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A Science-based Interpretation and Framework for Considering the Contribution of the Relevant Fish to the Ongoing Productivity of Commercial, Recreational or Aboriginal Fisheries

Interprétation scientifique et cadre pour la considération de la contribution des poissons pertinents à la productivité continue des pêches commerciale, récréative ou autochtone

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TABLE OF CONTENTS

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ABSTRACT

Amendments to the *Fisheries Act* include the need to consider the “contribution of the relevant fish to the ongoing productivity of commercial, recreational or Aboriginal fisheries” when making decisions on activities that may affect fish that are part of the fisheries and their habitats, and the fish that support the fisheries and their habitats. Here we consider that the contribution is measured by the impact that would be expected on the productivity of commercial, recreational or Aboriginal (CRA) fishery species if the change to the potentially affected species or habitats, associated with a work, undertaking or activity (w/u/a) takes place. We conceptualize the contribution as a relationship between the productivity of the fishery and state of the affected species or habitats. The shape of this relationship, the potential presence and position of inflections points and its slope can inform management decisions about risks associated with changes to the state of the affected species or habitats. Here we describe this contribution framework and outline the information needed for its application within a precautionary framework. This framework does not make the decisions automatically, but it does provide a structure for organizing information and bringing consistency to decision-making.

RÉSUMÉ

Les modifications à la *Loi sur les pêches* impliquent la nécessité de considérer « la contribution des poissons visés à la productivité des pêches commerciale, récréative ou autochtone » lors de la prise de décisions concernant des activités qui pourraient avoir des répercussions sur des poissons qui sont visés par ces pêches et leur habitat, et sur des poissons qui soutiennent ces pêches et leur habitat. Dans cette étude, nous considérons que la contribution se mesure par l'impact que devrait avoir le changement pour une espèce ou un habitat résultant d'une entreprise, d'une activité ou d'un ouvrage sur la productivité des pêches commerciale, récréative ou autochtone (CRA). Nous conceptualisons la contribution en tant que relation entre la productivité de la pêche et l'état de l'espèce ou de l'habitat touché. La forme et la pente de cette relation, ainsi que la présence et la position éventuelles de points d'inflexion, peuvent servir d'indicateurs pour la prise de décisions sur les risques associés aux changements à l'état des espèces ou des habitats touchés. Dans cette étude, nous décrivons ce cadre de contribution et présentons l'information nécessaire à son application à l'intérieur d'un cadre de précaution. Ce cadre ne permet pas la prise de décisions automatiques, mais offre une structure pour organiser l'information et apporter une certaine uniformité au processus décisionne

1. INTRODUCTION

The amendments to the *Fisheries Act* (FA) make substantive changes to the way in which Canadian fishes and fish habitat are protected. Among these changes, the newly introduced Fisheries Protection Provisions (FPP) have the purpose of providing for the sustainability and ongoing productivity of commercial, recreational, or Aboriginal (CRA) Fisheries. These FPP replaced the former Habitat Protection considerations, and in the amended Section 35 establishes the prohibition that "*no person shall carry on any work, undertaking, or activity that results in serious harm to fish that are part of a commercial, recreational or Aboriginal fishery, or to fish that support such a fishery*". The amended FA defines serious harm to fish as "*the death of fish or any permanent alteration to, or destruction of, fish habitat*", and gives the Minister of Fisheries and Oceans Canada the capacity to authorize a work, undertaking, or activity (w/u/a) that causes serious harm if this is considered acceptable. One of the factors to be taken into account by the Minister in making this decision is "*the contribution of the relevant fish to the ongoing productivity of commercial, recreational or Aboriginal fisheries*". These factors also need to be considered in decisions regarding (i) fish passage, (ii) flow, (iii) w/u/a in an ecologically significant area (ESA), and (iv) the making of regulations. Further, decisions that involve fish passage, flow, or ESAs need to consider all harm to fish, not just serious harm.

In this context, the goal of this paper is to provide a technical basis for scientific advice towards a consistent interpretation of "*the contribution of the relevant fish to the ongoing productivity of commercial, recreational or Aboriginal fisheries*", and to put forward plausible options for the practical implementation of this concept. To keep the decision making consistent across the variety of decisions that must consider the contribution of the relevant fish, the advice provided needs to be applicable to the whole range of harm to fish as well as to the specific case of serious harm.

2. PREMISES AND DEFINITIONS

The Oxford English dictionary defines "contribution" as the part played by a person or thing in bringing about a result or helping something to advance, while the Merriam-Webster Learner's dictionary defines it as something that is done to cause something to happen.

The usage of "contribution" in the amended FA is in line with these standard definitions, and hence, the phrase "*the contribution of the relevant fish to the ongoing productivity of commercial, recreational or Aboriginal fisheries*" makes clear the "something to advance" is the "*ongoing productivity of commercial, recreational or Aboriginal fisheries*". Consistent interpretation of this provision of the *Fisheries Act* therefore requires contextual information on what constitutes "*ongoing productivity of commercial, recreational or Aboriginal fisheries*" and what constitutes "*relevant fish*".

Randall et al. (2013) provide detailed background information on the "*ongoing productivity of commercial, recreational or Aboriginal fisheries*"; for our purpose it suffices to state that the sustainability of ongoing productivity of CRA fisheries implies the maintenance of ecosystem structure and function.

The *"relevant fish*" needs to be defined in terms of fish that are part of a CRA fishery, or those that support such a fishery. Kenchington et al. (2013) provide a detailed description and interpretation of the term "*fish that support such a fishery*". Building on the analyses provided by Randall et al. (2013) and Kenchington et al. (2013) we consider here that, in a broad sense, the supporting role can be understood as providing the functions necessary for the sustainability and ongoing productivity of CRA fisheries.

The definition of *serious* harm provided by the amended FA indicates that this takes place when either fish die or fish habitat is permanently altered or destroyed. The amended provisions of the FA do not provide a definition of *harm* to fish (including habitat), which triggers sections 20, 21 (barriers and flows) and applies to ESAs. We define harm as a negative perturbation that can target one or more vital rates (such as survival, growth, maturity, or reproduction), life stages, or habitats. This definition of harm is consistent with other applications of the concept of harm, such as to species at risk (e.g., Vélez-Espino and Koops 2009).

Based on these considerations and premises, the following definitions are proposed:

2.1 "RELEVANT FISH"

From a Science perspective, relevant fish are all fish involved in a CRA fishery either as part of the fishery or in a supporting role of the ongoing productivity of the CRA fishery, including their habitats, which could be affected by a work, undertaking, or activity. There are policy aspects to *relevant fish* as well, particularly with regard to delineating the fish that are part of the fishery, both in terms of species and geographic range. Since we are specifically considering those fish or habitats that could potentially be affected by a w/u/a, we shall refer to affected species or habitats. The affected species or habitats include the fish that are part of the fisheries and their habitats, and the fish that support the fisheries and their habitats.

2.2 "CONTRIBUTION"

The contribution of the relevant fish to the ongoing productivity of a CRA fishery is measured by the impact that would be expected on the ongoing productivity of CRA fishery species if change to the potentially affected species or habitats, associated with a work, undertaking, or activity takes place.

Since contribution is a relative concept, not an absolute (binary) concept, case-specific decisions will need to be made. The role of science advice is to guide these decisions so they are based on sound expectations of impacts.

3. A CONCEPTUAL FRAMEWORK TO RELATE THE CONTRIBUTION OF SPECIES OR HABITATS TO THE PRODUCTIVITY OF CRA FISHERIES

3.1 RATIONALE AND GENERAL FRAMEWORK DESCRIPTION

The amended FA requires Fisheries and Oceans Canada (DFO) to not just identify the harm or serious harm of a w/u/a to the affected species or habitats, but to also gauge the consequences of the harm to the ongoing productivity of CRA fishery species. Harm, which can affect vital rates (such as survival or reproduction) or habitat functions, is rarely directly measured; instead, management agencies usually deal with changes to the affected species or habitats that result from a w/u/a. The simplifying assumption is that these observable changes are related to the vital rates and habitat functions that are the foundation of population viability and fishery sustainability. A simple conceptual depiction of impact to the ongoing productivity of CRA fishery species from observable cumulative changes (Fig. 1) provides a useful starting point to develop a framework for the implementation of these concepts.

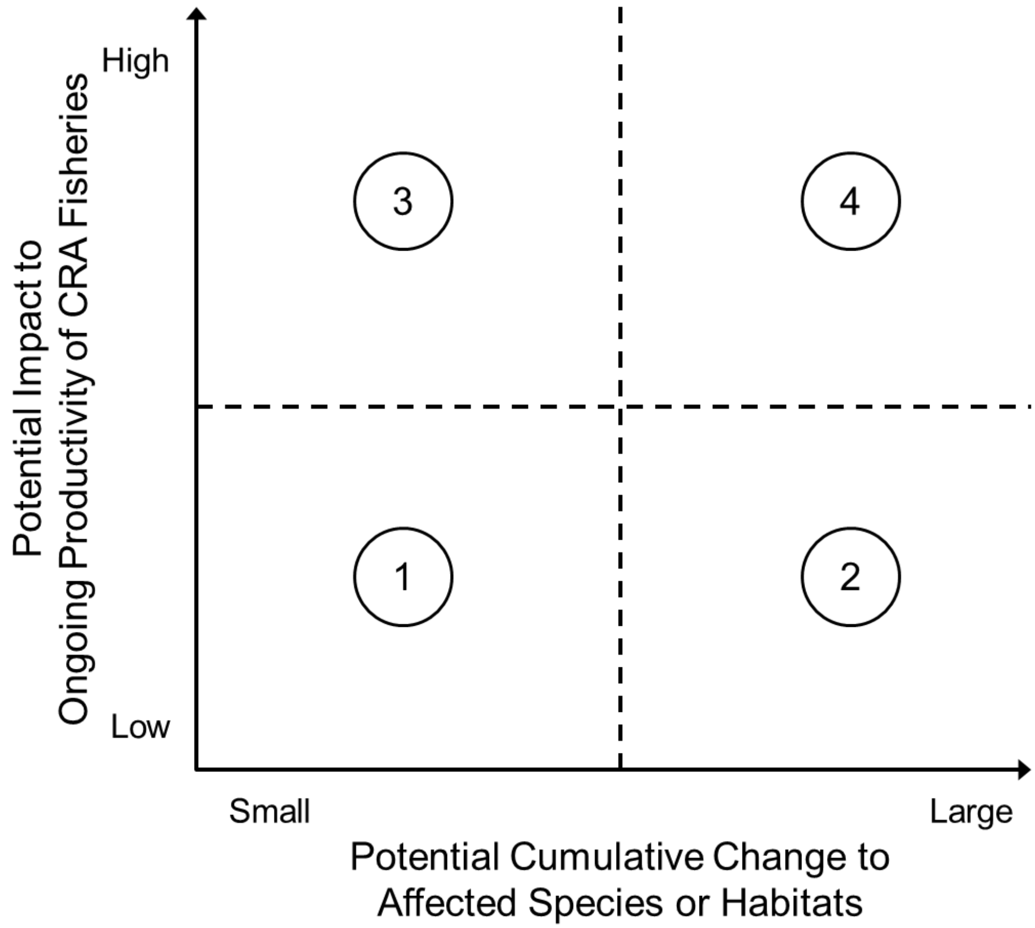

Figure 1. Schematic representation of a conceptual framework mapping the relationships between potential cumulative change to the affected species or habitats and the consequent potential impact to the ongoing productivity of CRA fisheries. Note: both axes are continuous variables; the dashed lines dividing the space into four quadrants are included for heuristic purposes and do not imply an a priori categorization.

There are a number of things to be noted about this conceptual depiction.

First, while there may be similarities to the risk management framework (RMF) currently used in the Habitat Management Program to classify projects, this conceptual depiction is not a modification of the current risk management framework. The current RMF practically facilitates the placement of individual projects in risk categories based on the scale of negative effects and the sensitivity of fish and fish habitat, and suggests methods for redesign and relocation to move either axis to a lower risk category. Fig. 1 is a conceptual diagram and is not intended to be used alone for the evaluation of individual w/u/a; it serves as the starting point for the development of a contribution framework (see section 3.2).

Second, while the axes are continuous variables, the change-impact space has been divided into four quadrants for heuristic purposes. This should not be taken as an expectation that these variables can be divided into binary categories. The relative size of the quadrants is also illustrative only.

Third, the cumulative change being considered in this framework is specifically change that is expected to negatively affect the sustainability and ongoing productivity of fisheries. Human actions can be applied with the intent to positively affect populations and ecosystems (e.g., recovery or restoration activities); these are not the types of activities being considered here (but see section 3.2).

Fourth, while cumulative change is depicted here as a single variable, it is actually multidimensional. There are many different changes that humans affect in aquatic ecosystems that have the potential to impact fishery productivity. These multiple changes are collapsed into a single variable of cumulative change for conceptual and presentation purposes, but the true multidimensional nature of this variable should not be ignored.

Finally, the productivity of CRA fisheries may involve multiple species. In addition to the fishery species there are the fishes that support these fisheries and there can be multiple CRA fisheries within a functional ecosystem. Hence, there will be interactions in the ecosystem among the species that are part of or support these fisheries, and human-induced changes may simultaneously affect one or more of these species. These final two points imply that providing for the sustainability and ongoing productivity of CRA fisheries needs to be addressed from an ecosystem perspective (e.g., Browman and Stergiou 2004; Hall and Mainprize 2004; Francis et al. 2007; Koops et al. 2009; Rice 2011), and evaluations of individual proposals are best made in the context of the human activities already taking place in the affected ecosystem.

3.1.1 Interpretation of the “Impact” Space

Conceptually, we can consider a framework where a level of cumulative change to the affected species or habitats results in an impact to the ongoing productivity of CRA fishery species (Fig. 1). To begin, let us consider the four quadrants of this state-space.

In Quadrant 1, the potential for cumulative change to the affected species or habitats will be small and will have a low impact on the productivity of fishery species. This is a low risk scenario.

In Quadrant 2 the fishery is generally insensitive to cumulative change to the affected species or habitats so that even large amounts of cumulative change or w/u/a with large individual changes will have relatively low impacts on the productivity of the fishery species. This could be a scenario where there is a very shallow slope on the relationship between productivity of the fishery species and the state of the affected species or habitats.

Quadrant 3 represents a fishery species that is very sensitive to changes to the affected species or habitats. This is a situation where small amounts of human activity that change the state of the affected species or habitats will have large impacts on the productivity of fishery species. This may occur when a w/u/a affects a keystone species (c.f. Kenchington et al. 2013) or an ecologically significant area.

In Quadrant 4, the potentially large amounts of cumulative change (or a single large-scale w/u/a) to the state of the affected species or habitats will have high impacts on the productivity of CRA fishery species.

Quadrants 1 and 4 can be interpreted as cases where the magnitude of the impact on the productivity of CRA fishery species is proportional (not necessarily linearly) to the cumulative change generated by w/u/a; the impact of a w/u/a on CRA fishery species productivity is “scale-dependent” with the magnitude of the change. These are situations where the impact grows with the cumulative change; a moderate change to affected species or habitats causes a moderate impact on CRA fishery species productivity, a large change to affected species or habitats causes a high impact to CRA fishery species productivity. This does not imply that the relationship between change to affected species or habitats and impact on productivity is linear, but it does suggest a strong association between these variables.

Quadrant 2 encompasses at least two different types of scenarios. The first is simply a very strong change to the state of affected species or habitats, but with little consequences on CRA fishery species productivity; the affected species or habitats have a comparatively minor supporting role of the fishery species productivity *per se*, albeit still discernible, but may have a more important role in the maintenance of overall ecosystem structure and function. The second scenario, is where the affected species or habitats are currently in a poor state (e.g., depleted population, SARA-listed species), and hence the impact of cumulative changes on current fishery species productivity seems low, but there is either an expectation that an improved state would render a stronger link with fishery species productivity, or the recovery/rebuilding of these species is in itself a management objective (e.g., recovery of SARA-listed species).

Quadrant 3 provides a scenario where the link between cumulative changes to affected species or habitats and the productivity of fishery species is clearly not directly proportional, potentially representing strong impacts on key ecological processes. In this quadrant the effect on CRA fishery species productivity is more "process-dependent", than "scale-dependent". Here, the impact on productivity can sometimes take an on-off type of behaviour, and in some cases may be much more difficult to predict than "scale-dependent" impacts. Cases in this quadrant may require highly risk-averse management practices, and in some cases will provide good candidates for the establishment of ecologically significant areas; the scale of the anthropogenic impact appears small and localized (i.e., small cumulative changes), but may affect a critical area where a key ecosystem process takes place, and whose perturbation is dramatically amplified on the productivity of CRA fishery species.

3.1.2 Additional Considerations

Given the broad and diverse set of potential human activities affecting Canadian waters, the expected impacts to the sustainability of ongoing productivity of CRA fishery species can be driven by a multiplicity of ecological processes. In many cases, the full impact on CRA fishery species productivity will be determined by the cumulative effects of different, unrelated, human activities.

CRA fishery species take place in functional ecosystems whose spatial bounds are sometimes well delimited (e.g., lakes, watersheds, enclosed embayments, etc.) and sometimes are weakly defined (e.g., fishing banks, upwelling zones, etc.). Within each ecosystem multiple CRA fisheries can take place. Therefore, the overall productivity of CRA fisheries in that ecosystem can be understood as the combined productivity of each CRA fishery species, and includes the distribution of the contributions of each of them to the overall fisheries productivity. These individual CRA fishery species may be targeting specific management stocks which, ideally, are intended to represent biological populations. Therefore, the impact of a particular w/u/a on CRA fisheries productivity needs to be evaluated at both the population and functional ecosystem level; the concept of CRA fisheries productivity is essentially a multispecies one. Ideally, the impact of a w/u/a should be evaluated at the management stock level for all stocks in the affected ecosystem that support the CRA fisheries. Practically, this would minimally require an evaluation of the impact of the w/u/a on the ecosystem components most vulnerable to a particular pressure.

In this context, the spatial scale associated with a w/u/a is not necessarily proportional to its impact on CRA fishery species productivity; the impact on productivity is the result of the combined effects of all past and present w/u/a affecting the ecosystem where the CRA fisheries take place. In some cases, individual w/u/a, because of their nature and extent, would have potentially measurable effects on fishery species productivity (e.g., destruction of spawning grounds), but in most cases, the impact on fishery species productivity would only be measurable as a combined effect, and the incremental impact of a single w/u/a may not necessarily be detectable. This implies that one scale at which the impact on productivity is assessed needs to be the functional ecosystem scale. From a practical perspective, this may require, at least for those w/u/a deemed low risk at the individual level, developing guidelines for specific classes of activities and the levels of these activities that could be allowed in different classes of ecosystems (considering both their biological features and impact history).

The conceptual framework depicted in Fig. 1 does not fully address cumulative effects; these impacts emerge not simply from the addition of similar types of perturbations, but also from the interactions between the impacts produced by different types of perturbations, as well as the state of the ecosystem when those perturbations take place. However, by considering change in habitat features, the framework provides an initial approach to capturing the first order cumulative impacts on affected species or habitats associated with increasing perturbations on specific system characteristics. This implies that providing for the sustainability and ongoing productivity of CRA fishery species needs to be addressed from an ecosystem perspective; the ability to conduct such assessments improves with development of systems of accounting for all activities affecting ecosystems, not just those individual w/u/a that trigger *Fisheries Act* authorizations.

The amended FA includes in its definition of serious harm, the ’permanent’ alteration of fish habitat. Since this notion of ’permanent’ is associated with impacts on CRA fishery species productivity (i.e., ultimately affecting the biological productivity of the species involved), the notion of ’permanence’ needs to be measured in time scales compatible with the biology of the species being affected (e.g., generation times), rather than with a human perspective on the duration of a given w/u/a. For example, if a given spawning bed is completely altered during a project construction phase, but later reclaimed and returned to its pristine state after construction, this may be seen as a ’temporary’ alteration from a human perspective, but if the construction time is far longer than the generation time for the affected species, this alteration is effectively ’permanent’ for one or more fish generations. The lasting consequences on biological productivity may be large even if the habitat is restored, and depends greatly on the likelihood of re-colonization events, which in turn would depend on the existence of nearby populations capable of providing a source of fish.

From an ecological perspective, the notion of permanence is linked to the ability of the affected ecosystem (or part thereof) to recover from a given perturbation. In simple terms, this implies that ’permanent’ should be assessed in terms of the capability of the ecosystem to restore the functionality of the affected habitat. If after the w/u/a is finished, the restoration of the ecological/biological functionality is possible and with an acceptable probability within a reasonable number of generation times for the affected CRA fishery species or fish that support a CRA fishery, then the habitat alteration could be considered temporary for the individual w/u/a. If the restoration is either not possible, or has a low probability of occurring within the expected generation times after the activity is finished, then the habitat alteration should be considered permanent. The recurrence of w/u/a in an area, even if the habitat alterations caused by each individual w/u/a can be deemed as temporary, could be considered as causing permanent alterations if the frequency of recurrence prevents the full restoration of the ecological/biological functionality.

3.2 A CONTRIBUTION FRAMEWORK

To identify the quadrant (from Fig. 1) in which a particular activity may reside, we need to relate changes to the state of the affected species or habitats to the productivity of the fishery species. This can be conceptualized as a relationship between productivity of the fishery species and the state of the affected species or habitats (Fig. 2). Forms of this type of approach can be found in the scientific literature (e.g., Norris and Thoms 1999, Allan 2004, Rice 2009). Small amounts of change may have little or no impact on the productivity of the fishery species. However, at some magnitude of change a threshold is crossed (S1 in Fig. 2) where additional change has increasing impacts on the productivity of the fishery species. There may exist a second threshold (S2 in Fig. 2) where change to the affected species or habitats is great enough that it no longer contributes to the productivity of the fishery species. At this point the fishery cannot be impacted further through additional change to the affected species or habitats; however, the productivity of the fishery species is depressed. Identification of the first threshold (S1) can provide the conditions where general regulations can define permissible human activities. The second threshold (S2) identifies the potential cumulative change that can impact the fishery species. The P1 reference point is the benchmark reference productivity, and can be defined from fisheries management objectives, recovery targets, or other management goals. The difference between the benchmark productivity of the fishery species in the absence of change (P1) and the depressed productivity of the fishery species beyond the S2 change threshold (P2) represents the total potential contribution to the ongoing productivity of the fishery species. The positions of S2 and P2 define the relative positioning in the cumulative change-impact state-space (Fig. 3).

The types of change being considered here are those expected to negatively affect the viability of populations or sustainability of fishery species. Each additional w/u/a that effects change on an ecosystem will move us to the right along the state axis. Some w/u/a may initially move a system farther to the right with the system moving back to the left as the ecosystem naturally adjusts to the changes. Another way we may move to the left is through human activities that are intended to recover or restore species or ecosystem functions. Presumably, this is also the intent behind management strategies that require compensation or banking (c.f. Minns 2006; Roni et al. 2008); some perturbation is intentionally applied to counter negative impacts to the productivity of fishery species that result from other perturbations.

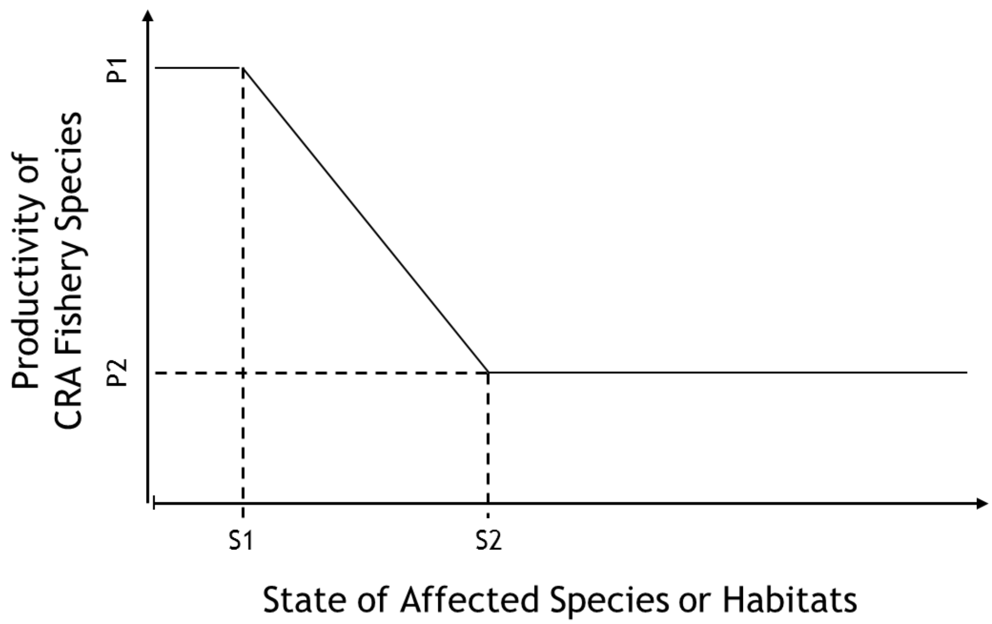

Figure 2. Schematic framework of how the ongoing productivity of CRA fishery species may be impacted by change to the state of the affected species or habitats. The X-axis indicates state as measured along a continuum from good (left) to poor (right). The Y-axis indicates productivity as measured along a continuum from low (bottom) to high (top). Four reference points are identified: S1 is the threshold below which change to the affected species or habitats has little or no impact on productivity of fishery species but above which additional change to the affected species or habitats translates into reduced productivity of the fishery species; S2 represents the point where cumulative change to the affected species or habitats is great enough that its contribution to the ongoing productivity of CRA fishery species is eliminated and the fishery is depressed; P1 represents the benchmark reference productivity of the CRA fishery species; P2 represents the depressed productivity of the CRA fishery species under maximum cumulative change to the affected species or habitats.

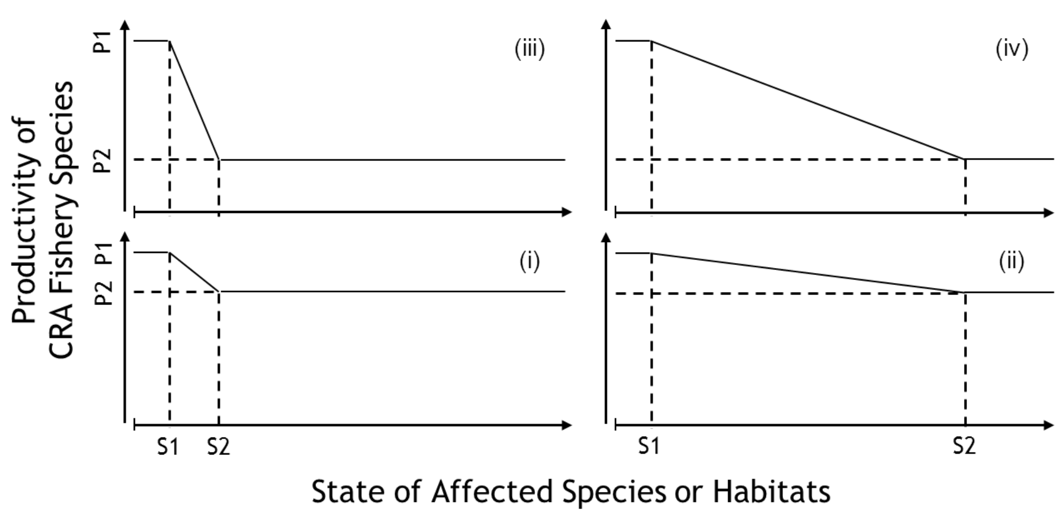

Figure 3. Four representations of the productivity-state relationship demonstrating how the positioning of thresholds S2 and P2 determine the relative location of the relationship in the cumulative change-impact space of Figure 1. The X-axis indicates state as measured along a continuum from good (left) to poor (right). The Y-axis indicates productivity as measured along a continuum from low (bottom) to high (top).

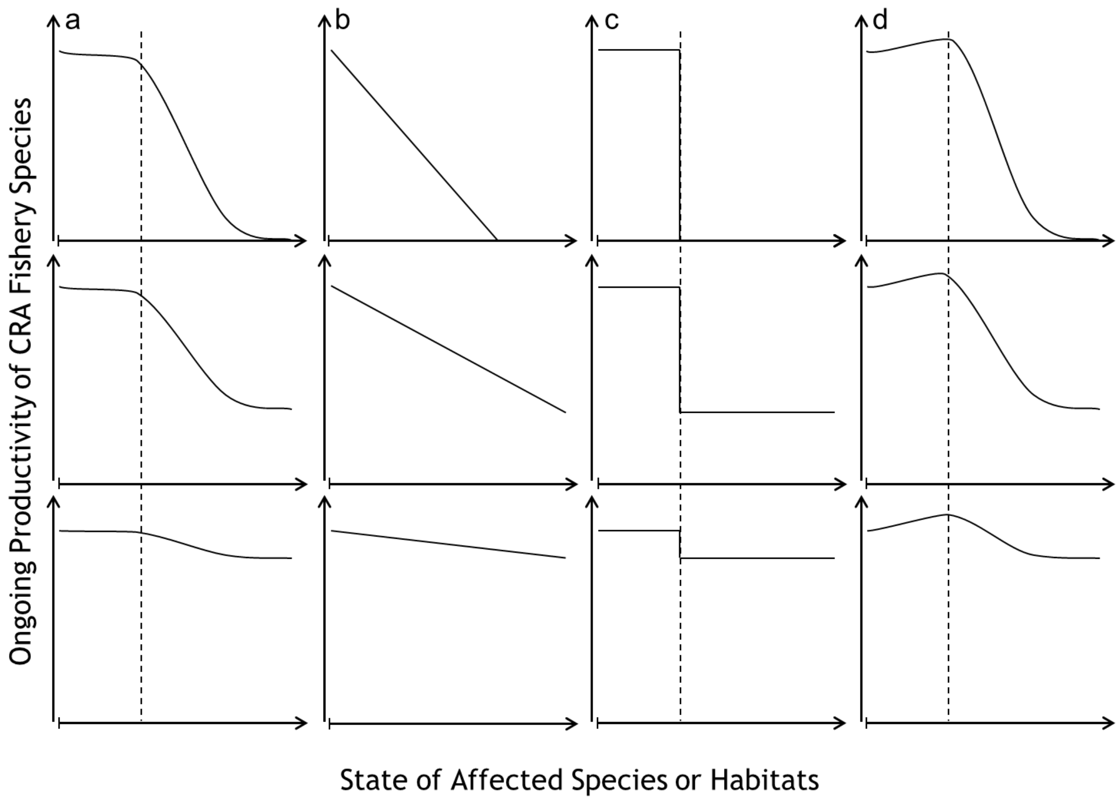

Figure 4. Representations of some of the different shapes of the productivity-state relationship: (a) curvilinear response (similar to the lines in figures 2), (b) linear response (difficult to identify a threshold), (c) step response, and (d) subsidy-stress response. Three different forms of each shape are presented representing low, moderate, and high potential impacts to the productivity of CRA fishery species from changes to the state of the affected species or habitats (from bottom to top). The vertical dotted lines represent the threshold (S1) beyond which impacts to the productivity of the fishery species increases more quickly. Note: there is no point that objectively represents this threshold when the response is linear (column b). The X-axis indicates state as measured along a continuum from good (left) to poor (right). The Y-axis indicates productivity as measured along a continuum from low (bottom) to high (top).

The shape of the productivity-state curve can take different forms (Fig. 4), which has implications for the management of human activities that may change the state of the affected species or habitats. These curves are expected to be functions of the specific species, the ecosystem where they live, and the status of the specific stock. We here show and discuss four classes of curves (Fig. 4). The curvilinear response (Fig. 4a) represents a situation where a small amount of change to the state of the affected species or habitats has little or no impact on the productivity of the fishery species, but there is a level of cumulative change beyond which the impact to the productivity of the fishery species increases quickly (this is threshold S1). When the response is entirely linear (Fig. 4b), incremental changes to the state of the affected species or habitats translate into incremental reductions to the productivity of the fishery species, but there is no objective threshold where the rate of impact to the fishery species increases with increasing change to the state of the affected species or habitats. In this case, management will need to decide what impact to the productivity of the fishery species is acceptable. When there is a step response (Fig. 4c), all the potential impact to the productivity of the fishery species occurs over a very narrow range of the state of affected species or habitats. In this case, it would be precautionary to keep cumulative change well below the threshold to avoid incurring the sudden reduction in productivity to the fishery species. The main difference between the curvilinear and step response is the high rate at which productivity declines when the threshold is exceeded. The step function could represent a regime shift which may be difficult or impossible to reverse. Finally, a subsidy-stress response (Fig. 4d) occurs when small amounts of change to the state of the affected species or habitats increases the productivity of the fishery species, but then the cumulative change depresses the productivity of the fishery species.

The final link is the connection from changes to the state of the affected species or habitats back to the human w/u/a being managed. If it is a management concern then we expect a w/u/a, at some level of intensity or scale or frequency, to effect a change on the affected species or habitats. As with other responses, changes to the state can be linear or non-linear. However, to apply this framework, it is necessary to have at least a nominal expectation of the type and level of change that will result from a w/u/a. The existing pathways of effects can provide a way of making this connection (see section 4.3.3).

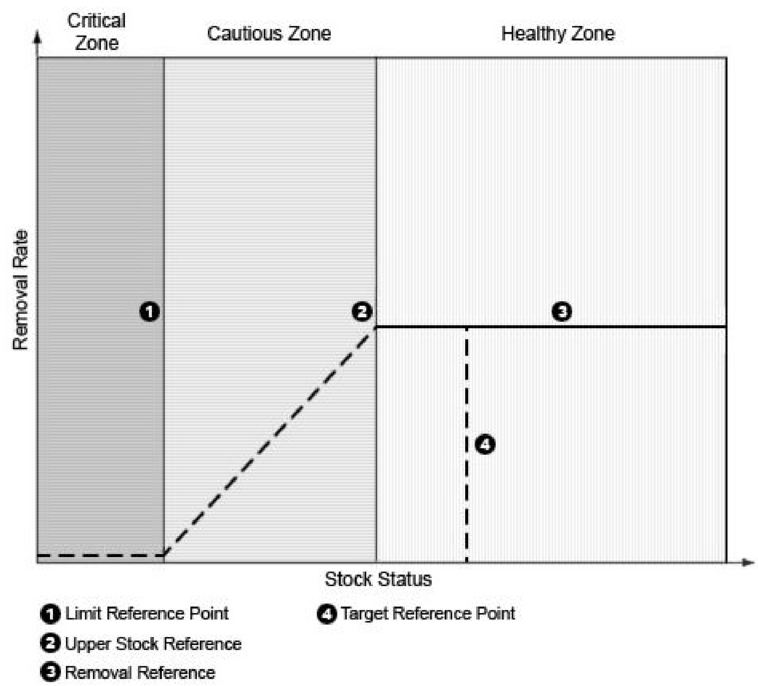

Figure 5. Schematic representing a Precautionary Approach (PA) framework that has been developed as part of DFO's Sustainable Fisheries Framework (SFF (DFO 2006).

3.3 THE APPLICATION OF PRECAUTION

A framework for application of precaution in applying the FPP can be developed, adapting the Precautionary Approach (PA) framework that has been developed as part of DFO's Sustainable Fisheries Framework (SFF; Fig. 5). However, the FPP framework is different than the fisheries PA framework, because harvest management decisions in the PA framework set the overall level of impact of a fishery on a stock (the quota for a fishery) but do not deal with decisions about activities of individual fishers. In contrast, decisions under the FPP are about individual w/u/a and not about the overall impact of all potential w/u/a on productivity of CRA fisheries. In addition some forms of changes to affected species or habitats are not reversible, whereas the

SFF assumes that stock rebuilding is always possible. However all the considerations in the PA Framework for fisheries harvest management are captured in the proposed framework for the FPP, as well.

Given a proposed w/u/a, the FPP framework would require five pieces of information:

a) how productivity depends on habitat quantity and quality (illustrated in Fig. 3 as the functional relationship between productivity of CRA fishery species and the state of affected species or habitats),

b) the current state of the affected species or habitats, taking into account any targets that may have been set for habitat status (in Fig. 3, the position of the area in which the w/u/a will be undertaken on the state-productivity relationship),

c) the resilience of fish productivity to further habitat perturbations (in Fig. 3 the slope of the state-productivity relationship in the neighbourhood of the current state of the affected species or habitats)

d) the expected ways that the proposed w/u/a may alter the state of affected species or habitats (how far the location would move on the x-axis of Fig. 3), and

e) uncertainties (about the functional relationship used, the present state of the habitat, the potential impacts of the w/u/a, and, when applied, the effectiveness of avoidance and mitigation measures).

Some potential shapes of productivity-state relationships are illustrated in Fig. 4. Comprehensive data will rarely be available to fully parameterize functions and positions for points (a) to (d) above and quantify uncertainty (e) for specific places and the fisheries in those places. However there is substantial research and expert knowledge of scientists, managers, and related professionals and these can inform the development of default forms for the functional relationships between measures of productivity and measures of the state of affected species or habitats and provide general guidance on the current state of affected species or habitats on moderate to large spatial scales. It is feasible to use existing knowledge to tabulate the following:

- Which species and habitat characteristics will be impacted by various types of w/u/a, and by how much? Existing work on Pathways of Effects provides the basis for building such tabulations. For some types of w/u/a, a single generic tabulation might apply across Canada, whereas impacts of other types of w/u/a would be different for major ecosystem types (large or small lakes, major rivers, secondary waterways, coastal areas, open ocean, etc.);
- Which measures of state of species or habitats best link productivity and changes caused by various types of w/u/a? The choices here will build on research results and expert knowledge of scientists and field professionals. It is important to seek measures that are practical to implement by proponents of small-scale w/u/a. Indicators of habitat status and potential impact that are more complex should also be identified for use for evaluation of large-scale w/u/a where investments in impact assessments are being made;
- How does productivity vary with the state of species or habitats (taking into account the available measures of state and productivity)? For this task researchers and field professionals would have to develop guidance for which form in examples shown in Fig. 4 would be appropriate to apply in various combinations of type of ecosystem and

type of w/u/a. It is likely that this could be done at scales to be defined in consultation with management;

- What is the current state of the affected species or habitats? Researchers and field professionals would use expert knowledge to develop general guidance on the current state of various types of systems, at zonal or regional geographic scales. Evaluating the "current states of affected species or habitats" requires at least an approximation of the cumulative change that has occurred in the ecosystem where a decision is being made regarding a w/u/a. A broader treatment of cumulative effects will need to be developed, if the productivity of CRA fisheries is to be fully protected.

These relationships and tabulations would be prepared under the aegis of DFO, using mixes of experts from within and, as appropriate, outside the Department, and updated periodically as knowledge increases. Most of the relationships and tabulations would initially be relative and/or qualitative, because of limitations in data and analytical capacity. In addition major changes to the status of the fish that are part of the CRA fisheries might require revising the shape of the productivity – state relationships. For w/u/a located in areas of particular concern because of their ecological sensitivity or importance to policy, more site-specific information may be required, and the costs and time for collecting such information may become a consideration. Once these tabulations are available, case-by-case decision making could be based on simple decision rules. Policy and management will have to set risk tolerances for the expected decline in productivity that would be considered a concern in case-by-case decisions.

Use of this framework does not make the decision automatic. However, it provides a structure for organizing information and bringing consistency to decision making. Although it was developed and will be tested for consideration of impacts of w/u/a on productivity of CRA fisheries, other types of decision making are also specified in Section 6 of the *Act*. After appropriate evaluation, the framework may also prove useful in informing some of the other types of decisions as well. This framework would require testing at the scale(s) selected by managers (refer to section 4.0).

4. OPERATIONALIZING THE FRAMEWORK

To implement this framework, the following are needed:

1. an idea of the shape of the productivity-state relationship; this will define which quadrant(s) (Fig. 1) are relevant,

2. an approximation of the location of the threshold (S1; Fig. 2),

3. a connection between changes to state and the w/u/a being managed, and

4. an estimate of current position along the productivity-state relationship (i.e., an estimate of cumulative change).

These pieces, and suggestions for their implementation, are covered in sections 4.1 to 4.4.

4.1 POTENTIAL PRODUCTIVITY-STATE RELATIONSHIPS

To describe a productivity-state relationship, we need to populate these two axes. Often it is not possible to directly measure productivity, and surrogates are often used in place of direct measures (see Table 1 for a selection of measures and surrogates). While surrogates are often expedient or the only feasible metrics given the available data, it needs to be recognized that the use of surrogates includes uncertainty about the mechanisms by which human activities translate into impacts on fishery productivity. For more specifics on measures of productivity, see Randall et al. (2013).

A time-constrained review of the literature (Table 2) yielded a sample of 25 papers that examined some form of impact to fish or fish habitat and some form of an ecological response; 13 described the form of the response relationship. The papers reviewed examined the following types of changes: land use, habitat loss, chemistry, flow, fishing, turbidity, sedimentation, and composite disturbance. Reponses to these changes included fishery catches, fish abundance and density, fish migration, survival, recruitment, fish and benthic community composition, species richness and diversity, growth potential, and fish indices (e.g., index of biotic integrity, IBI). The majority of described responses were curvilinear, with a few representing a linear response. At this point, this should not be taken as evidence of the rarity of linear, step, or subsidy-stress responses. However, it would appear that curvilinear responses are commonly observed. There are sure to be more papers that present productivity-state relationships. In fact, some of the papers reviewed were themselves reviews of a broader literature (e.g., Allan 2004, Wheeler et al. 2005) that was not reviewed due to time constraints. This limited review does, however, demonstrate that the literature exists to describe potential productivity-state relationships. Future work could be invested in a thorough review of the literature to identify the prevalence of different forms of the productivity-state relationship and whether there are ways to predict when one form is more likely to occur (e.g., based on type of ecosystem or change or response measure).

4.2 IDENTIFICATION OF POTENTIAL THRESHOLD POINTS

Estimates of thresholds were identified in 30% of the papers reviewed (Table 2). Some of the activities included in the reviewed papers did not lend themselves to identifying a threshold as the activities tended to be all or nothing, such as dredging (Bilkovic et al. 2010) or tidal marsh access (Madon 2008). Thresholds were most commonly identified in papers that examined land use adjacent to streams; most land use thresholds tended to be in the 5-15% range. Jensen et al. (2009) identified thresholds for sedimentation at 10% for sediments finer than 0.85 mm and 25-30% for other fine sediments. Gray et al. (2012) found that slight increases in turbidity (to 5 NTUs) reduced egg hatching success by 24% in Spotted Gar. These thresholds typically correspond to the S1 threshold (in Fig. 2); the threshold at which impacts to the productivity of fishery species (or surrogate thereof) is clearly detectable. This limited review suggests there is information in the scientific literature that can help to identify change thresholds; and at least in some cases, there seems to be consistency across studies regarding the position of the S1 threshold on the state axis. Future work could be invested in a targeted review of the literature to develop thoroughly documented and defensible thresholds in a process analogous to the identification of reference points for fisheries management or scientific reviews of the pathways of effects (e.g., Smokorowski and Pratt 2007).

4.3 CONNECTING MANAGED ACTIVITIES TO POTENTIAL CHANGE

4.3.1 Summary of Activities for which DFO has Issued Authorizations

Under the former Habitat Management Program, considerable success had been achieved in streamlining the handling of referrals received by the department. Prior to 2006, the department received 8,624-13,089 referrals, and issued 395-555 authorizations per year. Recognizing that the majority of referrals involved low risk activities, mechanisms were put in place to reduce effort on the part of the department in handling low risk projects, including the development of Operational Statements (OS) and Class Authorizations. Since 2006, the number of referrals received declined to 7,245-7,722 with 238-271 individual authorizations issued per year. When a proponent recognizes that their project would fall under an OS it is requested that they notify DFO (e.g., 4,035 notifications received in 2008) although it is not mandatory. Class authorizations were developed largely for agricultural drains in Southern Ontario, but other classifications of projects could also warrant a class watershed authorization (e.g., Placer mining in the Yukon). DFO has received 156-347 Class Authorization notices per year since 2007.

While these streamlining tools have achieved their desired effect, the recent changes to the *Fisheries Act* are designed to further reduce the handling of referrals. It is therefore important to try to clarify the types of activities that were automatically considered low risk (covered by actions that function like OS did under the previous provisions of the FA), or those that came in as a referral and went out without an authorization and are therefore low risk (e.g., letters of advice). In this manner DFO could define *a priori* which types of activities can proceed without any form of DFO review (i.e., those that fall under Quadrant 1, Fig. 1). It is important to note, however, that these activities should be tracked in some manner in order to account for potential cumulative effects that could push the impact into another quadrant. Similarly, by examining the referrals that were authorized as 'high risk' we may be able to clarify the types of activities DFO needs to continue to handle on a case by case basis.

4.3.2 Classification of Activities

Operational statements covered 25 specific activities in and around water (Table 3). In total there were 93 activity sub-categories available for use by habitat managers within the DFO Habitat tracking database (Program Activity Tracking for Habitat, PATH), and thus many were not covered by an OS. Operational Statements were specific to a province, but wording and conditions contained therein were similar when the category was the same. Conditions under which OS were applicable were similar across different categories, as were the ecological concerns surrounding a w/u/a within or around a water body (Table 3). Erosion, sedimentation, loss of riparian vegetation and introduction of deleterious substances appeared most frequently, and mitigation measures were provided for addressing these concerns in each case. In general it would be safe to consider that the types of activities covered in Table 3 remain low risk and do not need to be individually evaluated by DFO.

Over the past 5 years a total of 1,439 individual (non-class) authorizations were issued, of which 1,140 were assessed for risk level; of those 492 (43%) were considered high risk and 612 (54%) were considered medium risk and were issued individual authorizations. The vast majority of high risk projects were in riverine habitat (68%), followed by marine (17%), lacustrine (9%), estuarine (2.6%), wetland (1.6%), and riparian (1.4%). The medium risk referrals followed a near identical habitat distribution. While some activities covered under the OS categories fell into a high risk category (e.g., maintenance dredging, riparian vegetation management) these individual cases occurred in sensitive habitat or around a valuable fishery (e.g., lobster). In the same time period there were only 48 referrals that were rejected as proposed and did not receive an authorization but received a request for relocation or redesign of the project to avoid a harmful alteration, disruption or destruction (HADD). These projects usually involved direct mortality to a species at risk (SAR), timing concerns that could result in the killing of a large number of fish in a fishery, a negative impact to a sensitive area or species (e.g., dredging fish spawning habitat, insufficient flows in a salmonid spawning run), or a request for a variance in a Streamside Protection and Enhancement Area (SPEA) that did not meet the criteria for a variance. In some cases, it appeared that the DFO biologist recommended options that would mitigate or avoid the HADD, and the proponent redesigned the project in order to proceed.

4.3.3 Biological and Ecological Processes Affected by Activities

When the summary of high risk authorizations is examined, it becomes clear that both the triggers and ecological effects have commonalities across activities (Table 4). The most common triggers, regardless of the activity, include direct losses of productive habitat due to infilling, simplification of habitat (e.g., removal of aquatic or riparian vegetation), SAR presence, or direct killing of fishes. The direct loss of fish habitat or the direct mortality of fishes by means other than fishing is an obvious violation of the former *Fisheries Act*, but depending on the scale, habitat, and species involved, may or may not result in an impact to the ongoing productivity of a CRA fishery, and need to be examined on a case-by-case basis. Loss of habitat heterogeneity can result in the loss of prey and forage opportunities, and could lead to increased mortality via predation. Loss of riparian vegetation could result in the alteration of temperature dynamics and reduced shelter. Erosion and sedimentation concerns arise from almost all activities, particularly during the construction phase. Both of these habitat impacts also appear frequently in the OS activities and can often be mitigated if appropriate measures are applied. However, if sedimentation or erosion is a result of the activity itself (e.g., dredging) or because of the dynamics of the resulting habitat (e.g., reduced stability of banks), mitigation may not be possible and the result could be the smothering of habitat, loss of interstitial spaces, reduced invertebrate production, and mortality of sessile species. A change in instream flow is a relatively unique alteration resulting from water management/taking activities, and the installation of water control structures (e.g., dams, culverts) can result in habitat fragmentation, channelization, or the complete transformation of habitat type (e.g., reservoir from a river). Although several of these impacts are also discussed in Kenchington et al. (2013) on “supports”, it is clear from both ecological grounds and past practice that the impacts can also be managed on the basis of their potential for direct impacts on CRA fishery species.

The Operations branch of the Fisheries Protection Program compiled a list of works, undertakings and activities that similarly classified the impacts resulting from the 93 sub-categories into 6 impact types (Table 5). Previously, Pathways of Effect (PoE) diagrams were developed by DFO as a tool to communicate potential effects of referrals affecting fish and fish habitat and were developed through extensive consultation often with science and external experts (e.g., see Clarke et al. 2008). The PoE diagrams take the activity, link it to a stressor, and then link the stressor to the receptor or ecosystem component of concern. It follows that the PoE diagrams can be used as a mechanism to link the w/u/a being managed to the potential change in habitat, and ultimately to the impact on the ongoing productivity of the CRA fishery species. Table 5 completes the first step linking the impact type to w/u/a to the affected ecosystem component and thus the potential of the activity to change the ecosystem. The next step in this process is to assess how that activity will change the position of the affected ecosystem along the productivity-state relationship. The state change will be determined partially by the scale of the activity and by the type of ecosystem affected. A number of case studies could be assessed in the short term to illustrate the process, using Fig. 4 as a framework for guiding how an activity fits into the various potential productivity-state relationships under different scales and ecosystem types.

4.3.4 Relevant Findings for the Development of Policies under the New Fisheries Act

Activities that are similar to those listed in the OS, with potential ecological concerns that could be mitigated by the types of guidelines provided in the various OS, should fall into quadrant 1 (Fig. 1) and likely not need to be assessed by a referral biologist. However, in some cases it will be the scale of the activity or habitat type that will determine if there is potential for serious harm and if section 35(1) is triggered and the factors under Section 6 need to be considered. Since the initial assessment will be made by the proponent, it is important that criteria or thresholds be made clear such that they can make a sound judgement determining if an application to DFO is needed. There would be operational benefits if the initial assessment process could include a web-based questionnaire whereby a proponent follows through a decision flow chart that results in either an OS type of process or suggests a site-specific review is needed. As a proponent answers each question, the data could be collected for the low risk projects that will not require site specific review, allowing for the assessment of cumulative effects. If it is determined that a site-specific review by DFO is necessary, then additional details should be entered into PATH or a similar database. Such data collection tools will be invaluable and essential for the department to be able to assess the success of their program under the new Fisheries Protection Provisions in protecting fisheries of value to Canadians.

4.4 CURRENT STATUS AND CUMULATIVE EFFECTS

Implementation of this framework requires at least an approximation of the cumulative change that has occurred in the ecosystem where a decision is being made on a w/u/a. At a minimum, this needs to allow for an estimate of whether or not current state has exceeded an S1 threshold or other level of acceptable impact to the productivity of fishery species.

One possible approach to identifying current state along the productivity-state relationship is to use some of the human stressor indices that are available from the literature. For example, Chu et al. (2003) map human stresses in Canadian tertiary watersheds, then combine these human stresses with fish biodiversity and an environmental index (to measure ecosystem potential) to assess pressures on freshwater fishes at the watershed scale. Gergel et al. (2002) and Stanfield (2012) use landscape indicators as metrics of human impacts on streams. Dolbeth et al. (2012) argue that secondary production is a good indicator of human disturbance in aquatic ecosystems. Any of these approaches could be used as a surrogate for an initial assessment of cumulative effects. Low levels of human stress/pressure/impact would suggest that cumulative effects may not (yet) be an issue, while high levels of human stress/pressure/impact could be an indication that the S1 threshold (Fig. 2) may have been passed.

Another approach could be to use semi-quantitative data that can be combined with expert judgment to generate an index of the cumulative change exerted on an ecosystem. Some of the papers reviewed used this type of approach to identify a habitat concerns index (Bradford and Irvine 2000) or the level of human disturbance in a system (Pont et al. 2006). These composite indices can work as well as the available quantitative data, and in some cases, may more accurately reflect the multidimensionality of the cumulative change in an ecosystem better than a single quantitative variable.

4.5 RESEARCH NEEDS

To move this framework toward implementation will require additional research and science advice, including the following:

- A literature review to identify forms of the productivity-state relationship. The limited review conducted for this working paper shows that there is sufficient information in the scientific literature to inform the task of identifying at least some of the forms of the productivity-state relationship. This information should be extracted and summarized in support of management decisions about w/u/a. If there is sufficient information about the effect of human-induced change on fishery productivity, it may also be possible to develop the capability to predict the form of this relationship in ecosystems where data are limiting.

- Identification of specific shapes and thresholds for the productivity-state relationship based on ecosystem types and classes of activities. Developing the capability to generalize these relationships will help to inform a risk management framework that must make decisions on the basis of best available information.
- Evaluate the stability of shapes and thresholds of the productivity-state relationship for different levels of stock status.
- Dry-run a number of case studies using different activities that fall into the various shapes and thresholds in a range of ecosystem types to illustrate this process.

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Table 1. Examples of potential measures and surrogates of the ongoing productivity of CRA fishery species and state of the affected fish or habitats.

Productivity measures/surrogates	**State measures/surrogates**
Production	Mortality or survival
Surplus production	Quantity of available habitat
Catch	Barriers to movement
Yield	Prey availability/abundance/density
Biomass	Somatic growth
Abundance	Age/size at maturity
Density	Quality of available habitat
CPUE/BPUE	Rate of reproductive failure
Individual condition factor	Delayed/reduced reproduction
Recruitment	River flow rate
Body size	Habitat suitability index
Biodiversity	Disturbance index
Genetic diversity	Land use
Habitat productivity index	Sedimentation
Fish index	Habitat removals (e.g., dredging)
Community index	Turbidity
Species richness	Nutrients
Secondary production	

*Table 2**.** A brief review of a sub-sample of the scientific literature to identify potential productivity-state curves and thresholds. Descriptors of the form of the curve relate to those shown in Figure 4. References to tables and figures in the comments column refers to the tables and figures in the reviewed paper.*

Impact to Fish/Habitat	Ecological Response	Form of Curve	Threshold	Comments	Source
Tidal marsh access	Food consumption, diet, growth potential	Unspecified	Without tidal marsh access, fish consumed less food, shifted prey, and had lower growth potential		Madon (2008)
Biotic and abiotic drivers	Fish community	Unspecified		Reviews effects of predation, competition, climate, basin morphology, flow, chemistry, habitat heterogeneity on assembly of fish communities	Jackson et al. (2001)
Flow regime, net primary productivity	Species richness	Curvilinear		See Fig. 3	Guégan et al. (1998)
Proportional reduction of flow from base flow	Proportion of fish displaced	Curvilinear	Hypothetical, dependent on life stage with older life stages being more readily displaced	See Fig. 4	Young et al. (2011)
Winter O_2 and lake connectedness	Fish community	Unspecified	In low connected lakes, fish community loses large piscivores at winter O_2 levels ~ 6 mg/L; winter O_2 not a factor in highly connected lakes	See Fig. 5	Tonn and Magnusson (1982)
Chlorophyll-a	CPUE	Curvilinear, species-dependent	As Chl-a increases, catch dominance shifts from coregonids to perches to cyprinids		Persson et al. (1991)
Woody debris removal	Diet change and reduced growth of largemouth bass	Unspecified	Unknown; experiment was BACI design	See Fig. 4 & 5	Sass et al. (2006)
Habitat (coral) disturbance	Emigration	Unspecified	Habitat specialists showed less propensity to move and did not move as far as habitat generalists		Feary (2007)

Impact to Fish/Habitat	Ecological Response	Form of Curve	Threshold	Comments	Source
Dredging	Fish community total abundance or biomass	Unspecified	Dredged v undredged		Bilkovic (2010)
Nutrients, chemicals, NIS, temperature	Secondary production	Curvilinear		See Fig. 3 for conceptual model of changes in production from nutrient loadings	Dolbeth et al. (2012)
Land use (agriculture, urban, road density, logging)	Annual change in recruitment	Linear	None	See Fig. 2	Bradford and Irvine (2000)
Urbanisation (especially impervious cover)	Fish density, species richness, diversity, index of biotic integrity	Curvilinear	8-12%	See Fig. 1	Wang et al. (2001)
Urbanisation	Species diversity	Mostly curvilinear	8-15%	Based on literature review	Allan (2004)
Disturbance based on land use and water quality	Wetland fish community as measured by IBI	Unspecified	As disturbance increases, IBI decreases	See Fig. 5	Uzarski et al. (2005)
Impervious land cover	Fish and benthic community changes	Unspecified	8-10%	Based on literature review	Wheeler et al. (2005)
Human disturbance (a composite index)	Fish community (based on fish index)	Linear	Increasing human disturbance leads to lower fish index values	See Fig. 4	Pont et al. (2006)
Impervious land cover	Water quality index; rapid bioassement protocol score; benthic taxa richness; Hilsenhoff biotic index; habitat score	Curvilinear	Effects seen at 5% impervious cover; uniformly impaired by 10%	See Fig. 3	Shiff and Benoit (2007)
Urbanisation	Benthic index of biotic integrity	Unspecified; correlational	Correlational; negatively related to %impervious and %urban; positively related to %forest	See Table 4	DeGasperi et al. (2009)

Impact to Fish/Habitat	Ecological Response	Form of Curve	Threshold	Comments	Source
Landscape changes, especially hydrology and physico-chemical	Stream fish community composition	Unspecified	Fish species diversity, richness and biotic integrity were lower in streams with higher frequency of spate flows		Helms et al. (2009)
Mining	Fish community composition	Unspecified	Loss of larger, habitat specialist fishes replaced by smaller, ubiquitous fishes		Brosse et al. (2011)
Land use (agricultural, urban forest)	Fish community changes as measured by the European Fish Index (EFI)	Unspecified; thresholds based on a regression tree	~7% agriculture; ~2% urban; interactions	See Fig. 5 & 6 and Table 5	Trautwein et al. (2012)
Reduced abundance	Reduced abundance in trawl	Curvilinear	Unidentified		Rice (2009)
Mortality (modelled as fishing mortality)	Reduced yield; stock collapse	Unspecified, based on the lowest MSY mortality of all species modelled	5%	See Fig. 1 & 2	Gaichas et al. (2012)
Sedimentation	Reduced egg to fry survival	Varies by species, mostly curvilinear. Some show rapidly declining survival with sedimentation, some show a plateau before rapid decline	10% for sediments finer than 0.85 mm; 25-30% for other fine sediments	See Figs 1 & 2	Jensen et al. (2009)
Turbidity	Reduced egg survival	Unspecified	Increasing turbidity to ~5 NTU resulted in a 24% reduction in egg survival		Gray et al. (2012)

Table 3. Types of Operational Statements and the province in which they are applicable. Application conditions and ecological effect of concern are not unique to a particular OS. Note: OS are not used in the provinces of Nova Scotia, New Brunswick and PEI as there are pre-existing processes and agreements with the provincial government that are analogous to OS.

Operational Statement Title	Province	Application Conditions	Ecological Effect
Aquatic vegetation removal in lakes	BC, MB, NB, NL, QC	• All state that mitigation measures as outlined must be applied • All state that municipal, provincial and other federal guidelines/legislation must be followed (incl. SARA) • Can't be located in a class A stream; avoid spawning habitat • Habitat to be affected is small in area (e.g., alterations combined total < 25% of total riparian area; footprint of dock infill < $15m^2$ (ON, MB) <24m2 (BC) or $50m^2$ including structures above high water mark). • Water withdrawal will not exceed 10% of instantaneous flow • Riparian work occurs only above the high water mark • Explosive use limitations • Guidelines on use of heavy machinery • Guidelines on sediment and erosion control • Guidelines for timing of in water work (fisheries) • Revegetation guidelines • Guidelines for avoiding input of deleterious substances into the water • Guidelines for avoiding the entrainment or impingement of fish • Guidelines for types of materials to use for in-water structures.	• Sedimentation • Erosion • Disturb banks and bottom of waterbody • Disruption of sensitive habitat (e.g., spawning) • Alter water temperature • Alter groundwater flow • Flooding • Addition of deleterious substances • Alter riparian habitat • Barrier to fish movement • Spread of aquatic invasive species.
Beach creation for residential use	BC, MB, NL, ON, QC		
Beaver dam removal	AB, MB, NL, ON, SK		
Boat launching facility repair and reconstruction	NL		
Bridge maintenance	AB, BC, MB, NL, NT, NU, ON, QC, SK		
Clear span bridges	AB, BC, MB, NL, NT, NU, ON, QC, SK		
Cottage lot development	NL		
Culvert maintenance	AB, BC, MB, NL, NT, NU, ON, SK		
Dock and boathouse construction in freshwater	BC, MB, NL, NT, ON, QC		
High-pressure directional drilling	AB, BC, MB, NL, NT, ON, QC, SK		
Ice bridges and snow fills	AB, BC, MB, NL, NT, NU, ON, QC, SK		
Isolated or dry open-cut stream crossings	AB, BC, MB, NT, ON, QC, SK		
Isolated pond construction	AB, BC, MB, NL, ON, QC, SK		
Marine wharf repair & reconstruction	NL		
Maintenance of riparian vegetation in existing rights of way	AB, BC, MB, NL, NT, ON, QC, SK		
Mineral exploration activities	MB, NT, NU, ON		
Moorings	AB, BC, MB, NL, NT, NU, ON, QC		
Overhead Line construction	BC, MB, NL, NT, ON, QC, SK		
Public beach maintenance	BC, MB, NL, ON, QC, SK		
Punch & Bore crossings	AB, BC, MB, NL, NT, ON, QC, SK		
Routine maintenance dredging	AB, BC, MB, NL, NT, NU, ON, QC, SK		
Submerged log salvage	AB, MB, NL, ON, QC, SK		
Temporary stream crossing	AB, BC, MB, NL, NT, NU, ON, QC, SK		
Underwater cables	AB, BC, MB, NL, NT, ON, QC, SK		

Table 4. Summary of high risk authorizations issued over five years (2008-2012), the authorization trigger, and the ecological issue of concern listed in the authorization or the EA Screening.

Main Category (492)	Sub category	Trigger (examples)	Ecological effects
Watercourse crossing (161)	Culverts(84), bridges(50), open cut crossing(24), trenchless crossing(1)	Destruction of habitat due to infilling, alteration of habitat due to shoreline stabilization works, culvert installation, diversion often required, SAR presence	Loss of productive habitat, alteration of sediment characteristics and passage ability, temporary sedimentation and siltation issues.
Instream works (74)	Channel modifications(51), drain and ditch maintain(12), aquatic veg removal(4), debris removal(4)	Often emergency authorizations issued for flooding concerns. Most involve dredging. CRA fish species and SAR presence.	Simplification of habitat heterogeneity via removal complex habitat (instream vegetation, log jams), dredging and realignment of stream channels affecting valuable spawning habitat, sedimentation, siltation,
Structures in water (72)	Breakwater (22), wharf (13), boat launch (11), water intake(7), marina(6), marine terminal(5), docks and boathouse (1), fish weir(1)	Loss of fish habitat via infilling, often dredging involved, killing of fish at intakes and screens/fences, SAR presence.	Destruction of productive habitat, direct mortality of fishes, erosion and sedimentation, smothering of sessile species and invertebrates.
Water management (71)	Hydroelectric project(41), dam (13), diversion(8), water withdrawal(4), stormwater management(3), dyke(3), ponds(1)	Often s32 trigger due to stranding or entrainment of fishes (e.g., shutdowns for maintenance), often issued on an emergency basis, diversions result in the destruction, alteration and disruption of productive habitat, construction results in destruction of habitat, disruption of migration, operations result in permanent alteration of habitat.	Direct fish mortality, disruption of habitat due to dewatering, loss of forage, destruction of spawning, nursery and riparian habitat, flow alterations result in alteration of habitat (affecting behaviour, forage ability, growth, reproduction, survival), loss of access to habitat.
Shoreline works (39)	Infilling(18), shoreline stabilization(17), riparian vegetation management(1), groyne(1)	Often issued on an emergency basis particularly for shoreline stabilization, large areas of infill.	Loss of riparian and rearing habitat, reduction in food production and cover
Dredging (28)	Maintenance(15), new(13)	Large areas (e.g., 2600m^2, 4000m^2, 9000m^2), large volumes (e.g., 260,000m^3), ocean disposal triggers s32.	Temporary invertebrate production loss, minimal riparian loss for habitat, sedimentation, destabilization of gravel bed resulting in loss of spawning and rearing areas, morphological simplification, smothering of fishes.

Main Category (492)	Sub category	Trigger (examples)	Ecological effects
Mineral aggregate, oil & gas exploration, extraction, production (18)	Hard rock mining(7), placer mining(5), tailings impoundment area(4), production well offshore(1)	Loss of large areas of fish habitat (e.g., 14,459 m^2 riverine and 36,270m^2 lacustrine), SAR presence, dewatering, use of explosives	Direct loss of productivity due to dewatering and infilling, increased turbidity and sedimentation, obstruction of fish passage, introduction of deleterious substances, reduction in flow and baseflow, increase temperature,
Log handling (6)	Log dump into water(6)	Introduction of log waste debris over large areas.	Burial of benthic habitat, loss of habitat heterogeneity (vegetation), increase of anaerobic decomposition, sedimentation, loss of riparian vegetation for access
Contaminated site (6)	Contaminated site remediation(6)	Destruction of riparian and wetland habitat to allow for construction of an engineered wetland; capping contaminated sediment with coarse sand; temporary diversion of creek due to leaking oil pipeline.	Loss of food and nutrient production for downstream habitat; loss of aquatic vegetation, sedimentation, disruption to the food supply, direct loss of habitat due to dewatering creek, sedimentation from diversion channel.
Habitat improvement (2)	Habitat restoration(2)	Infilling due to construction of berms/dykes to create shallow embayment/wetlands.	Loss of low productivity habitat to create high productivity habitat.
Control nuisance species(1)	Installation and application(1)	Infilling due to installation of control structure, exclusion of spawning fish due to carp control measures.	Loss of habitat.
Other (10)	E.g., use of explosives, plant maintenance, penstock maintenance,	Fish kills due to substantial dewatering, explosives.	Direct fish mortality.

Table 5. List of works, undertakings and activities classified by impact type and linked to the Pathways of Effects and ecosystem component of concern from those Pathways diagrams.

Impact Type	**Works/Undertakings/Activities**	**Pathway of Effect Title**	**Effect on Ecosystem Component (from Pathways of Effects)**
Infilling/footprint	Any structure constructed within a water body (e.g., piers, abutments, dams, bridges, culverts, wind turbines), urban, cottage and harbour development (e.g., docks, boathouses, moorings, wharves, breakwaters, berms, groynes, boat launches and ramps), shoreline stabilization works (e.g., retaining walls, rock protection, erosion control, armouring)	Placement of Material or Structures in Water; Fish Passage Issues; Structure Removal; Offshore Renewable Energy Technologies: Construction and operation; Aquaculture: Placement/removal of site infrastructure.	Change in structure and cover of habitat, change in food supply, change in nutrient concentrations, change in sediment concentrations, change in access to habitat, change in contaminant concentrations, change in sediment transport, erosion and deposition patterns, change in hydrodynamic characteristics and patterns.
Deposition of non-deleterious substances in water	Organic material from aquaculture facilities operations, logging operations, or open water dredging spoils.	Dredging; Excavation; Aquaculture Site and Stock Management.	Change in structure and cover of habitat, change in sediment concentrations, change in food supply, change in contaminant concentrations, change in nutrient concentrations, mortality of organisms, change in dissolved oxygen, change in water temperature, change in baseflow, change in primary productivity.
Changes in Flows/Water levels	Water taking including groundwater/upwelling extraction (e.g., bottling, municipal, industrial, agricultural, thermal/nuclear generating station uses) and operation of water control structures (e.g., hydro). Water deposition.	Change in Timing, Duration, and Frequency of Flow; Water Extraction; Fish Passage Issues; Wastewater Management	Displacement or stranding of fish, change in migration/access to habitats, change in sediment concentrations, change in habitat structure and cover, change in food supply, change in water temperature, change in contaminant concentrations, change in nutrient concentrations, change in total gas pressure, change in salinity, change in dissolved oxygen, pathogens, disease vectors, exotics.
Dredging and excavating	Any dredging or excavation below the high water mark (e.g., for recreational purposes, navigation, mining and oil sands projects, aggregate removal, drainage maintenance, under water cables and pipelines).	Dredging; Excavation; Vegetation Clearing; Addition or Removal of Aquatic Vegetation; Organic Debris Management	Change in food supply, change in water temperature, change in sediment concentrations, change in baseflow, change in structure and cover of habitat, change in contaminant concentrations, change in nutrient concentrations, change in dissolved oxygen.
Permanent watercourse alteration	Realignment/relocation, obstruction to fish passage, channel modification, channelization, reservoir creation (e.g., from culverts and dams), water control structures.	Fish Passage Issues;	Change in access to habitat, change in thermal cues or temperature barriers, changes in total gas pressure, changes in salinity, interbasin transfer of species.

Impact Type	Works/Undertakings/Activities	Pathway of Effect Title	Effect on Ecosystem Component (from Pathways of Effects)
Fish mortality	Killing of fish via use of explosives (in or near water), turbine operations (tidal power and hydro dams and spillways), dewatering and temporary flow diversions, impingement of fish onto screens and fences, or entrainment.	Water Extraction; Fish Passage Issues; Use of Explosives; Use of Industrial Equipment; Marine Seismic Surveys; Streamside Livestock Grazing; Offshore Renewable Energy Technologies: site investigation, construction, maintenance, decommissioning, operation	Lethal or sublethal effects on fishes/eggs/ova; direct or indirect mortality of fish.
Fish disturbance	Any W/U/A in water generating noise, vibration, electromagnetic radiation, or light.	Use of Industrial Equipment; Use of Explosives; Marine Seismic Surveys; Offshore Renewable Energy Technologies: site investigation, construction, maintenance, decommissioning, operation	Physiological effects on fishes, change in sediment concentrations, change in contaminant concentrations, change in nutrient concentrations, change in habitat structure and cover, change in access to habitat, change in migration/movement patterns, change in behaviour, communication and/or navigation or orientation.
Riparian alteration	Affecting riparian vegetation, riparian slope, or direct inputs into water from land-based activities.	Vegetation Clearing; Riparian Planting; Cleaning or Maintenance of Bridges or Other Structures; Grading; Use of Industrial Equipment; Streamside Livestock Grazing.	Change in habitat structure and cover, change in sediment concentrations, change in water temperature, change in food supply, change in nutrient concentrations, change in contaminant concentrations, change in pathogens/bacterial levels, chemical barrier to fish passage.