A SCIENCE-BASED FRAMEWORK FOR ASSESSING THE RESPONSE OF FISHERIES PRODUCTIVITY TO STATE OF SPECIES OR HABITATS

Figure 1: Department of Fisheries and Oceans' (DFO) six administrative regions.

Context

In June 2012, the Government of Canada introduced amendments to the Fisheries Act*. While many of these amendments are not yet in force, the Fisheries Protection Provisions (FPP) made substantive changes to the protection of Canadian fishes and fish habitat. Scientific advice and support are needed to inform implementation of the FPP. Specifically, the FPP include an explicit purpose for decision-making to provide for the sustainability and ongoing productivity of commercial, recreational and Aboriginal (CRA) fisheries (Section 6.1), and a need to consider the contribution to CRA fisheries productivity when making decisions related to serious harm to fish and permanent alteration to fish habitat (Section 6 of Fisheries Act).*

Previous science advice (DFO 2012) has been provided, including biological interpretations of the terms productivity *and* contribution*, and a framework to guide how the contribution of the relevant fish to the ongoing productivity of CRA fisheries should be evaluated. The contribution framework considers how the productivity of CRA fishery species will be affected by changing the state of species or habitats likely to be affected by human activities. The framework allows consideration of both the direct impacts of a project on productivity of CRA fisheries and the potential cumulative impacts when new or increased stressors (e.g., change of flow regime, addition of nutrients, or sedimentation) are introduced. Such new or increased stressors may initially have no measurable impact on productivity, but alter the state of affected species or habitats in ways that interact with other stressors to decrease productivity.*

To implement this framework, an expectation of how productivity will respond to state changes in specific aspects of fish habitat is required. The Pathways of Effect (PoE) can be used to link human activities to state changes in habitat features. Productivity-state response curves then form the link from changes in state of habitat features to changes in productivity. In this SAR a number of PoE endpoints are assessed and operational advice and guidance is provided on these productivity-state relationships.

This Science Advisory Report is from the March 12-14, 2013 National Peer Review on Additional Science Guidance for Fisheries Protection Policy: Science-based Operational tools for Implementation. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

SUMMARY

- This SAR provides examples of productivity-state (P-S) response relationships which describe the likely response of fisheries productivity to various common types of habitat changes. Pathways of Effect (PoE) are used to link classes of development activities (stressors) to the types of habitat changes they are likely to cause.
- The operational examples provided within this SAR demonstrate that the productivity responses to changes in state can be described and quantified. For some habitat features affected by stressors, it is possible to identify thresholds based on the scientific literature (e.g., change in temperature; effects of noise and vibration, relationship between flow and fish community response). For other features it may not be possible to identify thresholds given the state of current knowledge (e.g., effects of electromagnetic fields).
- Not all P-S response curves exhibit the same shape. For the PoE endpoints examined here, the identifiable shapes mostly exhibit a curvilinear or linear response of decreasing productivity, though other shapes are possible.
- Most often these P-S response relationships (response curves) are described based on metrics or surrogates of productivity.
- The appendices to this report provide operational guidance to Departmental officials, stakeholders and developers on the likely shape of the response of fisheries productivity to changes in state of species and/or habitats.

INTRODUCTION

The 2012 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) includes section 6.1 (the purpose for decision-making): to provide for the sustainability and ongoing productivity of commercial, recreational, or Aboriginal (CRA) fisheries". These FPP replace the former Fish Habitat Protection Provisions, and 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 CRA 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 allows the Minister of Fisheries and Oceans to authorize a work, undertaking, or activity (w/u/a) that causes serious harm to fish, if this is considered acceptable after taking specified factors into account. Section 6 of the amended *Fisheries Act*, identifies the factors for Ministerial consideration in decision-making:

a) the contribution of the relevant fish to the ongoing productivity of commercial, recreational or Aboriginal fisheries;
b) fisheries management objectives;
c) whether there are measures and standards to avoid, mitigate or offset serious harm to fish that are part of a commercial, recreational or Aboriginal fishery, or that support such a fishery; and
d) the public interest.

Taken together, the purpose (Section 6.1), a prohibition (Section 35), and factors for Ministerial consideration (Section 6) introduce the need for metrics of productivity and methods to assess how a project may affect productivity. This current SAR was requested in order to build upon the initial Science advice for Fisheries Protection (DFO 2012) that introduced a conceptual framework (productivity-response curves) for evaluating potential impacts of individual projects on productivity via changes in habitat or fish populations. The productivity-response curves provide linkages from the PoE to productivity.

When the assessment phases outlined in DFO (2013a) (hereafter the “Productivity SAR”) indicate that there is a likelihood that a project will affect the productivity of relevant fish (where “relevant species” are all fish that are part of CRA fisheries or that support such fisheries), through direct mortality or impacts on fish habitat, then further analyses are required to estimate the magnitude of the impacts on productivity.

The principal focus for this phase of analysis is the productivity-response curves developed for most endpoints of PoE models and most common types of freshwater habitats in Canada (although some literature on marine processes has also been incorporated). The guidance from DFO (2013a) (i.e., the “Productivity SAR”) assumes that a PoE exists for the major classes of stressors (projects) of concern and link endpoints from the PoE to life history aspects of fish productivity. The guidance in this SAR places the potential impacts of the specific project, including direct mortality, into an ecological context appropriate to the activity: the species affected, the features of the freshwater habitat type being affected, and the history of other human impacts on the habitat or fishery. Based on this information DFO FPP staff will be better informed to support or make many of the necessary decisions outlined in the Context section of this SAR.

The scale of the project and its impacts, and the species and habitats being affected will all influence the extent to which potential impacts on productivity need to be described, and in some cases quantified. As a generalization (with exceptions), projects expected to have larger impacts or those impacting rare or protected species or habitat types will usually require greater quantification of impacts than projects expected to have small impacts, and impacts on widespread and abundant species or habitats. The guidance and information in this current SAR and the “Productivity SAR” (DFO 2013a) will constitute the core approach to such quantifications. However, full quantification of impacts on productivity will often require additional advice on use of particular metrics and indicators of productivity, and more complex decisions will include considerations relevant to trade-offs and offsetting of residual impacts. Guidance on such quantitative aspects of evaluating potential impacts of projects on productivity will be developed in future SARs, as will a more detailed examination of impacts and response curves appropriate for projects in estuarine, coastal and marine environments.

ASSESSMENT

Productivity-State Response Curves

The contribution framework (Fig. 1) considers how the productivity of CRA fishery species will be affected by changing the state of species or habitats likely to be affected by human activities. The shape of the productivity-state (P-S) response curve may take different forms (DFO 2012, Koops et al. unpublished manuscript[1]), and may be a function of species, life stage, ecosystem, season, or stock status. No direction was provided in DFO (2013a) on how to choose among possible P-S response curves in specific cases beyond the need to conduct further reviews of the literature. However, conducting a review of the scientific literature to support each individual decision made by a management program is neither feasible not likely to result in consistent practice. This SAR provides advice on the selection of P-S response curves for many situations likely to be encountered in practice.

[1] Koops, M. A., Randall, R. G., Clarke, K. D., Enders, E. C., Smokorowski, K. E., Doka, S. E., Watkinson, D. A., and Bradford, M. J. 2013. A Review of Scientific Evidence Supporting Generic Productivity-State Response Curves. Unpublished manuscript.

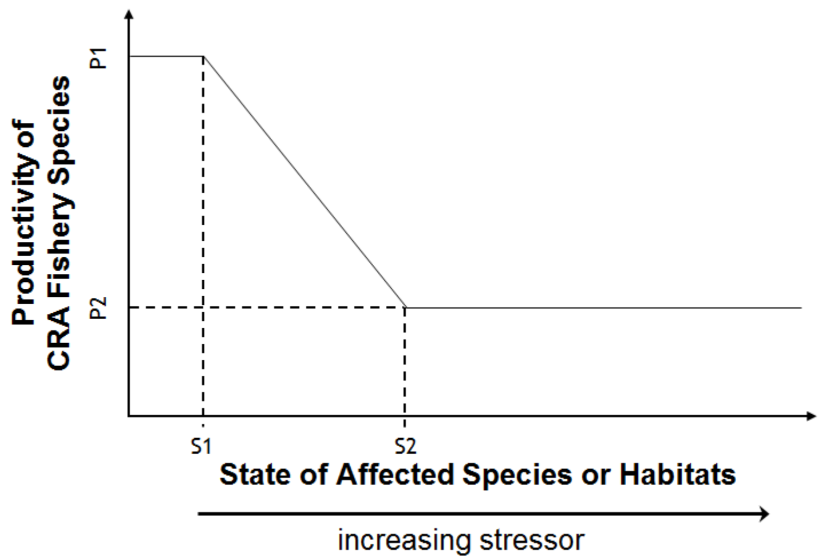

Figure 2: Schematic of the contribution framework. The y-axis represents productivity measured along a continuum from low (bottom) to high (top). The x-axis represents state along a continuum from good (left) to poor (right), movement along the x-axis represents a change in state of species or habitats as stressors increase. Four reference points are identified: P1 is the benchmark reference productivity of the CRA fishery species; P2 is the depressed productivity of the CRA fishery species under maximum total or cumulative change to the affected species or habitats; S1 is a threshold state to the left of which stressors have little or no impact on fishery productivity (i.e., the upper plateau) and to the right of which productivity declines as state is further reduced; S2 is the threshold where the maximum total or cumulative is large enough to eliminate the contribution of the affected species or habitats to the ongoing productivity of the CRA fishery species (i.e., the lower plateau).

The availability of information will determine the specificity with which P-S response curves can be described. There are three options:

1) When little or no information is available about the form of the response of fisheries productivity to changes in state, a default response curve can be used to support decisions.
2) When information is available in the scientific literature to identify the shape of the P-S response curve, generic curves may be described based on the literature. These can be based on other species or ecosystems than the one of concern, as long some justification can be provided for generalizing across species or ecosystems. Generic curves should provide a closer estimate of the shape of the curve than the default option.
3) When extensive site-specific information is available, it may be possible to describe species- or site-specific P-S response curves. There are strong scientific reasons to favour this approach conceptually, but is likely to be the exception as few species or ecosystems have been investigated fully enough to construct site-specific curves. However, if sufficient species- or ecosystem-specific information exists, it is preferable to use this information to support decision making.

In this SAR, first, a default P-S response curve is described, and then a rationale for choosing a generic P-S response curve for particular pressures and PoE endpoints (based on a review of the scientific literature), is provided for a sub-set of pathway of effect (PoE) endpoints.

Methods for development of P-S curves:

For each PoE endpoint, the scientific literature was reviewed to identify (i) how the stressor represented by the endpoint is expected to influence fishery productivity, (ii) appropriate metrics of productivity, (iii) evidence for a generic productivity-state response curve, and (iv) any conditions that may modify the form of the response curve. In recognition of the interconnectedness of many of the effects considered, response curves are often cross-referenced instead of repeating information. These cross-references point to other P-S response curves that may be relevant to decisions due to inter-related effects.

The generic P-S response curves are based on the current best available information, and are expected to be revised when sufficient new knowledge is available. Because they are generalized curves for a given stressor, they may not represent any specific species or ecosystem with accuracy and precision, but are intended to describe how productivity is generally expected to respond to increases in a stressor over a reasonable range of stressor levels. The presented graphs have no quantitative scales, because it is biologically inappropriate to establish any universal absolute benchmarks for changes in productivity or changes in habitat features. Species life histories and intrinsic productivities, and their sensitivities to the state and trends in different types of habitat features differ too greatly for a single number on either axis to ecologically represent the same thing for all species and ecosystems. Notwithstanding this specificity, the origin of each graph can be taken as (0, 0); that is, the lowermost point on the productivity axis is considered to be the situation where the species of concern cannot maintain any fisheries productivity in the area of interest. The left-most position on the state axis is considered to be the case where the habitat is in its baseline condition.

The establishment of the 'baseline condition' against which potential impacts are evaluated is a policy decision. Environmental policies (including fishery objectives) may provide guidance on the acceptable level of historic impact, and specify the operational baseline as either a particular state of the habitat or population, or its state at a particular time. Lacking policy guidance, the 'pristine' state of the ecosystem should be assumed.

Defining the baseline condition for the x-axis for specific ecosystems will require further consideration by both policy and science.

However the origin of the x axis is defined, many species and habitats will not be at the y-intercept of these response curves at the time a project is being assessed. Determination of the current state of affected species or habitats will be needed. Among the considerations yet to be fully addressed are how past impacts on the area impacted by the project should be taken into account, and how cumulative effects of either multiple different activities in the same area or multiple repetitions of similar projects in adjacent areas should be treated in each project assessment. Likewise the uppermost position (the y-intercept) on the productivity axis can be ecologically interpreted as any of; the maximum sustainable productivity, the productivity of a healthy population, or the productivity associated with the fisheries management objectives. Finally, the rightmost position on the x- axis is intrinsically open-ended. It cannot always be considered as change so large that the habitat feature no longer exists. Whereas some features (such as macrophyte cover) can be totally eliminated, for features like temperature there cannot be a case when there is "no temperature", although there certainly can be cases where temperature has changed to the point where it is outside the thermal tolerance of the species of concern. In other cases even elimination of a feature may not result in the metric of productivity falling to zero, because some species may be able to maintain non-zero productivity even when a feature like cover is totally eliminated. In these response curves we have tried to represent the scale of the state axis as the range of impacts considered to include the plausible "worst-case scenario" for the extent to which a habitat feature may be altered by a single project. In some response curves this means that the response curve will have an intercept with the state axis (i.e., the size of the habitat change is large enough to eliminate productivity) and in other curves, based on the best available evidence, it will not (i.e., there is some, if reduced, productivity, even at the most extreme plausible habitat change).

Multiple curves are presented in cases where the shape of the curve may depend on the described modifiers. In some cases, there may be a subsidy-stress response, where an initial addition of some stressor could increase productivity. While this response is real and documented in the scientific literature, it is not relevant to the assessment of potential loss of productivity. A subsidy may be relevant to a consideration of offsets.

Default P-S Response Curve

When no information is available to identify the shape of the P-S response curve, the precautionary choice is a linear response (Fig. 3). This choice avoids assumptions about the existence of an initial plateau or increase in productivity at low levels of pressure or change in species or habitat. Essentially, in the interest of protecting fisheries and providing for their sustainability and ongoing productivity, the default assumption should be that any stressor that degrades the state of affected species or habitats will lead to a directly proportional decrease in fisheries productivity. The slope of the proportionality is from maximum plausible productivity in the baseline habitat or population state, to zero productivity in the habitat or population state considered to be incapable of supporting any productivity. Choosing an alternate P-S response curve as a default would risk the authorization of activities that will reduce fisheries productivity under the mistaken assumption that fisheries productivity is not being negatively affected.

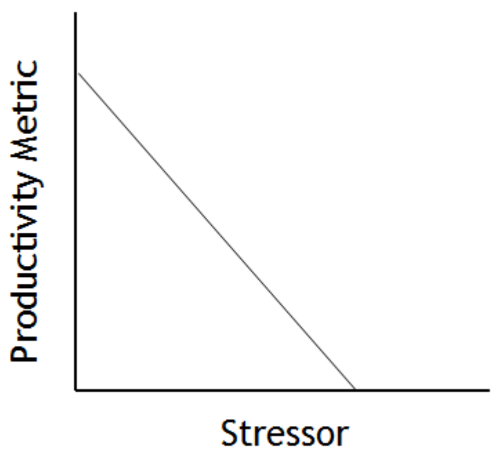

Figure 3: Proposed default productivity-state response curve when little or no information is available about the form of the response of fisheries productivity to changes in state.

Generic P-S Response Curves

While there is variability among the described productivity-state (P-S) response curves (Fig. 4), most demonstrate a curvilinear shape with the potential for an upper plateau and an initial (S1) threshold. Most of the response curves also show that there is potential for these stressors to reduce fishery productivity to zero if expressed strongly enough. In some cases, a linear response curve was a possibility, reinforcing the argument for use of a linear default P-S response curve when information is limited.

The rationales for identification of generic productivity-state response curves for 12 Pathways of Effect (PoE) endpoints are found in Appendices 1-13 below.

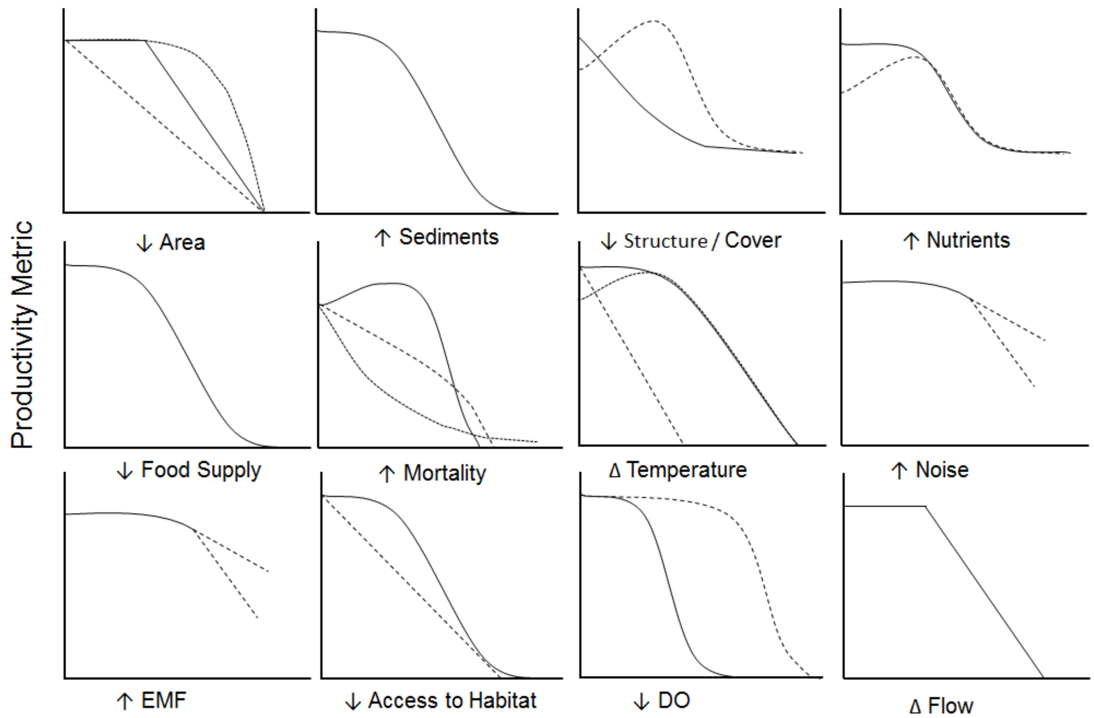

Figure 4: Generic productivity-state (P-S) response curves described for 12 pathway of effect (PoE) endpoints. No curve is shown for change in light (see below for explanation). The dotted/dashed lines indicate potential responses of various productivity metrics to stressors. Please refer to the relevant sections further in this document (and the accompanying Research Document) for additional explanations.

Sources of Uncertainty

Potential sources of uncertainty are relevant to the particular stressor in question. For a detailed discussion about sources of uncertainty, please refer to Appendices 1-13 below.

CONCLUSION

This SAR summarizes the findings of an associated Research Document (Koops et al. unpublished manuscript[1]) to provide examples of productivity-state (P-S) response curves. Consistent with the FPP, these curves are described based on metrics or surrogates of productivity (see DFO 2013a), and core features of habitats or populations that PoE analyses have concluded are likely to be altered by various classes of projects. The examples within this SAR demonstrate that the productivity responses to changes in state can be described and quantified, and for some stressors it is possible to identify thresholds based on the scientific literature. Not all P-S response curves exhibit the same shape. Of the identifiable shapes most exhibit a curvilinear or linear response of decreasing productivity, though other shapes are documented or hypothesized.

OTHER CONSIDERATIONS

Cumulative effects and multiple stressors are outstanding issues that need additional consideration. When making decisions, both the accumulation of effects from multiple impacts and the impacts from more than one stressor from a single project will need to be considered. Some of the scientific literature suggests that cumulative effects may be best considered at a strategic or regional level instead of the project level. The P-S response curves presented fit well in a cumulative effects assessment framework, but as currently developed are not a complete consideration of cumulative effects. Project level decisions typically will need to consider the impacts of multiple stressors from a given project. Each P-S response curve is presented as a productivity response to a single stressor (e.g.,, change in temperature or change in cover). Most projects will involve multiple stressors, and some stressors may interact (e.g., removing cover can affect temperatures).

No advice is provided here on combining the effects of multiple stressors from a single project. Future science advice should be sought on the handling of multiple stressors and cumulative effects in support of FPP decisions, as these have important implications for quantifying impacts on fisheries productivity and implementation of the Fisheries Protection Provisions.

Projects which do not cause measurable changes to habitats or populations cannot be said to meet the criteria of “serious harm” in the *Act*, and this framework cannot be applied. Nonetheless for pressures where the response curves predict substantial loss of productivity over some range of the habitat or population feature represented by the x-axis, other tools for managing the number of projects in a watershed might be desirable.

Additional Science work is required to provide guidance for defining the ‘baseline condition’ for the x-axis for specific ecosystems.

Finally, there is a need to periodically re-visit the advice within this report, particularly to update the Annexes as new information becomes available, and/or to include new stressors not addressed in this report, and to provide a more detailed examination of impacts and response curves appropriate for projects in estuarine, coastal and marine environments.

SOURCES OF INFORMATION

This Science Advisory Report is from the March 12-14, 2013 National Peer Review on Additional Science Guidance for Fisheries Protection Policy: Science-based Operational tools for Implementation. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

DFO. 2009. A Fishery Decision-Making Framework Incorporating the Precautionary Approach.

DFO. 2012. Science Advice to Support Development of a Fisheries Protection Policy for Canada. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2012/063.

DFO. 2013a. A science-based framework for assessing changes in productivity, within the context of the amended *Fisheries Act.* DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2013/071.

DFO. 2013b. Framework for Assessing the Ecological Flow Requirements to Support Fisheries in Canada. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2013/017.

APPENDIX 1: LOSS OF WETTED AREA

Loss of wetted area is a permanent loss in surface area (from wet to dry) of river, lake, estuary or coastal marine habitat. Loss of wetted area impacts fisheries productivity because it results in a reduction in the habitat available for occupancy and consequently may reduce the maximum sustainable population size (carrying capacity). This will occur whenever population carrying capacity (and fishing yield) is proportional to the size of the habitat area.

Typical Causes:

- Any in-water project that results in a loss of wetted area, including:
  - Infilling, i.e., the deposition of materials onto the bottom of any water body
  - Placement of structures in water that create a footprint (e.g., footings for bridge)
  - Whole lake destruction (such as lake disposal of tailings from a mine)
  - Man-made barriers that prevent fish access to habitat (described under: "Change in Access to Habitat").

Relationship:

- The relationship between the habitat area (x axis) and productivity (y axis) is curvilinear, with a sharp decline in productivity beyond a certain threshold of area loss (see figure)
- The width of the upper plateau before the threshold depends on habitat type and habitat supply, ranging from zero (no threshold if habitat is unique and not abundant elsewhere) to wide (if the type of habitat is abundant elsewhere and the species' life history allows some compensatory processes in alternative areas)
- The linear relationship (no threshold and proportional reduction in productivity) is the precautionary default (conservative)

Even if the relationship is curvilinear, it can be approximated with linear or segmented-linear regression, with linear the preferred approximation (when there is no reason to expect a broad plateau before the threshold), and with segmented regression another possibility (if there is reason to expect a plateau).

Mechanisms:

- Loss of wetted area impacts fisheries productivity because it results in a reduction in the habitat available for occupancy and consequently may reduce the maximum sustainable population size (carrying capacity)**.**
- Many vital rates, including recruitment, growth, survival and movements, are linked to area of occupancy. Hence population carrying capacity (and fishing yield) is proportional to the size of the habitat area.

Evidence:

- The habitat area-productivity relationships are based on science literature:
  - Quantitative habitat-population models
  - Habitat area-based conservation limits from fisheries management plans (e.g., 2.4 eggs/m^2 for Atlantic salmon)
  - Empirical stock-recruitment models showing some compensation or at least density dependence in the response of productivity (R) to spawning population size, and by inference to habitat available to support the spawning population
  - Empirical ecosystem-scale predictive models of fish biomass, production or yield

Metrics:

- State axis indicator (stressor) of the relationship is the quantity of each habitat type for which loss occurs.
- Productivity axis indicators (productivity) depend on the spatial scale of the project. For small to medium scale projects, which can be measured in square metres, the indictors are: growth, survival, reproduction, movements or other life history features. To infer the effects of small or medium sized projects on productivity for an entire fishery, the local loss of productivity (y-axis) should be scaled by the proportion that the area of affected habitat represents of the total habitat available to the population (full range of the x-axis).
- Alternatively, small or medium scale habitat assessments can be made by applying a similar proportional 'down-scaling' from knowledge of regional productivity to the relative size of the impacted area
- For large scale projects, measured in hectares (ha), the indicators are: production, biomass, abundance or yield

Modifiers:

- The generalized area-productivity relationship and the inferred loss of carrying capacity would apply to most regions of Canada.
- However, factors affecting the specific plateau and slope of the relationship include:
    - Ecosystem: the threshold and slope are related to ecosystem productivity (narrower plateau and steeper slope for highly productive ecosystems such as coastal wetlands and estuaries than for less productive ecosystems such as exposed coastal marine areas or exposed shorelines of large lakes)
    - Habitat type: reduced or no plateau and steep slope if habitat is unique (rare), essential fish habitat (important fitness consequences), or an ecologically significant area for other reasons (habitat that supports relatively high productivity and biodiversity)
    - Habitat supply: reduced or no plateau if the extent of similar habitat in the vicinity of the project is limited
    - Body size: for both species and life stages within species, large-bodied fish require more area per individual than small-bodied fish. Thus the threshold and slope of the area-productivity relationship depends on both the species and life stage.

Cautions:

- In addition to the loss of wetted area, habitat quality in the vicinity of the project may be affected, if residual effects occur despite mitigation.
- If local habitat is affected, other PoE endpoints of concern are change in habitat structure and cover, change in sediment concentrations and their relevant response curves. These endpoints can affect productivity because of impacts to vital rates.
- Impacts of small or medium scale projects would be difficult to measure at a CRA fish population scale, but cumulatively could be significant.
- If access to habitat is changed, curvilinear relationships would apply (described under "Change in Access to Habitat").

Other relevant curves:

- See Baseflow and Hydrodyamics. The loss of wetted area can affect many other physical parameters and should not be considered in isolation. Response curves for water temperature, oxygen, nutrient concentrations, access to habitat, and sedimentation are relevant with respect to loss of wetted area.

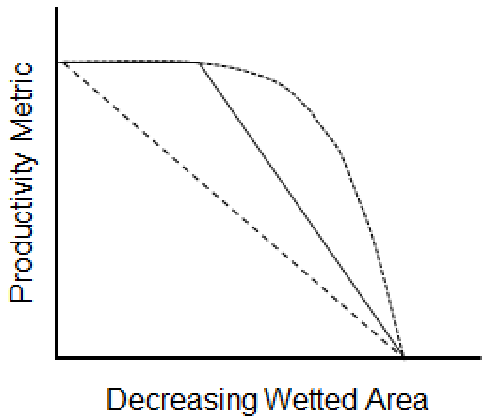

Figure 5: Response of fisheries productivity to decreasing wetted area.

Synopsis:

- The generalized relationships between loss of wetted area and productivity, showing response functions that are linear (default; dashed), segmented (solid line), or curvilinear.
- Data from the literature strongly support the curvilinear relationship.
- The width of the upper plateau, before a decline in productivity, depends on habitat supply and the habitat type being lost to the footprint or altered in the vicinity of the project. There would be no threshold if the lost habitat is unique or essential (high suitability) but a wider threshold if there is abundant habitat of a similar type in the vicinity.

APPENDIX 2: CHANGE IN SEDIMENT CONCENTRATION

Typical Causes:

- A change in sediment concentration can result from increases in either suspended sediment in the water column or fine material in the streambed. This endpoint appears in most of the current PoE from both land-based and in-water activities. It is well documented that response of fish to suspended sediment is a function of sediment concentration and duration of exposure.

Relationship:

- The relationship is non-linear. There is evidence for an initial plateau where small increases in sediment concentration do not have significant impacts on productivity. Very high suspended sediment concentrations can kill fish. Lower concentrations can elicit sub-lethal, behavioural and growth effects, including reduced egg survival. The width of the upper plateau and the rate of decline will be dependent on species and local environmental conditions.
- Increases in sediment concentration can affect fishery productivity through the following mechanisms:
    - fish habitat with increased sediment accumulation fills interstitial spaces, making these spaces less suitable for egg survival and larval emergence reduced by sediment accumulation;
    - direct physiological effects, especially sublethal effects;
    - foraging and growth is reduced by increased turbidity, decreased primary production and macrophyte growth, and reduced benthic invertebrates;
    - behavioural avoidance of turbidity (when possible); turbidity is known to break down behaviours such as dominance hierarchies, territoriality, schooling, etc.;

As a result of these types of processes, fish abundance is reduced and community structure changes with sediment accumulation in streams.

Mechanisms:

- A change in sediment concentration can result from increases in either suspended sediment in the water column or mobilization of fine material in the streambed. Suspended sediments can interfere with various biological and/or physiological functions of fish which are not acclimatized to such levels of sediment.

Evidence:

- The majority of studies have been conducted on salmonids; where studies have been conducted on other fishes, the results are generally consistent with those from salmon. The exceptions are fishes that use soft sediments; these fishes can be more abundant in streams with increased turbidity.

Metrics:

- Productivity metrics include fish production, fish abundance, fish community structure, survival, and growth.

Modifiers:

- Potential modifiers of the impact of sediment concentration on fishery productivity include duration of exposure (shorter exposures have lower impacts), stream flow rates (higher flow rates clear sediments more effectively), fish body size (smaller body sizes are associated with lower tolerance to sediment), and temperature (less tolerance at lower temperatures). These modifiers can change the width of the upper plateau or the steepness of the declining portion of the response curve, but they are not expected to change the curvilinear shape of the response curve.

Other relevant curves:

- Other response curves that can affect the response to changes in sediment concentration include temperature, baseflow, and hydrodynamics. Changes in sediment concentration can also interact with changes in structure and cover, nutrient concentration, food supply, access to habitat, light, and dissolved oxygen.

Cautions:

- Some fish species (e.g., Bull Trout) and life stages (e.g., early life history) can be particularly sensitive to increases in sediment concentration. These sensitive species and life stages may have little or no initial plateau, exhibiting declines in productivity with any sediment increases.

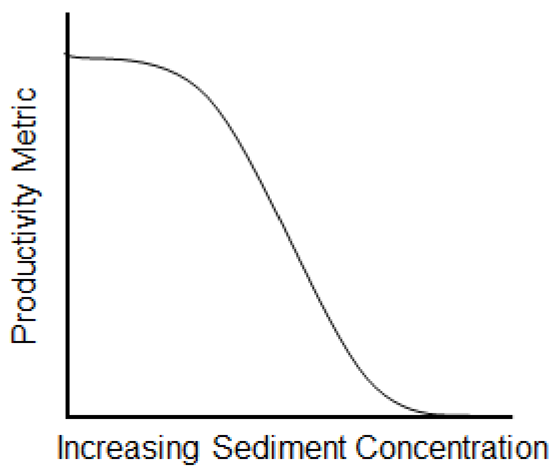

Figure 6: Response of fisheries productivity to increasing sediment concentration.

Synopsis:

- Fisheries productivity can be reduced through increases in either suspended or deposited sediments.
- There is extensive evidence that sediment can kill fish, elicit sub-lethal, behavioural and growth effects, and reduce egg survival.
- Sediment effects can be worsened by longer exposure time, lower flow rates, and lower temperatures. These conditions may narrow the initial plateau or steepen the rate of decline of the response curve.
- Some species or life stages may be more sensitive to sediments than other species or life stages.

APPENDIX 3: CHANGE IN STRUCTURE AND COVER

Typical Causes:

- A change in structural heterogeneity results from projects that reduce habitat complexity (e.g., dredging, channel realignment, shoreline stabilization, riparian clearing), or less frequently from projects that increase structural habitat complexity (e.g., habitat restoration via addition of boulders, woody debris, etc.).

Relationship:

- Experimental evidence supports a direct and proportional (linear) relationship between most aspects of habitat structure and cover and fishery productivity, but the maximum reduction may not result in zero productivity since habitat is not eliminated (curve a). There is some evidence in the literature to support a subsidy-stress response curve for a change in vegetative cover (e.g., macrophytes and seagrass) with maximum productivity achieved at intermediate densities (curve b).

Mechanisms:

- Structure and cover provide critical elements of fish habitat for various life history stages. The spatial arrangement of habitat types and the complexity of the aquatic ecosystems are important environmental drivers of fish distributions and diversity. At the individual level, structure and cover provide protection against predators; can reduce competition via visual barriers, and provide shelter against environmental elements (e.g., hydraulic forces in rivers).

Evidence:

- A meta-analysis provided the strongest evidence linking fish productivity to habitat structure and cover with 75% of experiments showing a significant direct response to habitat manipulation. A narrative literature review demonstrated less definitive results, with experimental simplification of habitat showing more consistent reductions in productivity measurements than increases in productivity associated with habitat restoration activities.

Metrics:

- Indicators shown to respond to change include fish diversity, biomass, and abundance.

Modifiers:

- Two suggested potential curve modifiers include the proximity of available suitable alternative habitat and the density of local populations. Both potential modifiers could reduce the slope of the curve and increase the level of the lower threshold by either shifting the location of population productivity to the alternate habitat, and/or releasing the remaining individuals from density dependent factors (e.g., reduction in competition can increase growth and survival).

Other relevant curves:

- Other relevant response curves include change in sediment concentrations, change in food supply, change in temperature, change in hydrodynamic patterns and access to habitat.

Cautions:

- Two cautions need to be considered when applying the response curves.

1) The recognition that even if absolute fishery productivity may not drop to zero at the extreme end of habitat simplification (e.g., a concrete channel), it is highly probable that the form of that productivity will likely not be highly valued species (e.g., Common Carp, which may persist at levels of cover so low that productivity has been lost by most other fish species more valued as CRA fisheries). Where available, the objectives of relevant fisheries management plans must be considered.
2) The potential increase in productivity with initial vegetation removal applies only in cases where the density of vegetation and extent are high and partial removal would increase habitat heterogeneity.

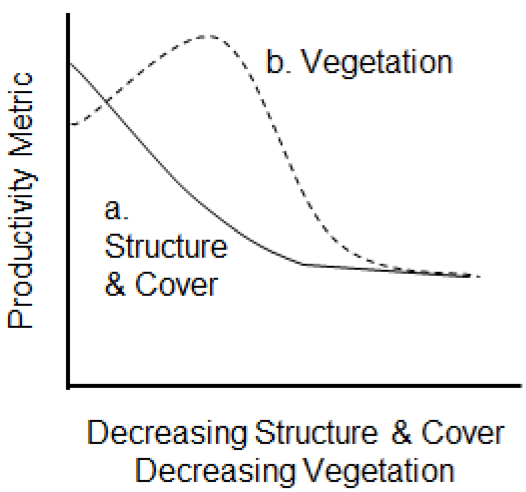

Figure 7: Response of fisheries productivity to decreasing structure and cover; decreasing vegetation.

Synopsis:

- Habitat simplification (loss of structure or cover) generally results in a loss of fisheries productivity. The relation is linear, meaning that in most cases, any amount of simplification will reduce fisheries productivity (curve a).
- Many fish that are part of CRA fisheries are sensitive, in at least some life stages, to habitat simplification. Sensitive fish will leave the area to seek more complex habitat, if it is available and accessible. In many ecosystems, the species that leave may be replaced by less sensitive species (e.g., Common Carp), so the overall fishery productivity may not be completely eliminated, even at extremes of habitat simplification (e.g., concrete channels). The replacement fish productivity results in the lower plateau of the response curve remaining above zero.
- However, at such extremes, the fish species that are able to thrive may not be valued as CRA fisheries or part of a fisheries management plan. The remaining fish productivity, therefore, may not be the type needed to meet fisheries management objectives. In this case the lower plateau of fishery productivity relevant to the FPP may be zero.
- The change in aquatic vegetation cover is a special case which can result in increased fisheries productivity at intermediate densities of vegetation (curve b). However, removal of vegetation is only likely to increase fisheries productivity if the original vegetation cover and extent is high.

APPENDIX 4: CHANGE IN NUTRIENT CONCENTRATION

Typical Causes:

- Activities leading to increased nutrient concentrations from point source and non-point source pollution; including removal of riparian or aquatic vegetation, row crop agriculture, organic debris management, livestock grazing, and industrial, agricultural and municipal wastewater management and habitat modification such as dredging

Relationship:

- The relationship is non-linear. In some species, total fish production, total fish biomass, and somatic growth are positively related to small or moderate increases in nutrient concentrations when initial concentrations are low to moderate, and productivity may exhibit a subsidy-stress shaped response curve. Initially, increases in nutrient concentrations may increase fishery productivity, but then fishery productivity will decrease in response to the decreased abundance of species intolerant of nutrient enrichment (hereafter "intolerant species") and other eutrophication impacts. In most eutrophic ecosystems, initial increases in nutrient concentrations are expected to have little or no impact on fishery productivity but fishery productivity can decrease at higher levels of eutrophication impacts. Except in cases where the fishery productivity is dependent on intolerant species (fish species that cannot adapt well to eutrophic conditions) or extremely eutrophic conditions are reached, fishery productivity is not expected to be completely lost due to increased nutrient concentration.
- The presence and abundance of intolerant species are negatively and linearly related to nutrient concentrations.

Mechanisms:

- Eutrophic systems are more likely to produce algal blooms and have indirect impacts on fish through reduction in dissolved oxygen and other habitat impacts (e.g., loss of aquatic macrophytes and benthic fauna).

Evidence:

- The productivity of fisheries is strongly determined ultimately by production at the base of the food web. Primary production is controlled by nutrients. Both phosphorus (P) and nitrogen (N) can be limiting nutrients in aquatic ecosystems; evidence suggests that freshwater ecosystems respond most strongly to phosphorus.
- Overall, fish production and total fish biomass are positively related to total phosphorus (TP) in freshwater. Nutrient increases are associated with better growth for some species.
- Species differ in their responses to the ecosystem effects of increased nutrient concentrations and the structure of fish communities change with ecosystem trophic state. Intolerant species are reduced in abundance or disappear in eutrophic ecosystems.

Metrics:

- Productivity metrics include fish production, invertebrate (secondary) production, fish growth and fish community composition.

Modifiers:

- Both the natural and current state of nutrient enrichment are potential modifiers of the shape of the P-S response curve. Naturally oligotrophic and eutrophic ecosystems can be expected to respond differently to changes in nutrient concentration. Changes in nutrient concentration are expected to interact with other stressors such as climate change and changes in hydromorphology and aquatic invasive species (AIS).

Other Relevant Curves:

- Increase in nutrient concentrations leading to eutrophication can have similar impacts as increase in suspended sediment concentration, can change food supply, light availability, and reduce dissolved oxygen. Changing nutrient concentrations affect fisheries productivity through the food web and therefore will be closely associated with impacts from change in food supply.

Cautions:

- Other ecosystem changes that result from increase in nutrient concentration may have indirect effects on productivity. Oligotrophic systems (low nutrients, low primary production) are more efficient at converting phytoplankton (primary production) to fish production.

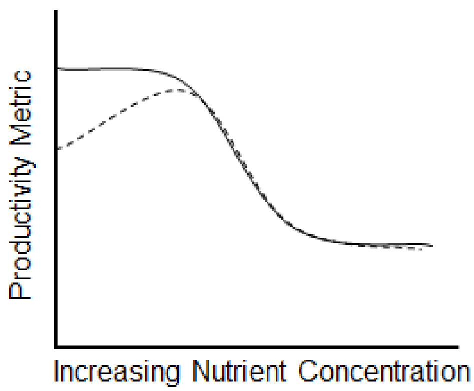

Figure 8: Response of fisheries productivity to increasing nutrient concentration.

Synopsis:

- Addition of nutrients may increase total fish production, especially in nutrient poor waters.
- Intolerant species will decrease in abundance and fish community composition will change with increasing nutrient concentrations.
- Increasing nutrients leads to eutrophication, which has many undesirable direct and indirect effects on fish.
- Except in cases where the fishery productivity is dependent on intolerant species or extremely eutrophic conditions are reached, fishery productivity is not expected to be completely lost due to increased nutrient concentration.

APPENDIX 5: CHANGE IN FOOD SUPPLY

Typical Causes:

- Activities leading to change in food supply include riparian and aquatic vegetation removal, water flow alteration, dredging, or the placement of structure in water (e.g., aquaculture facilities).

Relationship:

- The relationship is non-linear. Initial proximal reduction in food supply is not expected to reduce productivity; at a certain reduced prey density, however, consumption and therefore growth will decline in a linear or curvilinear manner. Decreases in food supply can be sufficient to completely eliminate fisheries productivity.

Mechanisms:

- The response of fish production, biomass, and growth to increases in nutrient concentrations is a response to changes in food supply.
- Nutrient enrichment may boost productivity at the base of the food web, which increases the availability of food and increases fish productivity.

Evidence:

- Extensive research, theory, and literature on bioenergetics show how fish growth changes in response to reduced food consumption. Extensive literature on functional responses describes how consumption changes in response to reduced prey density.

Metrics:

- Metrics of productivity can include fish production, growth, emigration, recruitment, and survival, or the abundance of an important prey species when they can be identified and monitored readily.

Modifiers:

- The response curve can be modified by factors such as ambient temperature which can affect metabolic rates and thereby the growth obtained from a given level of food consumption. Behavioural changes to changing food supply can also affect productivity. Increased time spent searching for prey as the food supply declines will increase metabolic costs, decrease the energy available for growth, and increase exposure of the fish to other predators. Turbidity, either from increased suspended sediment concentrations or eutrophication, can reduce the effectiveness of prey searching, increasing foraging costs and change both the functional response (slower increments or lower maximum consumption) and metabolic costs reducing energy for growth.

Other Relevant Curves:

- Change in food supply can be associated with loss of wetted area and changes in sediment concentration, habitat cover and structure, nutrient concentration, temperature, light, access to habitat, dissolved oxygen, and baseflow and hydrodynamics.

Cautions:

- Productivity responses to changes in food supply are not necessarily simple or direct, and are often affected by other conditions such as nutrients or temperature. Productivity effects may also exhibit delayed or indirect responses, and fish may exhibit alternative energy allocation strategies.

- Some life stages (e.g., larval fish) are known to be particularly sensitive to the timing and availability of food such that small changes in the availability of food can reduce survival and recruitment.
- Changes in the quality of food may have similar effects as reductions in the quantity of the food supply.

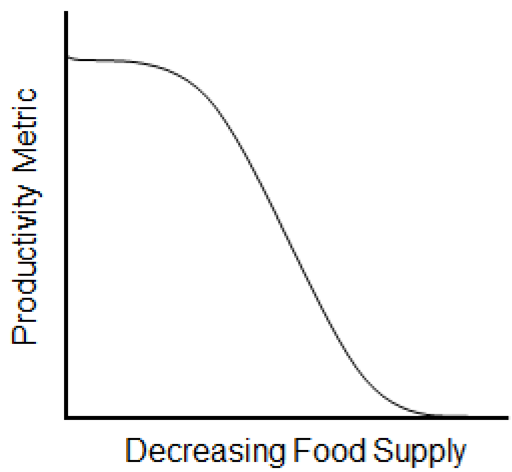

Figure 9: Response of fisheries productivity to decreasing food supply.

Synopsis:

- All organisms need food to survive, grow, and reproduce.
- If food is abundant, initial declines in food supply will not affect productivity. At some prey density, further declines in food supply will decrease and eventually eliminate fisheries productivity.
- Food quality can reduce productivity in a manner similar to food quantity.
- The productivity response to changes in food supply can be affected by environmental conditions that affect the capture and consumption of food (e.g., temperature, turbidity, availability of cover, or dissolved oxygen).

APPENDIX 6: DIRECT MORTALITY

Typical Causes:

- Direct mortality refers to the killing of fish, at any life stage, by any human induced mechanism other than fishing. Typically this can occur through rapid increases in pressure, crushing, entrainment/impingement, stranding and/or lethal changes in oxygen, temperature, sediments or nutrient enrichment.

Relationship:

- The default relationship between direct mortality and fishery productivity is assumed to be proportional up to a point where large levels of mortality will increase the rate of decline, eventually moving fisheries productivity to zero (Curve A).

Mechanisms:

- The relationship of stock productivity to direct mortality caused by fishing has been explored in depth as part of the Precautionary Approach (PA) framework in fisheries management.
- Although he axes of the functional relationships are typically represented differently in the PA framework, the general concepts, including healthy, cautious and critical zones for different combinations of mortality rate and stock status, may be transferrable to direct mortality in these contexts. DFO (2012) explores these points further.

Evidence:

- Mortality is one of the main rates studied in fisheries science. There is both strong theoretical and empirical evidence for the shape of the curves presented.

Metrics:

- Appropriate productivity metrics for these endpoints may include fish production, fish abundance and survival/mortality estimates.

Modifiers:

- The main modifier to the shape of the curve is the potential for density-dependent effects (see DFO (2013a).
- If the direct mortality mechanism occurs before some important sources of density dependent mortality, compensatory effects can result in an initial increase in productivity followed by a steep decline (Curve B).
- if there are no opportunities for density dependent compensatory responses after the direct mortality has occurred, then the direct mortality can reduce productivity below the default proportional line (Curve C).
- While it should not change the shape of the curve, the way the direct mortality occurs may mask the relationship in field conditions. Small levels of episodic mortality would not be expected to reduce fisheries productivity in a measurable way while large fish kills could move the relationship to the lower right of the graph quickly, from which an extended recovery time might be required.

Mitigation Measures:

- The “death of fish” (i.e. direct mortality in this context) for CRA fish species is prohibited and thus should be avoided and/or mitigated for whenever possible.

- The actual mitigation will depend on the mechanism causing the direct mortality. For example, fish screens and bypass structures may be used to reduce mortality caused by entrainment while timing windows for instream works might help prevent mortality due to crushing.
- In situations where detailed biological knowledge is known (i.e. population models) the Precautionary Approach to Fisheries Management (DFO 2009) provides a reasonable way to manage all sources of mortality.

Other Relevant Curves:

- Other PoE endpoints reviewed in this process that can lead to direct mortality changes in dissolved oxygen, temperature, sedimentation concentration, and nutrient concentrations as well as food supply.

Cautions:

- Density dependent effects should not be assumed in populations whose abundances have already been reduced by any stressor.
- There may be other policy frameworks (e.g., *Species at Risk Act*) which may specify a more restrictive level of mortality to guide management decisions.

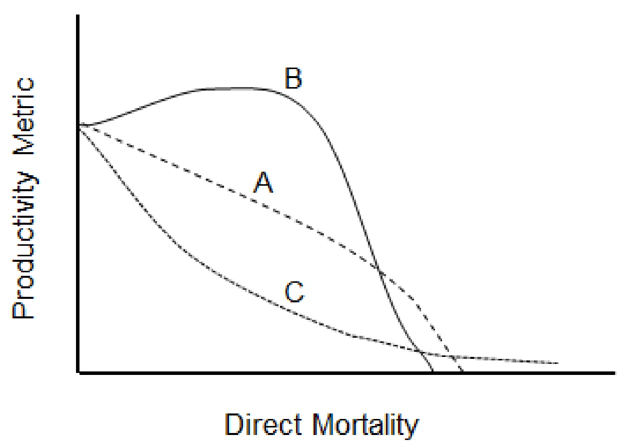

Figure 10: Response of fisheries productivity to direct mortality.

Synopsis:

- Direct mortality is within the scope of the Section 35 prohibition, and can reduce fisheries productivity.
- There are numerous methods to mitigate the effect of direct mortality on fisheries productivity and these should be employed whenever possible.

APPENDIX 7: CHANGE IN TEMPERATURE

Typical Causes:

- Industrial or development activities can directly affect water temperatures through heated thermal effluents, changes to groundwater exchange, or dams discharging hypolimnetic water. Projects that affect light penetration or clarity affect water temperature (e.g., riparian planting or removal, aquatic vegetation removal or addition, shading structures, suspended sediments, algal blooms, or contaminants). Projects that affect water depth or hydrodynamics also affect water temperature (e.g., filling/dumping, dredging, water drawdown, impoundment or release, shoreline modifications, channelization, and dams or dykes).

Relationship:

- The shape and rate of decline depends on the direction and magnitude of change in ambient temperatures relative to thermal optima. There may be a plateau before a decrease in production if temperature changes remain close to optima (solid line). There may be a subsidy-stress response if the temperature change approaches optima initially (dotted line) but then productivity is expected to decline with greater temperature changes from ambient. The decline in productivity may be linear and more steeply sloped if ambient temperatures are already close to physiological minima or maxima or lethal limits and the change moves closer to these limits (dashed line).

Mechanisms:

- Fish are ectotherms and therefore have adapted to and respond directly to the thermal conditions in their surroundings.
- Generation times and life stage development have adapted to natural temperature cycles and their variability by ecoregion.
- Almost every measure of individual and population success, diversity and biogeography of fishes can be related to environmental temperatures and climatic conditions in some way

Evidence:

- There is extensive experimental evidence that aquatic organisms respond to temperature changes. These responses will range from behavioural to bioenergetic, physiological, and sub-lethal effects to lethal effects.

Metrics:

- Spawning, nursery, and adult thermal habitat supply, all life stages' survival rates, growth rates, reproductive rates, abundance, diversity, biomass, spawn timing, distribution patterns, age-at-maturity, size spectra, maximum size, migration timing, species richness, community structure, yield, and production.

Modifiers:

- Shifting ambient temperatures closer to optima may result in a plateau or subsidy-stress response (solid or dotted line), depending on how close the ambient temperatures were to optima for fish that are part of CRA fisheries before the project. When ambient temperatures are shifted away from optimal temperatures (increase or decrease) a linear response is more likely. The closer to upper lethal limits the steeper the slope and the faster the decline in productivity (dashed line).

- The impact of temperature changes on productivity will depend on the size of the area affected, the magnitude, timing and duration of the change, and the habitats affected by the temperature change; all of which affect annual thermal habitat supply.
- Both thermal guild and life stage affect the shape of nonlinear curves or the slope of linear relationships depending on their sensitivity. Early life stages of many fish and some benthic organisms (both freshwater and marine) are more susceptible to temperature changes because they are unable to move quickly or are sessile. Larger individuals could move from unfavourable conditions but decreases in thermal habitat supply could have indirect density-dependent impacts in addition to the direct impacts.
- The spatial and temporal scale of the temperature change determines the change to annual thermal habitat supply for different guilds based on their ecology and niche shifts over the year. Species specific information and ecological knowledge is often required and may need to be calibrated for different ecoregions and species of interest.

Mitigation Measures:

- Avoid known spawning areas and times as incubating eggs and spawning adults are more susceptible to temperature changes.
- Avoid rapid changes in temperature or increased variation than normal (seasonally dependent).
- Especially avoid any increases to water temperature when ambient temperatures are close to upper lethal limits (habitat or species dependent).
- Avoid decreasing water depths in shallow areas during ice cover.

Other relevant curves:

- See Flow and Level Changes, Cover (esp. vegetation), Suspended Sediments, Dissolved Oxygen, Wetted Area, Access to Habitat, Direct Mortality for cross-references to temperature.

Cautions:

- Survival curves are based on gradual changes in temperature and responses in controlled laboratory conditions.
- More sensitive species should be prioritized but the number of thermal guilds present and habitat overlap by different thermal guilds requires caution if allowing temperature changes.
- Species and life stages have different optima so deviation from ambient temperatures will have to consider potential trade-offs both within (different life history stages with different optima) and among (different species with different optima) species.

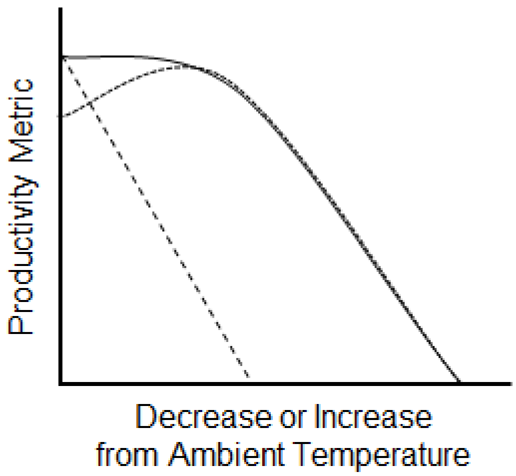

Figure 11: Response of fisheries productivity to change in ambient temperature.

Synopsis:

- Fish are adapted to local thermal structure.
- Fish mortality & growth is a strong determinant of productivity. Both are directly linked to temperature.
- Avoidance behaviour of unfavourable temperatures will change effective habitat supply and density-dependent functions.
- Depending on ambient temperature change relative to species' and life-stage optima there may be a plateau, increase, or linear decline in productivity.

APPENDIX 8: CHANGE IN NOISE AND VIBRATION

Typical Causes:

- Seismic surveys, pile driving, increased vessel traffic, mid- and low-frequency sonar equipment, underwater dredging and drilling activities, construction noise, land-based activities like excavation and drilling work.

Relationship:

- Field and experimental evidence support a curvilinear relationship between changes in noise and vibration and fishery productivity. There is evidence in the literature to support a broad initial plateau before a slow decline that will most likely not lead to complete reduction of the fishery productivity.

Mechanisms:

- Anthropogenic noise and vibration sources can result in changes in migration patterns of fish (avoidance behaviour), in communication of marine mammals, and in increased stress, which may affect fisheries productivity through a number of different mechanisms.
- Most of these effects are expected to be short-term with the duration of the effect less than or equal to the duration of the sound exposure and to vary between species and individuals.
- The ecological significance of such effects is expected to be low, except where they influence reproductive activity.

Evidence:

- Generation of high anthropogenic sound levels in water has been shown to impact the physiology and behaviour of aquatic animals, and in extreme cases cause harm to individuals (mortality).
- Much of the evidence has come from laboratory experiments, and there are no documented cases of population scale impacts of sound on productivity of CRA fisheries.

Metrics:

- Production, abundance, spawning and recruitment success, survival, and growth.

Modifiers:

- Hearing-sensitive species (e.g., marine mammals) are more likely to be affected. For these species, the plateau of the curve could be shorter and the slope steeper.

Mitigation Measures:

- Avoiding biological significant periods and areas like spawning grounds, migratory routes, schooling and nursing areas,
- Avoiding EMFs strengths that lie within the sensitivity range of the aquatic organisms by adjusting the frequency and amplitude of sound in relation to the sensitivity of the aquatic organism to not cause physical injuries or behavioural changes.

Other relevant curves:

- Access to Habitat

Cautions:

- No comprehensive examinations have been conducted to assess long-term effects of noise and vibration on a population level.
- Habituation to noise may occur after multiple exposures.
- Sound pressure levels are attenuated as the distance from the source increases. Sound pressure levels that may cause physical damage can only be observed within a few meters from the source, but the annoyance level leading to sub-lethal, behavioural and growth effects may extend much further. As a general rule, physical damage is highly dependent on the characteristics of the sound impulse.

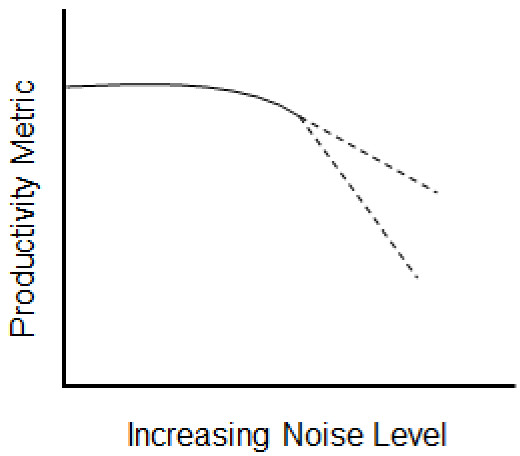

Figure 12: Response of fisheries productivity to increasing noise level.

Synopsis:

- Very high sound levels may have mortality effects. At lower sound levels, sub-lethal effects and changes in the migratory patterns are observed. The disruption of migration patterns caused by noise and vibrations may potentially lead to a decrease in the fisheries productivity when the changes to the duration and timing of migration lead to a decrease in survival or fitness and ultimately resulting in a reduced feeding or spawning success.
- The response, however, is not expected to be linear. There is evidence for an initial plateau where small increases in sound level will not have significant impacts. The width of the upper plateau and rate of decline is dependent on the species and local environmental conditions.

APPENDIX 9: LIGHT

Note: The principal focus of this Science review and advisory document is on the freshwater environment. The influence of light *per se* directly resultant from development activities is not noted to be a principal stressor on fisheries productivity in freshwater systems, or at least not of the same scale as other PoE endpoints. Any external influence which changes the light regime will also likely affect other principal stressors. The influence of "light" will be considered in future analyses in the marine environment. The reader is encouraged to refer to the discussion of "light" in the accompanying Proceedings document. No formal advice is provided at this time.

APPENDIX 10: CHANGE IN ELECTROMAGNETIC FIELD (EMF)

Typical Causes:

- Underwater electric cables and generators from renewable energy sources such as offshore wind power, wave and tidal power, and in-river hydrokinetic turbines.

Relationship:

- Field and experimental evidence support a curvilinear relationship between increasing electromagnetic field strength or increasing scale of the electromagnetic emissions and fishery productivity. There is evidence in the literature to support a broad initial plateau before a slow decline. Increasing electromagnetic field strength and extent are unlikely to lead to elimination of fishery productivity.

Mechanisms:

- Many invertebrate, fish, marine mammal, and sea turtle species can detect and may use electric or magnetic fields to orient, navigate, find prey or mates, or to cue particular life stages.

Evidence:

- Current understanding of the effect of EMFs on marine organisms is still sparse and predominantly based on laboratory studies.
- Several observational studies on a number of marine fish have demonstrated the effects of underwater cables on fish behaviour. Significant behavioural responses to underwater cables have been observed in some species, including impaired migration, avoidance, and attraction. However, none of these studies attempted to ascertain the exact relationship between electric or magnetic fields and the observed behavioural modifications. The significance of this stressor on fish populations is unknown and there has yet to be any evidence that existing underwater cables have caused significant disruptions to survival and reproductive success in any species. But EMFs may cause temporary and significant navigational disruptions (disorientation) to migrating species.

Metrics:

- Production, abundance, community structure, spawning success, survival, and growth.

Modifiers:

- EMF-sensitive species (e.g., elasmobranchs, eels, some gadids) and highly migratory species are more likely to be affected. For these species, the plateau of the curve could be shorter and the slope steeper.

Mitigation Measures:

- Avoiding migratory routes as well as spawning and rearing areas,
- Avoiding EMF strengths that lie within the sensitivity range of the aquatic organisms.

Other relevant curves:

- Access to Habitat

Cautions:

- Induced EMFs decrease relatively rapidly with distance, but the EMF 20 m from an underwater cable (horizontally or vertically) may still be within the detectable range.

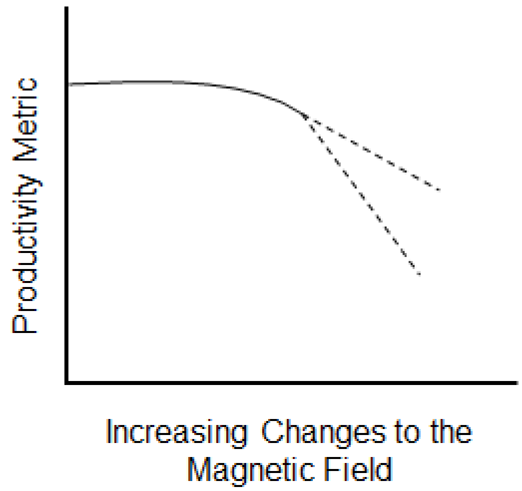

Figure 13: Response of fisheries productivity to increasing changes in magnetic field.

Synopsis:

- There is insufficient empirical evidence to determine if electromagnetic fields (EMF) associated with underwater cables or offshore energy pose a threat to fish populations and their associated fisheries.
- However, it is plausible to assume that small changes to the EMF will not have significant impact on fisheries productivity. Larger changes to the EMF have the potential to result in impacts to fisheries productivity, most likely through changes to behaviour such as interference with migration, avoidance or attraction.
- Research to date appears to assess impacts from single cables. Responses to the EMF from multiple cables and generators (e.g., large-scale grids or arrays) may be more significant, however information on the cumulative effects of arrays is currently lacking.

APPENDIX 11: CHANGE IN ACCESS TO HABITAT

Typical Causes:

- Physical barrier or a reduction in accessibility to habitats due to changes in hydraulic conditions or other factors. Impacts linked to change in access to habitat include infilling/footprint, changes in flows/water levels and permanent watercourse alteration.

Relationship:

- The relationship may take on several shapes depending on the life history of the species and the nature of the impediment to access:
- The relationship is curvilinear when fragmentation impacts riverine species that have a specific habitat requirement limited or made inaccessible by fragmentation. An initial plateau is expected, at which the flowing river segments are large enough for healthy populations to persist. A threshold exists at which population size deceases with decreasing river reach length until the population is extirpated.
- A linear response may exist between the size of a free flowing reach and the size and viability of the population within the reach. However, exceptions do exist, suggesting other factors may limit some populations.
- A permanent barrier does not allow for recolonization following a catastrophe, changes habitat quality and reduces habitat quantity for fish species whose life cycle is dependent on migration (e.g., diadromous fishes). A linear relationship between habitat quantity and productivity is assumed unless compensatory or depensatory processes can be established.

Mechanisms:

- Some fish species are fluvial specialists and require flowing water to support key aspects of their life history.
- Migration may be required between different habitats for fish to successfully complete their life history. In barriers and flow management can alter access to habitats in four different dimensions: longitudinal (river corridor, in both upstream and downstream directions), vertical (surface and groundwater interactions), lateral (connection to flood plain) and finally temporal, which interacts with the three physical dimensions. Changes in any one of these dimensions may impact habitat quantity and quality, impose migratory delays, increase predation or result in delays in development. These impacts can result in reduced productivity, shifts in community structure and species richness.

Evidence:

- Modelling water withdrawal rates and observed changes in fish community biodiversity have found a linear to curvilinear relationship. Stream size and community type defined by water temperature determine the shape of the relationship and the sensitivity to withdrawal.
- Correlative studies on the decline in distribution and abundance riverine specialist species have concluded declines are direct consequence of habitat fragmentation.
- Generally the relationship between fragmentation and flow changes result in negative consequences for the fish community, however, positive responses have been observed when flow reductions improve habitat for specific life histories stages that benefit from flow reductions (e.g., young of the year and juvenile).

Metrics:

- Fish production, fish abundance, biomass, species richness, species diversity and fish community composition.

Modifiers:

- The shape and slope of the response curves can vary based on magnitude (large changes have larger impacts), timing (impacts species life history), duration (longterm changes have the potential to impact the fish community and productivity), frequency and rate of flow changes (more frequent and higher rates changes have higher impacts), species habitat requirements (riverine are more sensitive than habitat generalist species), life history stage (different life histories often have different habitat requirements; therefore impacts differ), size of the system (smaller streams are generally more sensitive), and fish community type (warm /cold water, warm generally more sensitive).

Other Relevant Curves:

- See: Loss of Wetted Area, Change in Sediment Concentration, Electromagnetic Field, Noise and Vibration, Change in Habitat Cover and Structure, Change in Nutrient Concentration, Change in Food Supply, Direct Mortality, Change in Temperature, Baseflow and Hydrodynamics, and Change in Dissolved Oxygen

Cautions:

- Determining the critical threshold for different species at which populations respond to fragmentation would be the key challenge. Many species have a critical threshold for population-scale responses to fragmentation. This threshold is related to a loss or reduction of a habitat component that acts as a limiting factor. Limiting factors are generally poorly understood and are sometimes determined only after the impacts of fragmentation have occurred.
- Impacts of flow change can be different depending on the underlying natural hydrograph of the system.
- A positive or negative productivity response to flow changes for one species or a particular life history of the same species may be contrary to the response of another species or life history stage. These changes need to be considered in combination with fisheries management objectives (e.g., lotic versus lentic or generalist species).
- Flow changes that affect access to habitat are cumulative.
- Barriers with fish passage may still produce delays or limit the movement of some proportion of the population. In such cases, lower survival rates are expected in both upstream and downstream migrations.

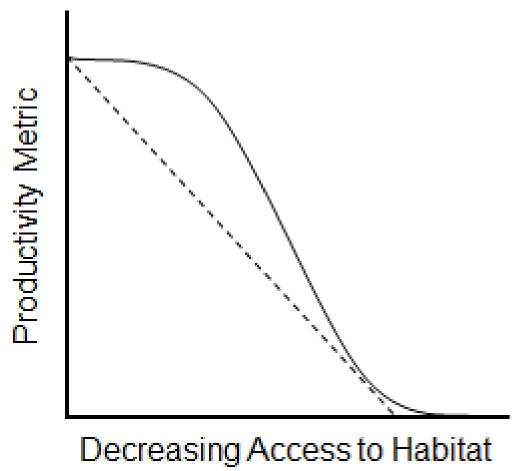

Figure 14: Response of fisheries productivity to decreasing access to habitat.

Synopsis:

- Wholly freshwater fish that require riverine habitat can tolerate some level of fragmentation if the flowing reach size is large enough to meet all their life history requirements. This minimum reach size is species and fish community specific. The relationship is curvilinear, once reach size limits a critical aspect of the life cycle the populations will exist at lower abundance or disappear from that reach.
- Fish that migrate between saltwater and freshwater to complete a critical aspect of their life cycle are less tolerant to loss of access to habitat as the habitat beyond a barrier is completely unavailable for fisheries production. A linear response is assumed.
- In riverine systems water withdrawals will impact the species composition and abundance although the sensitivity of the system to the withdrawal is system size and fish community dependent.

APPENDIX 12: CHANGE IN DISSOLVED OXYGEN

Typical Causes:

- Industrial or development activities can directly affect dissolved gases (e.g., bubblers, turbulent supersaturation). Indirect effects on dissolved oxygen content in water include modification of water temperatures that in turn affects oxygen saturation levels or air exchange (e.g., thermal effluents, drawdown, stratification changes, ice dynamics, hydrodynamic changes, salinity changes, or sedimentation). Some activities increase biological or chemical oxygen demand in water (e.g., excessive nutrients, contamination, algal blooms, aquatic vegetation changes, suspended solids), which may reduce oxygen available for fish.

Relationship:

- The width of the initial plateau varies across species and life stages depending on their tolerances to low oxygen conditions. The shape of the response curves is similar but the rate of decline from higher productivity also depends on the rapidity and magnitude of oxygen loss and the ability of fishes to move or find refuge. The length of the productivity plateau also depends on species or life-stage sensitivity to decreasing dissolved oxygen levels (sensitive species - solid line; tolerant species – dotted line).

Mechanisms:

- Most fish need sufficient levels of dissolved oxygen to breathe through their gills. Individual and population success measures as well as diversity are related to suitable oxygen levels and oxygenated habitat supply.
- The natural seasonality of oxygen dynamics in lakes and rivers as hypolimnetic and some wetland areas will naturally fluctuate seasonally or daily in oxygen levels.
- Differences in dissolved oxygen both in space and time from ambient conditions will change behaviours, species and habitat interactions, and ultimately production of native CRA fisheries, especially between 6 to 3 mg/L.

Evidence:

- It is well established that dissolved oxygen is essential for the survival of all aquatic organisms, including fish. Additionally, oxygen affects a vast number of other water quality indicators, and is thus perhaps the most well-established indicator of water quality.

Metrics:

- Spawning, nursery, and adult habitat supply, all life stages' survival rates, growth rates, reproductive rates, abundance, diversity, biomass, spawn timing, distribution patterns, migration timing, richness, community structure, yield, and production.
- Optima or preference curves for different groups (e.g., sensitive, intolerant) and for different life stages (e.g., eggs, fry, juveniles) based on their environmental tolerances or growth curves can be used as a surrogate for productivity because they are directly linked to behaviour, survival or growth success.

Modifiers:

- The impact that oxygen changes have on production for a particular fish population, for a fishery species, or fish community will depend on the size of the area impacted, the magnitude, timing and duration of the change, and the habitats affected; all of which affect annual oxygenated habitat supply. Different life stages have different tolerances and affect the response curve.

- Season and habitat type affect oxygen dynamics setting ambient conditions. Oxygen needs for aquatic life increase with increasing temperature. Aquatic vegetation and algae impact diurnal oxygen dynamics through respiration and photosynthesis cycles. Excessive plant growth can lead to supersaturation during daytime and depletion at night which may stress fish and other aquatic organisms.
- The species and the life stage affect the shape and rate of decline of the nonlinear response curves. Depending on their sensitivity, early life stages or some benthic organisms are more susceptible to oxygen depletion because they are unable to move quickly or are sessile. Larger individuals could move from unfavourable conditions but decreases in oxygenated habitat supply could have indirect density-dependent impacts in addition to the direct impacts.
- Rapid shifts from ambient oxygen levels (e.g., contaminant spill) or high variability in oxygenation (e.g., intermittent releases of hypoxic water) have more acute effects on survival or growth then suggested by the response curves (see Cautions). The curves are more representative of a chronic change in dissolved oxygen levels.

Mitigation Measures:

- Avoid known spawning and nursery areas and times as incubating eggs, spawning adults, young are more susceptible to dissolved oxygen changes.
- Avoid rapid changes in temperature or dissolved oxygen or increased variation than normal (seasonally dependent).
- Especially avoid any decreases to dissolved oxygen when ambient levels are close to behaviour changes as lethal limits can be very close (habitat or species dependent).
- Avoid depleting oxygen under ice cover or in hypolimnetic waters when air exchange is limited.

Other relevant curves:

- See: Temperature, Nutrients, Flow and Level Changes, Cover (esp. vegetation), Suspended Sediments, Access to Habitat, and Direct Mortality for cross-references to dissolved oxygen.

Cautions:

- Survival curves are based on gradual changes in oxygen and responses in controlled laboratory conditions.
- More sensitive species and fisheries management objectives should be prioritized but the number of tolerance guilds present and the overlap in habitats between different groups in their early life stages call for a precautionary approach if allowing oxygen depletion.

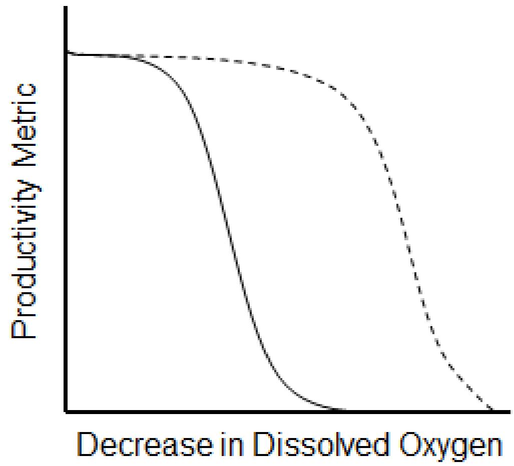

Figure 15: Response of fisheries productivity to decrease in dissolved oxygen.

Synopsis:

- Fishes are adapted to varying oxygen tolerances.
- Fish mortality and growth is a strong determinant of productivity. Both are directly linked to dissolved oxygen levels.
- Avoidance behaviour will change effective habitat supply and density-dependent functions.
- Depending on ambient oxygen level changes relative to species' and life-stage tolerances there may be sharp or gradual nonlinear decline in productivity.

APPENDIX 13: BASEFLOW AND HYDRODYNAMICS

Typical Causes:

- Changes in baseflow can be defined in a very broad context but as a stand alone endpoint it occurs with respect to alterations of ground water. Changes through this mechanism can reduce fisheries productivity by altering water temperature, oxygen levels and nutrient concentrations which can lead to a reduction in habitat quality. Baseflow reductions can also lead to a loss of wetted area.
- The change in hydrodynamics by the placement of large structures in flowing water can lead to changes in sediment erosion and transport which will reduce both habitat quality (sediment concentration) and quantity (altered substrate composition).

Relationship:

- The response curve for these two endpoints will be captured under the broader context of alterations to the hydrograph. This was the subject of a previous CSAS process with associated advice (DFO 2013b).

Evidence:

- There is substantial literature on the effects of flow changes on riverine ecosystems which was previously reviewed as a separate CSAS process with associated advice (DFO 2012).

Metrics:

- Appropriate productivity metrics for these endpoints may include fish production, fish abundance, fish community structure, recruitment, survival, and growth.
- Modifiers:
- There are a variety of hydrographs in Canada and that is why a 10% deviation was selected as a precautionary threshold limit, after which a more detailed assessment of the flow change at a site level would be warranted.
- While in general the 10% threshold is thought to be precautionary, populations that are sensitive to a concurrent temperature change may exhibit reduced productivity with a lower flow change (of less than 10%).

Mitigation Measures:

- There are a number methodologies for prescribing flows designed to protect ecosystems, the strengths and weaknesses of each are outlined in DFO (2013b).

Other Relevant Curves:

- Flow changes can affect many other physical parameters in flowing water and should not be considered in isolation. Curves for water temperature, oxygen, nutrient concentrations, Access to Habitat, Sedimentation and wetted area are relevant with respect to changes in flow.

Cautions:

- A second threshold of 30% of the mean annual discharge (MAD) to protect low flow situations should be used for flow management in addition to the response curve.
- Hydrodynamics in this instance only refers to changes that may occur from the placement of structures in flowing (i.e. riverine) waters. The potential change in hydrodynamics in lake and/or coastal areas that may occur through the placement of structures in these environments was not considered.

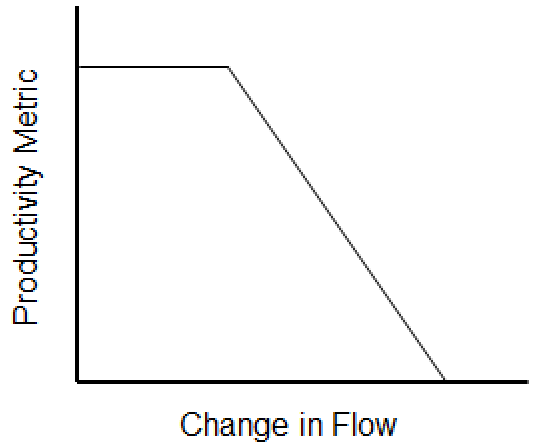

Figure 16: Response of fisheries productivity to change in flow.

Synopsis:

- Generally, projects that do not cross the 10% threshold would not be expected to alter fisheries productivity.
- Exceptions to this include flow changes during low flow events (i.e. 30% MAD) or when the CRA population(s) is known to be temperature sensitive.
- When the 10% or 30% threshold is surpassed the probability of productivity effects are increased and a more detailed assessment of the project should be undertaken.

APPENDIX 14: TERMINOLOGY

PoE endpoint: is the ecological component to be valued. Guidance on the management, protection and conservation of the various PoE endpoints identified can be found in the thirteen (13) appendices to this SAR.

Project: In-water or land-based activity that potentially affects fish; term used for simplicity. Synonymous with "work, undertaking or activity" per the *Fisheries Act*.

Response curve: describe how various metrics of productivity respond to varying levels of specific stressors.

Threshold: the point at which a relatively small change in external conditions causes a rapid change in an ecosystem. When an ecological threshold has been passed, the ecosystem may no longer be able to return to its state. The trespassing of ecological threshold often leads to rapid change of ecosystem health.

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