SCIENCE ADVICE TO SUPPORT DEVELOPMENT OF A FISHERIES PROTECTION POLICY FOR CANADA

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

Context:

Canada's Fisheries Act, amended via Bill C-38 (last amended June 29, 2012) contains new terminology, some of which requires scientific definitions to deliver the management responsibilities of the Department. In particular, the Act refers to the "ongoing productivity of commercial, recreational and Aboriginal fisheries"; the "fish that support such a fishery", and "the contribution of the relevant fish to the ongoing productivity of commercial, recreational or Aboriginal fisheries". DFO Program Policy Sector requested scientific advice regarding the ecological concepts associated with these new terms in the amended Fisheries Act.

The assembled experts discussed these biological and ecological concepts as a basis for guidance on development and implementation of policies, regulations and operational practices. As well, participants examined the level of preparedness of DFO Science, operational sectors and (where appropriate), external experts and parties to apply this guidance, including addressing any important information gaps. Similar to the development of advisory frameworks for implementation of the Species at Risk Act and the Oceans Act, this guidance will not only inform policy and management functions, but also address mechanisms by which DFO Science will provide this support.

This Science Advisory Report is from the Fisheries and Oceans Canada, Canadian Science Advisory Secretariat, National advisory process of August 29-31, 2012, to support development of a Fisheries Protection Policy for Canada. Additional publications from this process will be posted as they become available on the DFO Science Advisory Schedule at http://www.dfo-mpo.gc.ca/csas-sccs/index-eng.htm.

SUMMARY

- This Science Advisory Report (SAR) provides advice to policy and management primarily regarding scientifically significant terms in the amended *Fisheries Act* (2012). In respect of commercial, recreational or Aboriginal (CRA) fisheries, policy-makers sought scientific definitions for “the *sustainability* and ongoing *productivity*”, the “fish that *support*” such CRA fisheries, and “the *contribution* of the relevant fish”. The scientific advice provided is organized accordingly.

“Sustainability and Ongoing Productivity”:

- Productivity is determined by vital rates (e.g. reproduction, growth and survival) and life history characteristics (e.g. fecundity, age at maturity) that determine the fish production rate, that is, the growth in population biomass per unit area per unit time. Yield is a function of fish production. Fisheries productivity is sustained yield of all CRA fishery species.
- The *Federal Sustainable Development Act* indicates that *sustainability* “means the capacity of a thing, action, activity, or process to be maintained indefinitely”. The ecological concept of sustainability recognizes that populations fluctuate over time. Sustainable development does not preclude short-term or transitory impacts on the environment, but threats should be managed to avoid, mitigate or offset impacts such that there is a reasonable expectation of avoidance of serious adverse impacts or recovery from unavoidable impacts within a biologically reasonable period of time.
- The ecological concepts of ecosystem productivity, biodiversity and resilience are linked. A more diverse ecosystem tends to have higher overall productivity and to be more resilient to natural or anthropogenic perturbation than a less diverse ecosystem. In fisheries, habitat complexity and population diversity have been shown to positively correlate with both production and yield, supporting on ecological grounds the consideration of both direct and indirect links between habitat features and productivity of CRA fishery species, and evaluating impacts of projects on multiple scales.
- It is rare to measure all components of productivity. A pragmatic approach can take advantage of existing surrogates which range from habitat-based approaches for a smaller-scale work, undertaking or activity (w/u/a) to productivity-based approaches (using proxies for productivity) for larger ones.

“Fish that Support a CRA Fishery”:

- The support functions of an ecosystem are those functions which are essential for sustaining the production of CRA fishery species within the bounds of natural variability, over short- and long-term temporal scales.
- Support functions and “supporting fish” populations which affect the productivity of CRA fishery species may occur in areas outside of the distribution of the CRA fishery species and be connected to the CRA fishery species through food webs, inter-dependencies of sub-populations of a species and movements or migrations.
- On ecological grounds to be a species that “supports” fish that are part of a CRA fishery (in the sense of Section 35 of the *Fisheries Act*), two conditions have to be met. Firstly, the productivity of the fish that are part of CRA fisheries has to be impacted by changes in status of the species that “supports” them in a consistent manner. Secondly, there would

be few or no ways that the ecological functional role of the supporting species would be fulfilled by other species more resilient to impacts of the w/u/a.

- Two important *support* functions that arise from direct interactions with CRA fishery species are (i) the roles of key prey species and (ii) any species that create biogenic habitats (i.e. habitats created by the bodies or behaviors of organisms) that the CRA fishery species requires to complete its life cycle and contribute to the ongoing productivity.
- In addition to the direct support functions provided by key prey and structure-forming species, the dynamics of some ecosystems (and hence the productivity of CRA fishery species) may depend on certain other ecological functions provided by these or other species.

“Contribution of the Relevant Fish”:

- The “contribution of the relevant fish to the ongoing productivity of commercial, recreational or Aboriginal fisheries” is measured by the impact that would be expected on the productivity of CRA fishery species if the change (associated with a w/u/a) to the potentially affected species or habitats takes place. 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.
- Contribution can be conceptualized as a relationship between the productivity of the fishery and the state of the affected species or habitats. The shape of this relationship, the potential presence and position of inflection points and its slope can inform management decisions about risks associated with changes to the state of the affected species or habitats.
  Application of the contribution framework to support decisions within a precautionary framework requires the following five pieces of information:

  1. understanding how overall productivity depends on the affected species or habitats,
  2. the “current” state (i.e., the state before the w/u/a commences) of the potentially affected species or habitats,
  3. resilience of fish productivity to perturbations of the affected species or habitats,
  4. how the proposed w/u/a may alter the state of affected species or habitats, and
  5. uncertainties about the relationship, the current state of affected species or habitats, the potential impacts of the w/u/a, and, when applied, the effectiveness of avoidance and mitigation measures.

- Comprehensive data will rarely be available to fully parameterize functions and positions for (a) – (c), to quantify (d) precisely, and to 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. These can inform development of default forms for the functional relationships between productivity and state of the affected species or habitats, and provide general guidance to support decision-making.
- Use of this framework does not make the decisions automatic. However, it provides a structure for organizing information and bringing consistency to decision making.

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) have the purpose of providing 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 gives the Minister of Fisheries and Oceans the authority to authorize a work, undertaking, or activity (w/u/a) that causes serious harm to fish, if this is considered acceptable after taking specified considerations into account. Per S.6 of the amended *Fisheries Act*, the factors for Ministerial consideration in decision making are:

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.

In this context, this Science Advisory Report (SAR) provides the technical basis and scientific advice towards a consistent interpretation of "*<u>ongoing productivity</u>* of CRA fisheries", "the *<u>contribution</u>* of the relevant fish to the *ongoing* *<u>productivity</u>* of CRA fisheries", and which "fish *<u>support</u>* such a fishery". The SAR offers plausible options for the practical implementation of these concepts. To keep the decision making consistent across the variety of decisions that must consider the "contribution of the relevant fish", the advice provided has considered a wide range of applications and potential effects to CRA fisheries species or their habitats.

The 2012 amendments to the *Fisheries Act* include some additional terms such as fish that are "*part of* a CRA fishery", "*relevant* fish", "*harm",* and "*serious harm to fish".* Each of these terms may require science advice to support consistent interpretation in implementation, but also require further clarification of the legal and policy interpretation of these terms before such advice can be developed. Where those terms are used in this SAR, it is either as an extract of the *Fisheries Act* (amended 2012), or else the terms are used in their colloquial sense. No science guidance on their interpretation is intended at this time. Although the definition of "habitat" in the FA was modified with the amendments, the change is not substantive. The new definition is consistent with the continued DFO usage of the term "habitat" to include both biotic and abiotic components of aquatic ecosystems that are used by the fish species under consideration, which is how the term "habitat' is used in this SAR.

ASSESSMENT

1.0 "Sustainability and Ongoing Productivity"

1.1 Scientific Interpretation and Ecological Dimensions

Productivity of fish is determined by their vital rates (e.g. reproduction, survival, growth) and life history characteristics (e.g. fecundity, age at maturity). Production is the total elaboration of fish tissue during a unit of time regardless of whether or not the fish survives to the end of the time interval. Fisheries productivity is the sustained yield of all component populations available to support fisheries. These interpretations are consistent with definitions widely used in fisheries science.

The *Federal Sustainable Development Act* indicates that *sustainability* "means the capacity of a thing, action, activity, or process to be maintained indefinitely". In the present context, sustainability is interpreted as achieving a balance between the carrying out of current-day activities while allowing for future generations to achieve their needs. Sustainability ensures that important or key species are not driven by anthropogenic threats to levels of abundance that makes them unavailable to people, change their role in the ecosystem, nor results in the impairment of the genetic potential of the species. Avoiding, mitigating or offsetting impacts are important practices or approaches that contribute to or maintain sustainability. Sustainable development does not preclude short-term or reversible impacts on the environment. The ecological concept of sustainability recognizes that abundances of populations fluctuate over time, but threats should be managed so that when impacts are unavoidable, there is a reasonable expectation of recovery to more productive states within a biologically reasonable period of time.

The ecological concepts of ecosystem productivity, biodiversity and resilience are linked. A more diverse ecosystem tends to have higher overall productivity and is generally more resilient to natural or anthropogenic perturbation. In fisheries, aquatic ecosystem diversity and complexity have been shown to positively correlate with both production and yield. Similarly, diversity in life history traits (a component of biodiversity) has been shown to increase productivity and resilience.

When describing the dependence of productivity on the state of affected species or habitats, it is often not possible to directly measure productivity or state, and surrogates are often used in place of direct measures. Although surrogates are often expedient or the only feasible metrics given the available data, the use of surrogates usually provides less precise predictions of the effects of human activities on fisheries productivity.

1.2 Science Considerations for Management

The ubiquity of density-dependent processes is central to fisheries decision making and sustainable harvest levels, and measures of productivity must incorporate this concept. In general, threats to a population that occur prior to the stage(s) with strongest density-dependence will have less impact on population productivity than those that follow density-dependent processes.

Consideration of spatial scale will play an important role in the assessment of potential impacts of a w/u/a on affected species or habitats and on CRA fisheries. The scale of direct impacts of a w/u/a is usually well-defined; however, the spatial context in which those impacts are considered will affect the tools, metrics and criteria to be used for decision making. The interactions among spatial scales of w/u/a, impacts and productivities of CRA fisheries are considered in Section 4.0 of this SAR.

It is rare for all components of productivity to be measured. Pragmatic approaches that take advantage of existing surrogates range from habitat-based approaches for smaller w/u/a, to productivity-based approaches for larger ones (although for larger projects it may be difficult to measure productivity directly, and surrogate indicators may be necessary). When impacts to aquatic environments are evaluated along with social, economic and other environmental effects, the projects are usually relatively large and productivity-based approaches that evaluate impacts to fisheries will be more meaningful than approaches based solely on habitat measures.

When evaluating potential w/u/a impacts, projects can be sorted into three categories, with different approaches suitable for each category:

1. w/u/a that reduce habitat quantity (e.g. small-scale infills, exclusions). These projects will directly impact the size of the fish population and the sustainable yield by removing habitat from the system. For these types of projects, methods that quantify the relative amount of habitat change may be appropriate to infer the expected changes in productivity of CRA fisheries.
2. w/u/a that affect habitat quality, impacting vital rates of fish (e.g. projects that change sediment loads or flow). These projects may cause productivity and resilience of the population to decline. Pathways of effects can be used to identify linkages between ecosystem perturbations and vital rates. Changes in fisheries productivity may then be inferred from the expected changes in vital rates or their surrogates.
3. w/u/a with impacts on scales large enough to result in ecosystem transformation (e.g. reservoir creation), or removal of the affected parts of an ecosystem from use (e.g. whole lake loss, large infills). These can degrade the ecosystem by a number of pathways. Large-scale projects are likely best evaluated by assessing changes in fish production and fisheries productivity as directly as possible. Detailed case-specific studies and a variety of approaches may be used to determine the existing productivity, and to make predictions about future conditions. Because these are often whole-scale ecosystem changes, incremental approaches would be of limited value.

1.3 Implementation Needs

Operationally, to move from a site-level management approach to one that considers the ongoing productivity of populations and fisheries, existing tools can be used (as described above). Section 3.0 provides a framework that can guide implementation. However, new operational tools will be needed, based on additional scientific information including, *inter alia*:

a) Standards for choosing surrogate measures of productivity;

b) Spatial analysis tools;

c) Guidance on the development of regional productivity benchmarks;

d) Development of standards and thresholds for common types of w/u/a that may affect productivity of CRA fisheries;

e) Methods for the extrapolation of relevant data (from elsewhere) in data poor situations;

f) Methods and metrics for cumulative impact assessment.

Existing and new operational tools should be applied with an awareness that changes caused by habitat alternations may not be immediately evident, and initial impacts of a w/u/a may themselves cause further ecological changes, which take time to fully equilibrate. These potential lags in system responses and uncertainties about the power and reliability of operational tools to detect effects of habitat alterations in the context of the FPP, means that decision-making should include the application of precaution as laid out in the Government of Canada's "Framework for the Application of Precaution in Science-based Decision Making about Risk" (Privy Council Office). Consequently improvements to the implementation of the FPP would benefit from both improved effectiveness of monitoring programs to provide additional information on relationships between productivity of CRA fishery species and habitat features, and recording systems (i.e., databases) that could capture the number, type and magnitude of w/u/a in areas, to allow tracking and evaluation of cumulative effects.

2.0 "Fish that Support a CRA Fishery"

2.1 Scientific Interpretation and Ecological Dimensions

Certain generic functional roles are carried out by individuals and populations of species within all ecosystems with varying levels of control, such as potentially top-down control through predation, or potentially bottom-up control through provision of food as prey, and the formation or modification of habitats. The species that provide these support functions will differ across ecosystems and can vary within ecosystems and over time. Furthermore, some species can perform more than one functional role. The support functions of an ecosystem are those functions which are essential for sustaining the productivity of CRA fishery species within the bounds of natural variability over short- and long-term temporal scales. Support functions and "supporting fish" populations which affect the productivity of CRA fishery species may occur in areas outside of the distribution of the CRA fishery species but be connected to the CRA fishery species through food webs, inter-dependencies of sub-populations of a species (i.e. source-sink dynamics) and movements.

Not all species that contribute to one or more of the ecological functional roles (i.e. the "support *functions*") should be considered to "support" the fish with regard to application of Section 35 of the *Act*. On ecological grounds to be a species that "supports" fish that are part of a CRA fishery in the sense of Section 35, two conditions have to be met:

a) the productivity of fish that are part of CRA fisheries have to be impacted in a consistent and predictable manner by changes in status of the species that "supports" them, and

b) there would be few or no ways that the ecological functional role would be adequately fulfilled by other species either not impacted by or more resilient to impacts of the w/u/a.

However, all species that contribute to fulfilling these ecological functional roles may be relevant to consider when evaluating the impact of a w/u/a on the productivity of CRA fisheries, as part of the habitat of the fish that are part of the CRA fisheries species.

Two direct support functions of CRA fishery species are those fulfilled by key prey species and by fish that create biogenic habitats that the CRA fishery species requires to complete its life cycle and contribute to its ongoing productivity.

Some key concepts are:

Key prey species: the suite of species that are essential food items. Key prey can be distinguished from general prey items by the magnitude and consistency of the consequences of their relative abundance, diversity, availability and/or nutritional value for the productivity of a CRA fishery species.

Structure-providing species: these are the animal species that create biogenic habitats. The habitat may be the organism itself, such as a bed of mussels or sponges, or arise from an organism's skeletons, such as the mounds created by dead corals or sponges. These biogenic substrates provide three-dimensional habitats for a large variety of species. The link between the CRA fishery species and the biogenic habitat can range from essential to facultative or it may only be a preferred location, and the importance of habitat will vary seasonally and across life-history stages. Although only animal species are considered 'fish' as defined in the *Fisheries Act*, and consequently eligible to be considered a species that "support" fish that are part of CRA fisheries, plant-based biogenic habitats can be important to the productivity of some CRA fishery species. As such they would comprise part of the "habitat" of fish that are part of a CRA fishery, and in such cases would warrant consideration under the FA as would any other features of habitat contributing to the productivity of the CRA fishery. .

Inter-specific interactions that can indirectly influence a CRA fishery species are also important. In highly-connected ecosystems, these indirect interactions can exert strong influences on the CRA fishery species through tropho-dynamic processes especially where there is little functional redundancy in the ecosystems for that potential support species. Other functional roles that can exert influence on the productivity of CRA fisheries species through direct or indirect interactions include keystone species and/or wasp-waist species. Keystone species and wasp-waist species are not present in all ecosystems but when present, through their control functions, they can be important support species for CRA fishery species and may play a role in maintaining ecosystem stability. Apex predators can reduce the abundance of competitors or predators of the CRA fishery species. Some species are habitat modifiers and change the physical (abiotic) habitat in ways that can affect CRA fishery species. There are other supporting ecosystem functions that are known to affect fish production but that do not meet the legal definition of "fish". Those include plant-based biogenic habitats (e.g. Eelgrass meadows freshwater macrophytes, wetlands) and primary producing phytoplankton.

Keystone species: Species that influence ecosystem structure and function disproportionate to their biomass or abundance in the ecosystem (e.g. sea otter). Keystone species are not typically found at the highest trophic level. The criteria for a keystone species are that the species exerts top-down influence on lower trophic levels and prevents species at lower trophic levels from monopolizing limiting resources, such as competition for space or key producer food sources. They maintain community diversity by preying selectively on competitively superior lower trophic taxa, and thereby preventing the exclusion of relatively weak competitors (i.e. increasing biodiversity).

Wasp-waist species: A single species usually occupying an intermediate trophic level and expected to play a critical role in regulating the transfer of energy from primary and secondary producers to the higher trophic level species in the ecosystem (e.g. capelin).

Apex predators: Species that occupy the top trophic position in a community; these are often large-bodied and specialized piscivores whose adult stages have no predators of their own within their ecosystems. They can have a controlling influence on the structure of lower trophic levels, referred to as "top-down" control (e.g. large sharks).

Highly-connected species: Species with a high proportion of links to other species in a food web compared with the average number of links among species (e.g. krill)

Environment-modifiers: Species that directly or indirectly modulate the physical environment in which they live in ways that create resources for CRA fishery species and their prey. The activities of these organisms modify abiotic habitats that would not otherwise be available. This is often achieved by mechanical disturbance to the sediments (e.g. walrus).

Primary-producers: Photosynthetic algae living in the water column (phytoplankton). . The flow of energy from primary production through the food web will ultimately determine the productivity of CRA fishery species. "Bottom-up" control of productivity in higher trophic levels has been demonstrated in freshwater, estuarine and marine environments. Although phytoplankton are not "fish" as defined in the *Fisheries Act*, they may comprise part of the "habitat" of fish that are part of a CRA fishery and in such cases would warrant consideration under the Act as would any other features of habitat.

2.2.1 Science Considerations for Management - Key Prey Species

Identification of the principal dietary items of a CRA fishery species is usually achieved by examination of the stomach contents at various life-history stages although alternate methods have been developed (e.g. stable isotopes, genetic identification, and fecal analysis).

When determining which prey species, if any, are important support species for a CRA fishery species the following should be considered:

i) Whether the diet of the CRA fishery species is highly specialized by species or size-class in at least some seasons or life history stages. Evidence that a prey item is consistently common in predator diets is weak evidence for diet specialization. The evidence for specialization is stronger when the prey on which the predator specializes is more common in the diet of the predator than it is in the ecosystem (considering other species of similar size and general spatial and temporal availability to the predator);

ii) Whether components of productivity of the CRA fishery species (reproductive success, growth rates etc.) co-vary with the abundance of the prey population, particularly for relatively high or low abundances of the prey. Evidence that a prey species is a *key* prey that *supports* CRA fishery species is stronger if reductions in prey abundance or availability result in an increased likelihood and/or magnitude of population-level impacts on the CRA fishery.

iii) Highly specialized species are expected to show sharper responses to changes in prey abundance than generalist feeders, and a non-linear response to impacts is expected, dependent on alternative prey options. Evidence of such patterns also increases the strength of evidence that a prey is a "key prey".

The threats and types of impacts that would typically be evaluated relative to the productivity of CRA fisheries are the same types of impacts evaluated relative to their key prey. This may not be the case, however, if the distribution or the habitat usage of the prey and CRA fishery species are different and the impact is specific to the location of the prey and not the CRA fishery species. As examples, prey could be affected in a location during the time of year when a CRA fishery species is absent due to migratory habits; prey may occupy different habitats than the CRA fishery species and only overlap as prey during critical feeding periods; or the viability of prey populations that overlap in distribution with CRA fishery species may depend on dispersal from distant populations. Also the dependence of either the CRA fishery or the supporting species on particular habitats could mean that the impact of a w/u/a would be manifested differently for each of the two species even though the species' ranges overlap. In the incompletely overlapping case, natural and artificial barriers that would prevent the natural interaction of prey and CRA fishery species should also be considered. Generally impacts on key prey will affect productivity of the CRA fishery species on the same spatial scale at which the prey is impacted.

2.2.2 Implementation Needs – Key Prey Species

How far away (distant in space) impacts must be considered will be case specific, depending on the functional role and behaviour of the support species as well as the nature of its interaction with the CRA fishery species. In some cases activities may affect whole systems (e.g. watersheds due to upstream flow changes), while in other cases impacts may be more localized (e.g. restricted to a single lake, tributary, or portion of a coastline). Nonetheless, it is important to view alterations due to human activities in light of the natural variability in the key prey species and to take account of additional stressors on these species (e.g. invasive species, climate change, pollution etc.) in management. If sufficient data are available, the evaluation of risk associated with impacts to key prey species should consider the following:

i. the intensity or severity of the impact on the prey species being affected;
ii. the change in productivity of the CRA fishery species to the impact created through the change in abundance or availability of the prey species;
iii. the ability of the CRA fishery species to recover from transient impacts (resilience), and the rate of such recovery (i.e., within a biologically reasonable period of time);
iv. the extent to which other ecosystem functions may be altered by the impact.

For w/u/a likely to have large impacts to the ecosystem, the assessment of the above features and the development of thresholds of responses can be accomplished using a variety of approaches (e.g. population dynamics models, prey availability indices, predator-prey analyses, food web descriptions, bioenergetic models, and ecosystem modeling, analysis of trends, or other statistical tools) depending on the availability of scientific and technical capacity and sufficient data. For smaller-scale w/u/a, reference to tabulations of important prey of CRA fishery species, prepared on watershed scales or larger by experts based on literature and existing data sets can be used for qualitative assessments of impacts.

2.3.1 Science Considerations and Ecological Dimensions - Structure-Providing Species

Structure-providing species will rarely result in new geographic areas being included under the Fisheries Protection Provisions of the FA, unless that species itself has life-history stages that occur outside the range of the fish that are part of the CRA fishery. Typically some life history stage of the fish that are part of a CRA fishery would be associated with the structure-providing species, and the areas would be already included under the provisions of the FA due to presence of the fish themselves. However, the structure-providing species would be features of the habitat warranting particular consideration.

Considerations ii) and iii) in Section 2.2.2 (Implementation Needs - Key Prey Species) are also relevant for evaluating the importance of the quantity, quality and spatial configuration of structure-providing support species for a CRA fishery species. The vulnerability and sensitivity of these species to impacts and their ability to recover will depend on the life-history characteristics of the structure-providing species, their abundance and condition after impact, and their spatial configuration. The recovery potential of some structure-providing species may be low. Some of these are not easily re-established by human intervention and for long-lived species the biological processes that recreate them are often very slow.

There may be threats and activities that would have direct impacts to the key structure-providing species and thus indirect impacts (through habitat) on CRA fishery species. This may be especially true for permanent alterations where the sessile structure-providing species are unable to move and would be susceptible to being killed or damaged, while the CRA fishery species may be able to relocate, even temporarily, and avoid the stressor (e.g. dredging) thereby creating differential response curves. Impacts on structure-providing species may affect the productivity of the CRA fishery species on much larger spatial scales than the scale at which the structure-providing species is impacted, if the structure-providing species serves a concentration function for the CRA fishery species. Vulnerability of many benthic structure-providing species to impacts from some mechanical disturbances may be high due to their morphology; although some species may be able to tolerate short term impacts. Productivity of CRA fisheries may respond non-linearly to impacts on structure-providing species and the gradient of the response will be influenced by the strength of the association between the habitat feature and the productivity of CRA fishery, and degree of concentration of the structure-providing species, and whether the structure-providing species is a limiting component to the productivity of the CRA fishery species.

2.3.2 Implementation Needs - Structure-Providing Species

Structure-providing species may depend on source populations in areas never frequented by the CRA fishery species itself. Such areas would be appropriate to consider during the evaluation of potential impacts of the w/u/a, if the best available information suggests that the viability of the population of structure-providing species is dependent on the migration of individuals (or their reproductive products) from elsewhere.

For large scale w/u/a, or for a number of similar small-scale w/u/a, risk assessments can be conducted at regional and sub-regional scales to assess whether an activity will impact productivity of CRA fishery species. The elements to consider when assessing structure-providing species are the same as listed for the Key Prey species. Fortunately, for most of the key structure-providing species that would be encountered in Canada, there is a good body of knowledge on their role, life-history and in some cases recoverability or offsetting requirements. As for Key Prey Species it is important to view alterations due to human activities in light of natural variability in the system and take account of additional stressors on these species (i.e., invasive species, climate change, pollution etc.) in management decisions.

It is feasible, on scales of watershed or groups of similar watersheds, and for intermediate scales of marine and coastal areas, to prepare tabulations of considerations i), ii), and iii) (per Section 2.2.2), based on literature and expert knowledge Guidance on potential implementation approaches is provided in Section 3.3 of this SAR.

In some cases, it may be possible to estimate thresholds for identifying when impacts to structure-providing species affect the productivity of CRA fishery species. There are two questions to consider in making such estimates:

1) What quantity, quality and spatial configuration of the structure-providing species are needed to maintain the ecosystem functions that support CRA fishery species?
2) What quantity, quality and spatial configuration of the structure-providing species must be maintained if the structure-providing species is to sustain itself (and thus provide ecosystem services to other species)?

Future work could be undertaken linking thresholds directly to operational objectives for managing CRA fishery species with respect to these two questions. While rigorous empirical data coupled with statistical modeling for defining such relationships is preferred, simple rules may be sufficient for routine application. Regardless of the approach(es) identified here, the rationales and methods used for setting thresholds need to be logically linked to clearly articulated operational objectives.

2.4.1 Science Considerations for Management - Other Ecological Functional Roles

In addition to the direct support functions provided by key prey and structure-forming species, the dynamics of some ecosystems may depend on certain other ecological functions provided by these or non-CRA fishery species. Specifically, keystone species, wasp-waist species, highly-connected species, apex predators and environment-modifying species all have the potential to fill important roles in system dynamics. Because of their role in maintaining community structure and function and the potential for very large and rapid changes to ecosystems to occur if their ecological function is impacted, they are highlighted here. Impacts on these species can have disproportionately large and cascading effects from which recovery may not be rapid and secure.

2.4.2 Implementation Needs – Other Ecological Functional Roles

Quantifying food web structure is demanding. Data collection is expensive and time-consuming and reliable food web models are complex to build and validate. When validated food web models are not available for the CRA fishery under consideration an assessment of the feeding pathways leading to the CRA fishery species should be considered. For a prey further away in a food web to be considered to support the productivity of CRA fisheries, each species in the trophic path to the CRA fisheries species would have to meet the criteria for key prey. This standard is unlikely to be met for most “prey of prey”.

For other support functions a suite of structure and function indicators suitable for assessing changes in the tropho-dynamics could be used to determine the energy flow of the ecosystems. In future it would be possible to provide initial lists of keystone and wasp-waist species based on scientific advice from experts for different ecosystems across Canada. These are likely to have been documented for only a few of Canada’s aquatic ecosystems, however, so extrapolation of information from well-studied to less well-studied systems will be necessary.

Even though the substantial reduction or removal of species identified according to their indirect support function may cause dramatic changes to the ecosystem, it does not necessarily follow that CRA fishery species will be affected, particularly if the species are only altered in abundance and not completely removed. The factors identified for consideration in key prey and structure-providing species will also be relevant in evaluating the roles of these species in the productivity of CRA fisheries.

3.0 "Contribution of the Relevant Fish"

3.1 Scientific Interpretation and Ecological Dimensions

"The *contribution of the relevant fish to the ongoing productivity of commercial, recreational or Aboriginal fisheries"* is measured by the impact that would be expected on the productivity of CRA fishery species if change to the potentially affected species or habitats associated with a w/u/a takes place. 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.

3.2 Science Considerations for Management:

A simple conceptual depiction of impact to the ongoing productivity of the fishery from cumulative changes (whether due to multiple w/u/a or multiple impacts of a single w/u/a) provides a useful starting point to develop a framework for the implementation of these concepts (Fig. 2).

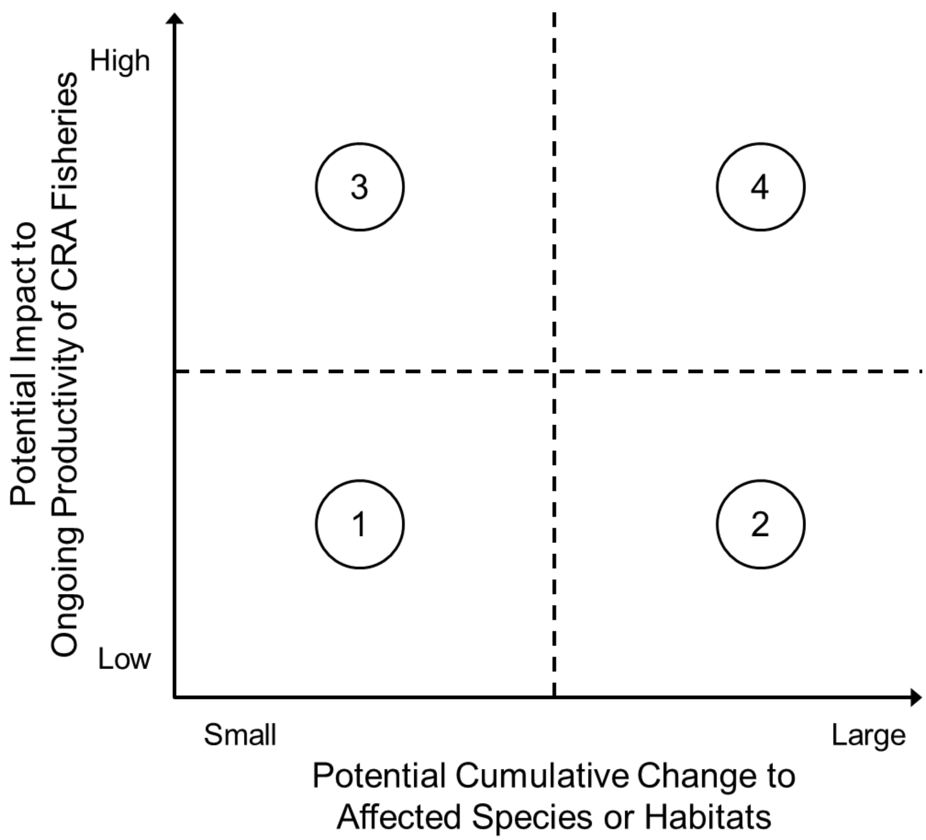

Figure 2. Schematic representation of a conceptual framework mapping the relationships between potential cumulative change to the affected species or habitats and the consequent potential impact to the ongoing productivity of CRA fisheries. Note: both axes are continuous variables; the dashed lines dividing the space into four quadrants are included for heuristic purposes and do not imply an a priori categorization.

In Quadrant 1, potential for cumulative change to the affected species or habitats is expected to be small and to have a low impact on the productivity of the CRA fishery species

In Quadrant 2, CRA fishery species are expected to have relatively weak response to change to the affected species or habitats, so that even large amounts of cumulative change or w/u/a with large individual changes have relatively low impacts on the productivity of the CRA fishery species.

In Quadrant 3, productivity of CRA fishery species has relatively strong response to changes in affected species or habitats. Small amounts of change to the affected species or habitats will have large impacts on the productivity of fisheries.

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

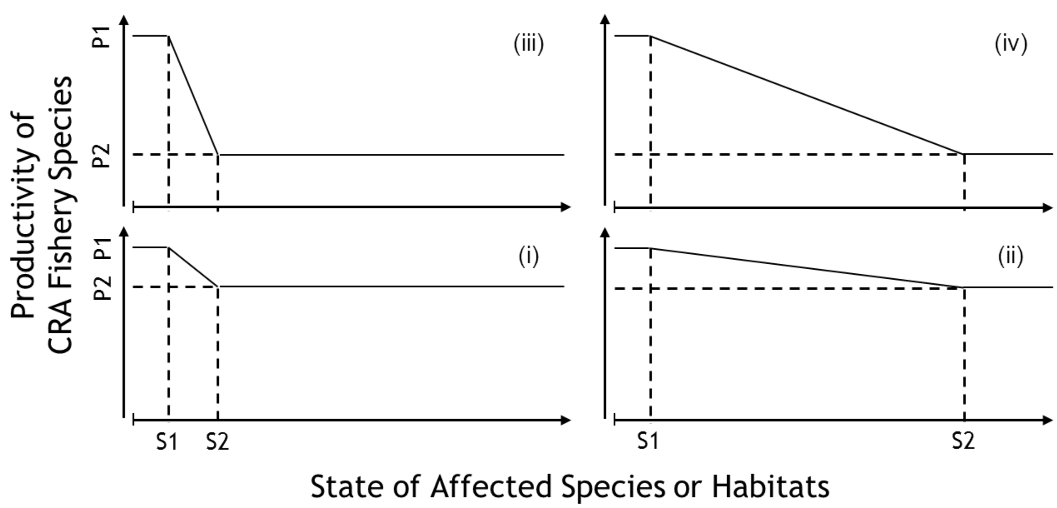

Figure 3. Four representations of the productivity-state relationship demonstrating how the positioning of thresholds S2 and P2 determine the relative location of the relationship in the cumulative change-impact space of Figure 2. The X-axis indicates state as measured along a continuum from good (left) to poor (right). The Y-axis indicates productivity as measured along a continuum from low (bottom) to high (top).

The factor to be considered is the contribution of the affected species or habitats to the ongoing productivity of CRA fishery species. This can be conceptualized as a relationship between productivity of the CRA fishery species and state of the affected species or habitats (Fig. 3), where state is measured along a continuum from good (left) to poor (right).

There are some potential reference benchmarks along the productivity-state relationship worth considering (Fig. 3). P1 represents a baseline condition set for the productivity of the CRA fishery species, taking into account both ecological considerations and management objectives. To the left of S1 changes to the state of affected species or habitats are not expected to result in changes to the productivity of CRA fisheries species. S2 identifies the total potential cumulative change to the state of the affected species or habitats that can impact the productivity of the CRA fisheries species. Further change in the affected species or habitats (the area to the right of S2), is not expected to result in further reduction in productivity of CRA fisheries species. The difference between the productivity of the fishery at P1 and the reduced productivity of the fishery at and beyond the S2 state threshold (P2) represents the total potential contribution of the affected species or habitats to the ongoing productivity of the fishery and its sustainability at those levels. The positions of S2 and P2 define the relative position in Figure 2 applicable to a particular CRA fishery and the species and habitats on which it depends. Further change to the affected species or habitats (the area to the right of S2) is not expected to result in further reduction in productivity of the CRA fishery species. The position of S1 and the slope of the line from P1 to P2 can inform management decisions about risks to productivity of CRA fishery species associated with changes to the state of affected species or habitats.

Within each ecosystem multiple CRA fisheries can take place. Therefore, the overall productivity of CRA fisheries in an ecosystem can be understood as the combined productivity of each fishery, and includes the range of contributions of each fishery to the overall fisheries productivity. There are also many different human activities that may affect aquatic ecosystems and have the potential to impact fisheries productivity. The cumulative change and state of affected species or habitats will be multidimensional. Consequently there are ecological reasons to consider sustainability and ongoing productivity of CRA fisheries on a functional ecosystem scale. However as noted in Section 1.2 (Science Considerations for Management – Ongoing Productivity) at least for w/u/a expected to cause only small changes to affected species or habitats, it is appropriate to evaluate them on a site-specific basis. If processes are established to track change for cumulative impact, those w/u/a should be captured by those processes.

3.3 Implementation Needs

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. 4). 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.

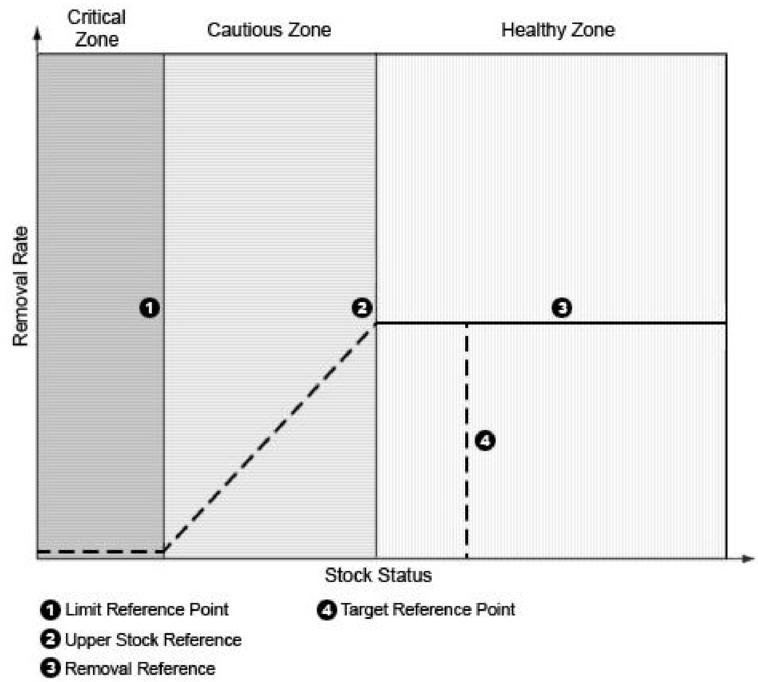

Figure 4. Schematic representing a Precautionary Approach (PA) framework that has been developed as part of DFO's Sustainable Fisheries Framework (SFF).

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 Figure 3 as the functional relationship between productivity of CRA fisheries and 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 Figure 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 Figure 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 Figure 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 Figure 5. 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 Figure 5 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).

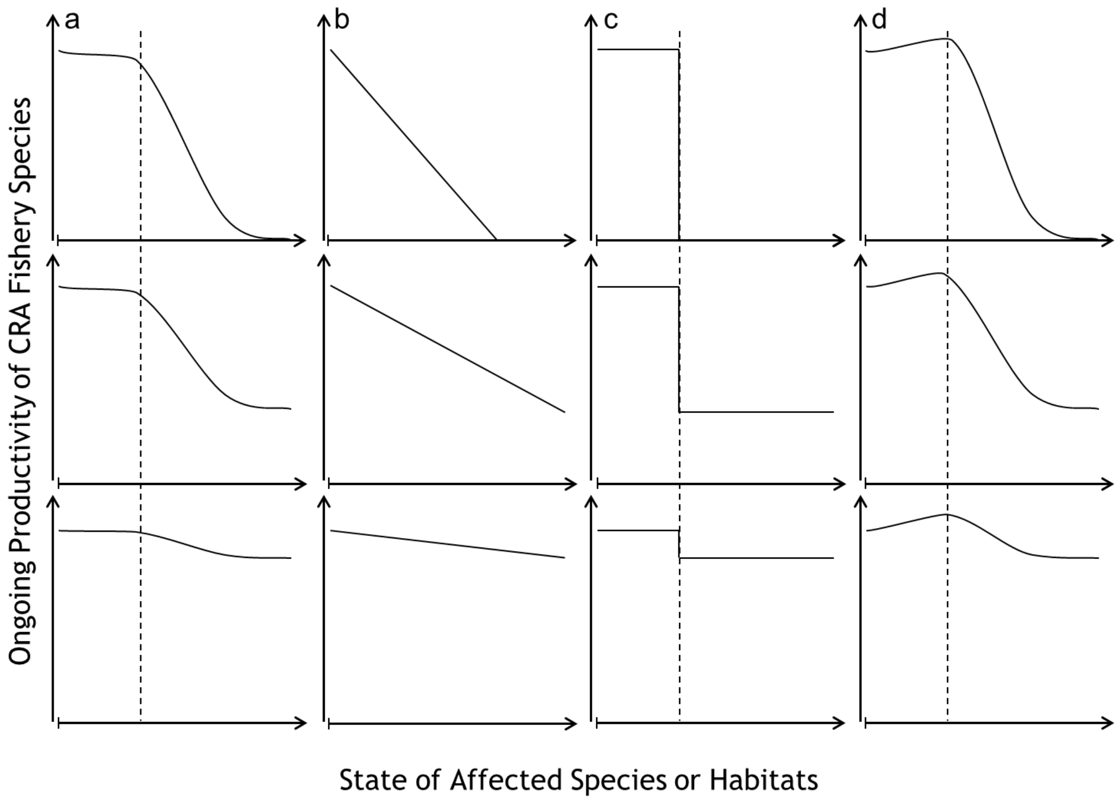

Figure 5. Representations of some of the different shapes of the productivity-state relationship: (a) curvilinear response (similar to the lines in figures 3), (b) linear response (difficult to identify a threshold), (c) step response, and (d) subsidy-stress response. Three different forms of each shape 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).

4.0 Scale Considerations

The spatial scale associated with a w/u/a is not necessarily proportional to its impact on CRA fisheries productivity; the impact on productivity is the result of the combined effects of all past and present w/u/a affecting the ecosystem that produces the CRA fishery species. In some cases, due to their nature and extent, individual w/u/a, would have potentially measurable effects on fisheries productivity (e.g. destruction of spawning grounds or nursery areas), but in most cases, the impact of an individual w/u/a on fisheries productivity would be expected to be small and difficult or impossible to directly detect through measurements of production. Nonetheless, the incremental impact of a single w/u/a may contribute to a much larger cumulative impact of many w/u/a on a CRA fishery species in an area. 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).

There are challenges to matching the scales of impacts of w/u/a to scales of potential impacts on the productivity of CRA fisheries. With few exceptions (e.g. some salmon and invertebrate fisheries), the scales at which Integrated Fish Management Plans (IFMPs) define commercial fisheries are much larger than the immediate footprint of all but the very largest potential w/u/a. For most recreational fisheries, scales at which licensed fisheries are defined are typically much larger than individual watershed or lakes. Hence if the only scale at which impacts of w/u/a were evaluated was the scale at which management units of fisheries were defined, rarely would any but the largest w/u/a, with impacts well beyond the location of the w/u/a itself, have meaningful impacts on fishery productivity. This would place many ecological processes at risk of major alteration due to the cumulative effects of many w/u/a that individually cannot be shown to measurably reduce the productivity of fisheries. Approaches are needed that protect the ongoing productivity of CRA fisheries when decisions are made at the scale of individual w/u/a but for which "fisheries" are defined on large spatial scales.

These are challenging problems and there is no single approach which will address them fully. However, a strategy for operations in the near term could include:

1) Assessments of the state of affected species or habitats at the landscape scale. Landscapes are composed of multiple habitats, and assessments at this scale can incorporate information on ecological processes. This scale is selected because it most closely approximates the scale of functional ecosystem units, and takes into account supporting functions. In many parts of Canada, it may be appropriate to do assessments for multiple landscape scale units together, based on similarities in their ecology and the threats to which they are exposed.

   These assessments could provide the basis to develop the default productivity – state functional relationships of Figure 5. These could be prepared for the major types of ecosystems and habitats within the landscape-scale units, for example large lakes, major wetland complexes, tertiary watersheds, riparian areas, coastal management areas, etc. The assessments could also be used to inform the selection of risk tolerance to be applied in the area. The nature of the assessments will vary depending on the quantity and quality of information available, and take into account management objectives set for the area. Many will be coarse and qualitative at first.

   In this context, there would be operational benefits for future assessments from maintaining or developing some capacity for tracking and accounting of the w/u/a being implemented at these functional ecosystem/landscape spatial scales.

2) Where there is more fine-scale information available, and/or fisheries management objectives were set at finer spatial scales than the landscape, the default functional relationships and risk tolerances could be updated with this additional information for use on finer scales or resolutions.

   Offset and remediation planning would also be applied at these landscape scales, and use the assessment information in their planning.

3) Individual w/u/a-based decisions would then be made at the scale of the impacts of the w/u/a, using the functional relationships and risk tolerances considered appropriate within the operational framework described above.

CONCLUSIONS AND ADVICE

This Science Advisory Report provides advice to policy and management primarily regarding the scientific interpretation of new terminology found in the recent amendments to the *Fisheries Act* (2012). Guidance is provided to policy-makers regarding scientific interpretation and definitions for "ongoing *productivity*" of CRA Fisheries "the *contribution* of the relevant fish", and "fish that *support*" such CRA fisheries.

In addition, implications for application at various spatial scales were considered, and a framework for ongoing scientific support is provided, along with recommendations for additional work required.

SOURCES OF INFORMATION

This Science Advisory Report is from the national advisory process of August 29-31, 2012, on "Science guidance for Fisheries Protection Policy". Additional publications from this process will be posted as they become available on the Fisheries and Oceans Canada Science Advisory Schedule at http://www.dfo-mpo.gc.ca/csas-sccs/index-eng.htm.

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APPENDIX: GLOSSARY

"biogenic habitat" - habitat created by a living organism *(i.e. sea pen fields, sponge reefs, deep sea coral, etc..)*

"*fish*" - as defined in the *Fisheries Act* (S. 2) includes "fish, shellfish, crustaceans and marine animals, any parts of those animals, as well as their eggs, sperm, spawn, larvae, spat and juvenile stages".

"fish habitat" – as defined in the *Fisheries Act* (S. 2), "means spawning grounds and any other areas, including nursery, rearing, food supply and migration areas, on which fish depend directly or indirectly in order to carry out their life processes".

"functional ecosystem" – in which the biota are explicitly linked to their physical surroundings; in which ecological cycles and pathways of energy in combination are more important than size or scale in delineating the ecosystem.

"habitat-based approaches" - methods that measure physical habitat properties of ecosystems or physical habitat features but then make assumptions or inferences about the productivity of the fishes associated with those features.

"landscape scale" - composed of multiple habitats and assessments; at this scale can incorporate information on ecological processes.

"*productivity-based approaches*" - methods that measure biological attributes that relate directly or indirectly to fisheries productivity.

"*resilience*" - capacity of a population or ecosystem to recover from a disturbance.

"*source-sink dynamics*" – a theoretical model used by ecologists to describe how variation in habitat quality causes individuals to move from productive habitats to areas of low habitat quality. Populations in low quality habitats are subsidized by immigration, and are thus considered the "sink".

"systems" – within this SAR, the term 'systems' is used synonymously with 'ecosystems'.

"w/u/a" (singular and plural) – a "work, undertaking or activity", as found in various sections of the amended *Fisheries Act* (2012). Within this SAR, the term 'project' is used synonymously with 'w/u/a'.

FOR MORE INFORMATION

Contacts: Dr. Jake Rice
Fisheries and Oceans Canada
200 Kent Street
Ottawa, Ontario K1A 0E6
Tel: 613-990-0288
E-Mail: jake.rice@dfo-mpo.gc.ca

Roger Wysocki
Fisheries and Oceans Canada
200 Kent Street
Ottawa, Ontario K1A 0E6
Tel: 613-998-5171
E-Mail: roger.wysocki@dfo-mpo.gc.ca

This report is available from the:

Canadian Science Advisory Secretariat
National Capital Region
Fisheries and Oceans Canada
200 Kent Street
Ottawa, Ontario
K1A 0E6

Telephone: 613-990-0293
E-Mail: csas-sccs@dfo-mpo.gc.ca
Internet address: www.dfo-mpo.gc.ca/csas-sccs

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