framework flowchart.

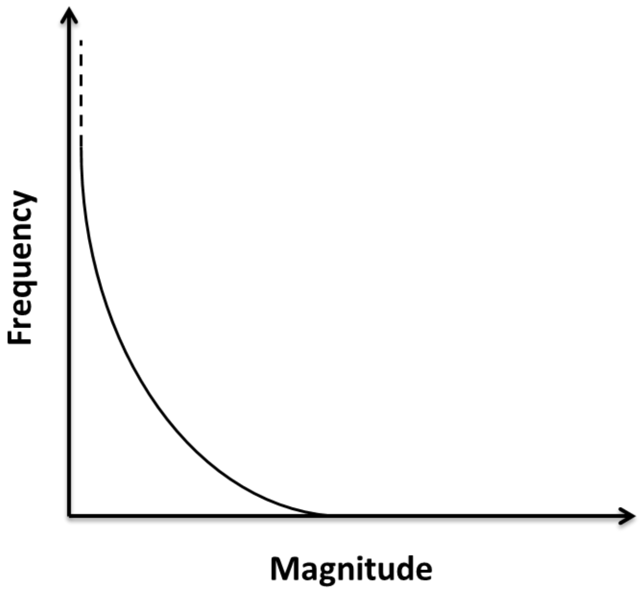

Figure 3. A schematic showing the expected decline in the tolerable frequency of mortality events as a function of the magnitude of the mortality evcent. Sensitivity to mortality will be affected by traits related to body size such that larger-bodied fishes will be able to sustain lower magnitudes of mortality.