A SCIENCE-BASED APPROACH TO ASSESSING THE IMPACT OF HUMAN ACTIVITIES ON ECOSYSTEM COMPONENTS AND FUNCTION

Figure 1. The six administrative regions of Fisheries and Oceans Canada (DFO). The dashed line indicates Canada's Economic Exclusive Zone (EEZ).

Context

A key component of integrated oceans management is a nationally-consistent approach to the identification of marine and coastal areas (including ecosystem components and functions) that are experiencing human-induced pressures. As part of a larger risk management process, Fisheries and Oceans Canada requires a scientifically-sound approach for determining the impact of an anthropogenic pressure on ecosystem components and function. This approach should be independent of time and space, and consistently applicable to any anthropogenic pressure.

This Science Advisory Report is from the December 9-11, 2014 National Science Advisory Process titled Ecological Risk Criteria to Support Integrated Oceans Management. Additional publications from this meeting will be posted on the [Fisheries and Oceans Canada (DFO) Science Advisory Schedule](#) as they become available.

SUMMARY

- This Science Advisory Report (SAR) provides a structured approach for assessing the impact of an anthropogenic pressure on an ecosystem component and its function. The impact is assumed to result from a change in the status of an ecosystem component caused by a pressure. This approach is merely one aspect of a larger, multi-step risk management process.
- This advice incorporates previous advice related to assessing how pressures may impact fisheries productivity and how fishing may impact stock status. This approach can be applied consistently to any ecosystem component, pressure, and ecosystem function, and is independent of time and space.
- The relationships between any ecosystem component and any pressure, as well as the ecosystem function provided by the ecosystem component will often be non-linear and usually sigmoidal. In cases where data is limited, informed inferences will be necessary and should include a measure of uncertainty.
- This advice includes three categories of impact that characterise the status of ecosystem function as a result of changes to an ecosystem component. The boundaries between these categories represent transition points that indicate where an incremental change in the status of an ecosystem component substantially affects its ability to perform its function. Depending on risk tolerance levels, management action may be appropriate at any point along the spectrum of pressure (i.e. negligible impact to high impact). However, at the transition points the nature or necessity of management action may change more than incrementally.
- Integral to this advice are the Pathways of Effects (POEs) models that have been developed for major classes of anthropogenic pressures. In cases where POEs do not already exist, these (or other similar analyses, e.g. interaction matrices) will be required to identify the potential impacts of human activities on ecosystem components of concern.
- In addition to understanding the interaction between pressures and the ecosystem, an understanding of the relative contributions of different ecosystem components to the ecosystem function of interest and of the amplitude of variability linked to natural factors improves the ability to apply the approach provided in this advice.
- The likelihood of an ecosystem component being exposed to a pressure and the level of risk tolerance in policy and decision-making must be considered in a broader risk management process; however neither of these aspects is discussed in this advice.

INTRODUCTION

Integrated Oceans Management (IOM) is an approach to planning and managing human activities in order to reduce the potential for conflict and to ensure the sustainable use of shared marine resources and ocean space. Part II of the *Oceans Act* directs the Minister of Fisheries and Oceans Canada (DFO) to lead and facilitate IOM in all Canadian estuarine, coastal, and marine waters. The *Act* recognizes that application of an Ecosystem Approach, Precautionary Approach, and Sustainable Development principles will guide IOM planning.

IOM implementation should be supported by a nationally-consistent approach to the identification of marine areas that are experiencing anthropogenic pressures, the evaluation of the threats and risks posed to the ecosystem by those pressures, and, if required, the selection of appropriate management measures to manage the risks by addressing the identified threats.

Measures to address the threats to ecosystem components from anthropogenic pressures can be derived from regulatory options under the *Oceans Act,* and from other management and policy tools administered by federal, provincial, and territorial regulators with the authority to manage activities in or affecting Canadian oceans.

Implementation of IOM will have higher success if the results of risk assessments are considered credible to partners and stakeholders. Both credibility and legitimacy increase if a consistent approach is taken in all cases. This approach must be flexible enough to accommodate case-specific differences in the nature of the pressures, the ecosystem, and in the quantity and quality of data. One aspect of a nationally-consistent risk assessment process is a scientifically-sound approach for assessing the impact of human activities on ecosystems, which includes understanding how ecosystem function responds to changes in the status of an ecosystem component. This approach must be applicable to different pressures, ecosystem components, and ecosystem functions, and also must be independent of time and space. A consistent, science-based approach such as the one provided in this report provides a foundation for informing management decision-making and is essential to reducing subjectivity in how risk from anthropogenic pressures is assessed and managed.

This advice provides a structured approach for assessing the impact of anthropogenic pressures on ecosystem components and functions. The impact is assumed to result from a change in the status of an ecosystem component caused by the pressure. Integral to this advice are the Pathways of Effects (POE) models that have been developed for the major classes of anthropogenic pressures in Canadian oceans. POEs, or other similar analyses (e.g. interaction matrices), will need to be developed for all pressures and ecosystem components of concern in order to apply this advice. In addition to understanding the interaction between pressures and the ecosystem, an understanding of the relative contributions of different ecosystem components to the ecosystem function of interest and of the amplitude of the inherent variability of the function in response to natural factors improves the ability to apply the approach.

The advice provided in this SAR is one aspect of a more comprehensive risk management process. The ISO 31000:2009 risk assessment framework indicates steps that should be included in a general risk management process and which have informed the development of an IOM risk management process for Canadian marine areas to date (Figure 2).

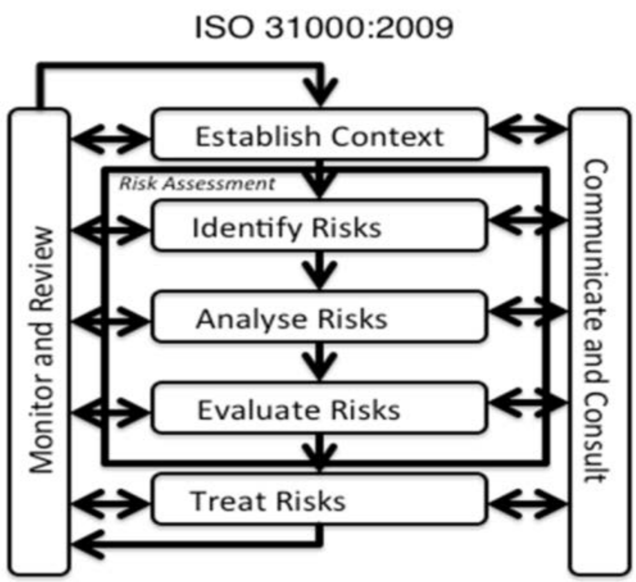

Figure 2. Contribution of risk assessment within a broader risk management process as defined by ISO 31000:2009.

ANALYSIS

Glossary

A number of words and phrases are used in this document to express specific technical meanings and many of these terms also have vernacular meanings. For clarity, a glossary is provided (Appendix 1) to provide definitions for terms in the context of this advice.

Considering Existing Science Advice

DFO has previously produced Science advice relevant to ecosystem components in the context of risk assessment for IOM, and specifically during the development of a nationally-consistent, scientifically-sound approach to determining how ecosystem function responds to changes in the state of ecosystem components. These two approaches are:

1. A Harvest Strategy Compliant with the Precautionary Approach (DFO 2006a); and
2. A Science-Based Framework for Assessing the Response of Fisheries Productivity to State of Species or Habitats (DFO 2014).

There are important similarities between these two approaches. Notably, both assume a non-linear, often sigmoidal relationship between a pressure and the status of an ecosystem component. In addition, both of these approaches include categories that describe how the ecosystem is responding to the pressure, as well as clearly defined boundaries between the categories. Although the two approaches have notable similarities, there are also important differences to consider regarding the information required to create the curvilinear relationships, and how these relationships should be interpreted.

A Harvest Strategy Compliant with the Precautionary Approach

This approach includes three categories referred to as stock status zones (i.e. Critical, Healthy, and Cautious) that are delineated by boundaries referred to as the Limit Reference Point and the Upper Stock Reference (Figure 3). Stock status is usually represented by spawning stock biomass (SSB) or a suitable proxy, and reference points are defined for “normal” conditions of stock productivity based on the best available science. Of the boundaries between the categories, only the Lower (Limit) Reference point is defined by the biological properties of the stock (e.g. the SSB at the point where the probability of impaired productivity increases). The Upper Stock Reference is determined by the *uncertainty* in how well the SSB is estimated (a property of the *assessment*, not the SSB itself), as well as uncertainty about the effectiveness of management responses (a property of the *management system*, not the SSB). In this approach, the Cautious Zone simply reflects *how* management actions are recommended to vary between the Healthy and the Critical Zones, and not how the ecosystem component (e.g. SSB) is expected to vary as the pressure changes. The *pressure* (i.e. fishing harvest levels) on the y-axis is the *recommended* change in the pressure. The effects of fishing pressure in the past (or in scenarios being explored) are what determine where a *specific application* is positioned on the x-axis. That is, past and present fishing determines how large the SSB is *now.* The graph then says how high fishing pressure *should be,* to comply with the framework. This is the fundamental difference between this approach and the *Framework for Assessing the Response of Fisheries Productivity to State of Species or Habitats* (Figure 4).

A Framework for Assessing the Response of Fisheries Productivity to State of Species or Habitats

Similar to the *Harvest Strategy Compliant with the Precautionary Approach* outlined above (DFO 2006a), the *Framework for Assessing the Response of Fisheries Productivity to State of Species or Habitats* (DFO 2014) also describes how ecosystem function (i.e. fisheries productivity) is expected to respond to increasing pressure on the ecosystem component (i.e. habitat). In Figure 4, the upper plateau (prior to S1) is the zone where the natural resilience of the ecosystem can maintain full productivity in the face of changes to habitat, the lower plateau (after S2) is the zone where the habitat has been so degraded that further alteration to that habitat quality or quantity cannot lower productivity further, and the middle section (between S1 and S2) is the range over which any deterioration in the habitat quality or quantity is expected to cause a corresponding decrease in the ecosystem function (productivity).

The relationship outlined in Figure 3 is based on how management actions are expected to vary between the 'good' and 'poor' zones, whereas the relationship shown in Figure 4 describes a graded response of the ecosystem function to a change in pressure. The approach in the Fisheries Productivity SAR (DFO 2014) is more aligned with an IOM risk assessment process because it explicitly describes the relationship between the status of any ecosystem component and its function over the full range of any given pressure.

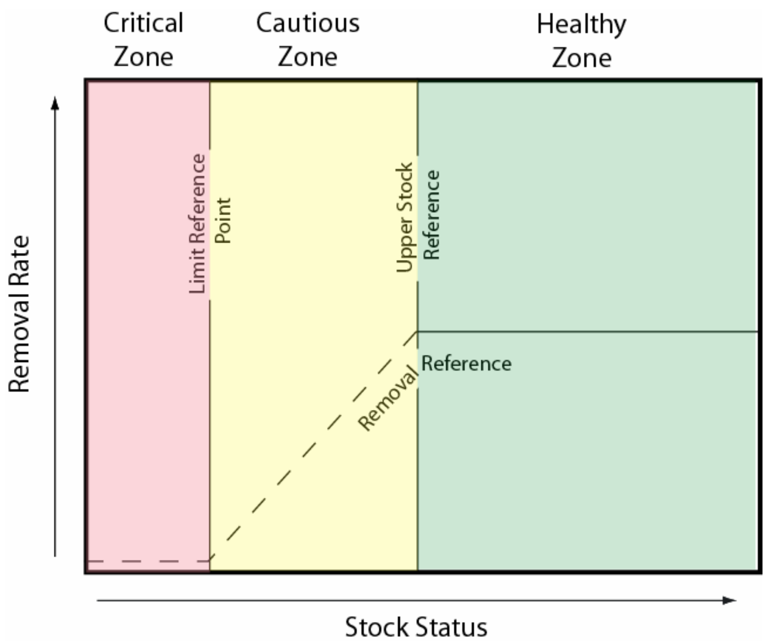

Figure 3. A harvest strategy compliant with the precautionary approach (DFO 2006a). In the Critical Zone, the status of the stock has declined to such a low level that it is considered to be in a precarious state. In the Cautious Zone, the status of the stock is approaching the Critical Zone and fisheries management actions should promote stock rebuilding. In the Healthy Zone, the stock status is considered to be good and the removal rate should not exceed the Removal Reference (e.g. spawning stock biomass). The Limit Reference Point is the stock level below which productivity is sufficiently impaired to cause serious harm, but above where the risk of extinction becomes a concern. The Upper Stock Reference is the stock level threshold below which the removal rate is reduced. The Removal Reference is the maximum acceptable removal rate.

There are aspects of the approach in the Fisheries Productivity SAR (DFO 2014) that make it particularly suitable for determining how ecosystem function responds to changes in the state of ecosystem components:

1. The use of POEs to identify functional relationships between the pressure and the ecosystem component, which facilitates the development of management strategies;
2. Using “productivity” as a common ecological currency to connect pressures to the effects on ecosystem functions;
3. Transition points (i.e. boundaries) useful for delineating management concerns in relation to escalating ecosystem responses to pressure. These transition points represent important changes in ecosystem states that decision-makers should be aware of when deciding if and what management actions may be required, because the response of the function to changes in the component is different to the left and right of the transition point;
4. Alignment with existing advice on how to identify ecosystem components upon which to focus analyses (e.g. EBSAs, ESSs, CPs); and
5. A predictable and systematic response of an ecosystem component to a graded increase in pressure.

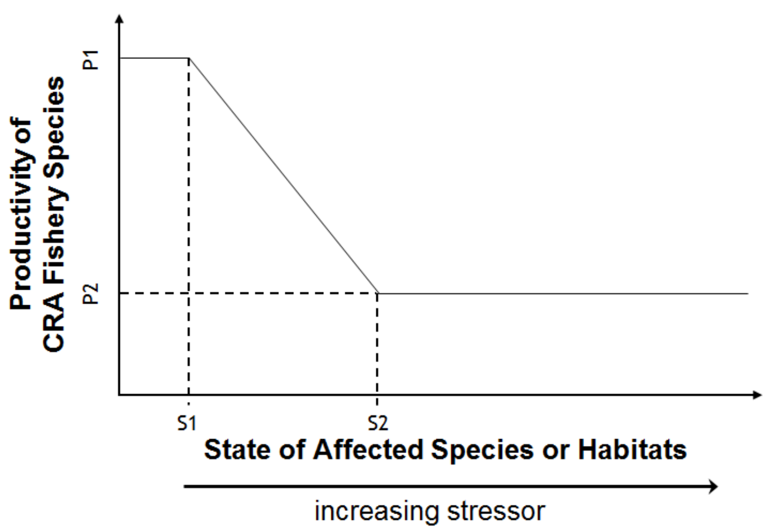

Figure 4. A framework for assessing response of fisheries productivity to state of species or habitats (DFO 2014). The y-axis represents productivity (ecosystem function) measured along a continuum from low (bottom) to high (top). The x-axis (ecosystem component) represents state along a continuum from 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 commercial, recreational, or Aboriginal 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).

Although the Fisheries Productivity SAR (DFO 2014) approach has many positive attributes that make it applicable for consideration in a broader IOM risk assessment process, like any approach it also has weaknesses. The potential areas of weakness and uncertainty associated with the approach in the Fisheries Productivity SAR (DFO 2014) are provided below, but it should be noted that they are also likely to apply, to varying degrees, to other approaches/frameworks, including the *Harvest Strategy Compliant with the Precautionary Approach* (DFO 2006a) discussed above.

Potential areas of weakness and uncertainty to take into account include:

1. Although the approach in the Fisheries Productivity SAR (DFO 2014) is able to consider multiple pressures, it does not indicate whether the impacts of the pressures are additive/cumulative, antagonistic, or synergistic. Multiple pressures may act on the same ecosystem component thereby compounding the impact and confounding management actions.
2. Not unique to the approach in the Fisheries Productivity SAR (DFO 2014), substantial data and analyses are required in order to determine the relationships between ecosystem components and pressures, and ecosystem components and the functions they support. In cases where data are limited, informed inferences will be necessary. However, analysis of a wide range of pressures on marine and freshwater ecosystems supports the assumption that there are likely generic shapes to these relationships. These generic relationships must be given parameters appropriate to the specific pressure and ecosystem to which they are being applied. Data quality and other factors (e.g. sampling error, process error, uncertainty in the functional response) that can distort the graphical representations of the ecosystem response are important to consider when determining the confidence level that is assigned to the supporting data and the assumptions inferred from that data.
3. Unlike the *Harvest Strategy Compliant with the Precautionary Approach* (DFO 2006a), the approach in the Fisheries Productivity SAR (DFO 2014) does not give explicit advice regarding specific methods to incorporate uncertainty about the relationships into the risk assessment or the risk management process. How uncertainty is taken into account will affect the outcomes of the analysis. Key effects of uncertainty include not just the rate of errors in management decisions, but whether errors are more likely to be misses or false alarms. “Misses” occur when application of the framework supports a decision not to take management action when in reality actions should have been taken, and “false alarms” occur when application of the framework supports a decision to take management action, when existing management measures were sufficient for sustainability or achieving objectives.

Although the two approaches outlined above in Figures 3 and 4 provide a basis for identifying the response of ecosystem components to pressures, it should be noted that each approach consists of two graphs, representing two relationships. One is the relationship between the level of the pressure and the status of the ecosystem component, and the other the relationship between the status of the component and the ecosystem function(s) it is thought to provide.

How these relationships are considered varies among approaches. For example, in the *Harvest Strategy Compliant with the Precautionary Approach* (DFO 2006a) neither of these relationships is plotted explicitly. The graph shown in Figure 3 is *based* on the relationship between the maximum fishing mortality that can be sustained (i.e. the pressure) and spawning stock biomass (SSB) (i.e. the ecosystem component). The classic stock-recruitment plot capturing the relationship between SSB and recruitment (i.e. a key function for the population) is rarely presented explicitly as part of the *Harvest Strategy Compliant with the Precautionary Approach*. However, it is that relationship which determines the location of the limit reference point and that determines the shape of the removal reference curve.

The approach in the Fisheries Productivity SAR (DFO 2014) demonstrates (see Figure 4) how fisheries productivity (i.e. ecosystem function) is likely to respond to a change in the status of species or habitat (i.e. ecosystem component). Although it is implied that as the pressure increases, the status of the ecosystem component will decrease, the actual relationship between any given pressure (e.g. sediment concentration, temperature, amount of structure/vegetation, etc.) and the ecosystem component is nowhere explicit in the framework. This relationship is estimated (using POE models, for example) *prior* to producing the graphical relationship between ecosystem component and ecosystem function.

The approach provided in this SAR makes both of the aforementioned relationships (i.e. component vs. pressure and component vs. function) explicit and part of the overall impact assessment framework; a necessary step if the approach is to be both consistent and inclusive of all potential types of pressures and ecosystem components.

A Science-Based Approach for Assessing the Impact of Human Activities on Ecosystem Components and Function

A key use of this approach is to inform decisions about managing anthropogenic pressures in ways that ecosystem function is not impaired. Decisions can be made for a specific proposed or ongoing activity, for a specific site being considered for spatially-based management, or for choosing among options that must be “traded off” for integrated management.

The approach outlined below would usually enter at an early stage in a larger risk assessment or integrated planning/management process, but once the assembly of information was underway and after the initial context setting/scoping and risk identification phases were complete (i.e. in the ‘Analyse Risks’ phase of Figure 2). It provides a structured process for identifying the degree of impact from a pressure on an ecosystem component and ultimately on the ecosystem function it supports.

The process of considering potential impacts to ecosystems in risk assessment is based on two graphical relationships:

1. The relationship between ecological components (i.e. dependent variable; y-axis) and pressures (i.e. independent variable; x-axis) (Figure 5); and
2. The relationship between ecological components (i.e. independent variable; x-axis) and the functions they provide in the ecosystem (i.e. dependent variable; y-axis) (Figure 6).

Both relationships are assumed to be non-linear (often sigmoidal) an assumption consistent with substantial scientific literature and with several existing approaches to categorizing impacts (Figures 3 and 4). This advice further assumes that these relationships follow generic shapes which can be parameterized for each ecosystem, an assumption identical to one made in the Fisheries Productivity SAR (DFO 2014) approach.

The process of assessing impacts to ecosystem components and functions in risk assessment is stepwise and consists of the following:

1. Assemble all relevant and available information within the scope of the analysis, including the ecosystem of interest and pressures that have occurred, are occurring, or may occur in the future.
2. Within the ecosystem of interest, select ecosystem components that are relevant to how well an ecosystem function is being provided, that are measureable, and that are sensitive to the pressure of concern. This step can be informed by POE models and other sources such as interaction matrices, etc. These models/analyses are informed by the scientific literature and existing DFO Science advice, including that related to selecting ecosystem indicators. If the relationship between the ecosystem component and the function it supports is not known, inferences will be required or an ecosystem component that is a better indicator of ecosystem function should be sought.
3. Using the aforementioned information and analyses, adapt the generic graphical relationships to the particular ecosystem component of interest (specific advice on how this can be done is available in DFO 2014):
    a. Select a relevant existing graph, or develop a new one presenting information as in Figure 5, to determine the status of the ecosystem component based on the expected/current level

of interaction with the pressure (or the potential ecosystem status if considering the potential impacts of future interactions).

   b. Select a relevant existing graph, or develop a new one presenting the information as in Figure 6, to determine the level of ecosystem function relative to the status of the ecosystem component. The degree to which the ecosystem function is expected to change based on the status of the ecosystem component (from 2), above) is determined using the categories provided in Table 1. Generally, the more an ecosystem function is impacted by a pressure (as indicated by a change in the status of the ecosystem component), the higher should be the priority given to managing that pressure.
   c. When there is sufficient information to identify the boundaries of the categories (Table 2), management decisions can be made using the results of the graph in b) (based on Figure 6) and comparing them to the categories/boundaries provided in Tables 1 and 2.

4. Repeat steps 2. to 3. for each pressure and ecosystem component of interest.
5. Considering the outputs of this process, identify priorities (pressures and ecosystem components) for further analyses and possibly management action.

When generating the graphical relationships discussed in 3) (above) there are several factors to take into account, including:

- Spatial and temporal overlap relating to both the ecological component and the pressure;
- Zone of influence of the pressure;
- Characteristics of the pressure;
- Sensitivity of the ecological component;
- Ecological significance of the ecological component; and
- Recoverability and resilience of the ecosystem.

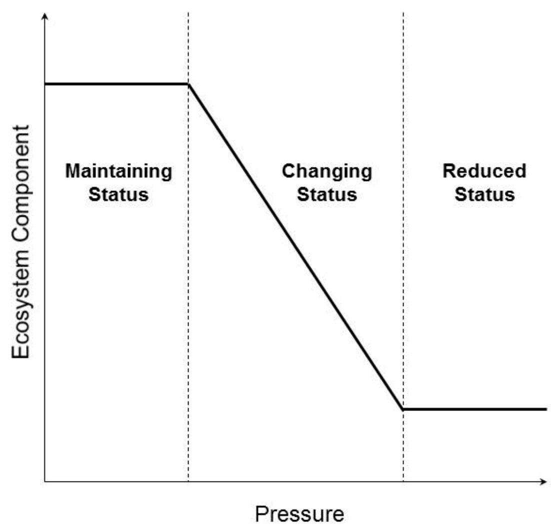

Figure 5. The relationship between ecological components and potential pressures.

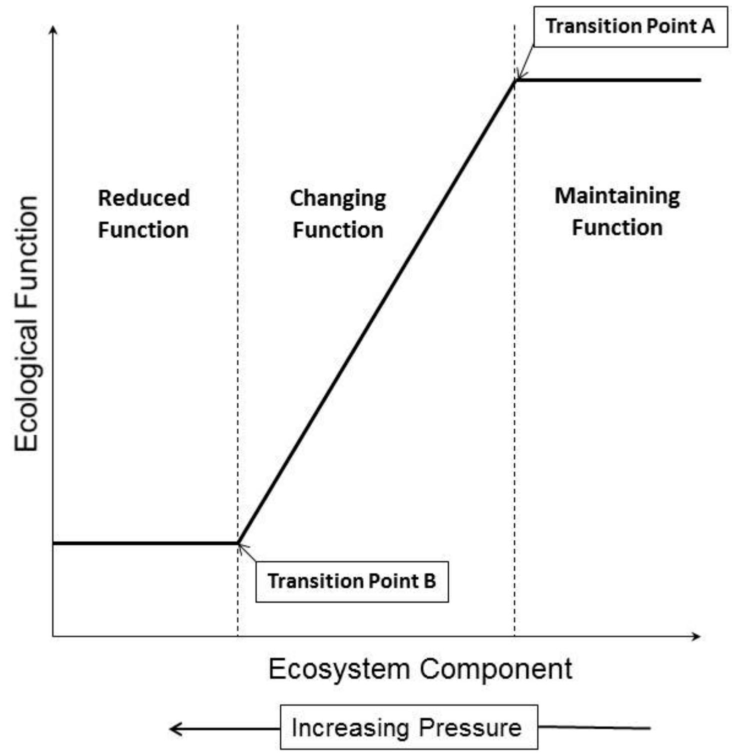

Figure 6. The relationship between ecological components and the functions they provide in the ecosystem.

Categories & Boundaries of Ecological Impact Criteria

The wide range of impacts, from none to catastrophic could justify policies recognizing many categories (or “criteria” in the policy sense) of impact. On the other hand, the need for policy clarity and the typical limitations on case-specific data pertaining to the pressures and the ecosystems make a case for recognising just a few categories. Three categories of increasing impact were considered the most workable compromise between those contrasting considerations (Table 1). For each category, there is: a) a phrase characterizing the corresponding level of impact to the ecosystem component, and b) a diagnostic criterion for determining if a specific case qualifies for inclusion in that category. The level of impact to the ecosystem function increases as the ecosystem component moves from “Maintaining Function” towards “Changing Function” and “Reduced Function” categories. The categories in Table 1 are important because policy-making considers each category to require different management actions. Management is usually more effective if decision-makers are aware that a transition point is being approached, and take appropriate actions before the transition is passed.

While the descriptions of these categories are intended to be generic so as to be relevant for a broad set of management applications, it is important to consider that both spatial and temporal scales will play a role in the response of the ecosystem function to the status of the ecosystem component.

Table 1. Categories of increasing impact which characterise the level of ecosystem function and a diagnostic criterion for determining if a specific case qualifies for inclusion in that category.

1. Maintaining Function	2. Changing Function	3. Loss of Function
a) *Ecosystem function is maintained although there may be changes in the status of the ecosystem component.* b) *The ecosystem component resists or rapidly[1] compensates in the face of perturbation so that it can be inferred that the ecosystem function it supports is maintained.*	a) *Ecosystem function systematically changes as the ecosystem component changes in the face of perturbation.* b) *The ecosystem component changes with perturbation, and is in states where decreases in function are generally likely to occur. Recovery[2] of the ecosystem component is expected to be secure, but a period of altered status of the component is expected.*	a) *Ecosystem function can no longer be supported by the ecosystem component.* b) *The ecosystem component has reached a status where evidence indicates that the function can no longer be provided; OR* *The ecosystem component has been degraded to a status where recovery is no longer secure; even if the pressure is removed the loss of the function will continue to accumulate.*

1 – The term “rapidly” must be interpreted ecologically, in the context of the ecosystem component of interest. For example, “rapid” for a beluga whale population may not be equivalent to “rapid” for a copepod population.
2 – The term “recovery” refers to the natural processes of ecological recovery. Hysteresis may occur such that the ecosystem component may follow a different pathway during recovery than during loss. However, “recovery” does not include artificial rehabilitation of degraded habitats or artificial enhancement of reduced populations. Policy or management may wish to consider habitat rehabilitation or population enhancement in their planning, but those considerations are outside this risk assessment approach.[1]

The boundaries between categories (Table 2) represent transition points where the incremental change in the status of an ecosystem component moves the ecosystem to a new state. Knowing where the upper and lower boundaries of Category 2 (Changing Function) are is crucial to making this approach operational.

Before reaching Transition Point A, the ecosystem component itself might have been changing for some time. However, case-specific information or general knowledge may suggest that there is ecological compensation for the function(s) served by the component. Such compensation could occur either through a more complete or more efficient use of the component with reduced availability, or through functional redundancy (substitution) with other ecosystem components.

The boundaries representing the transitions from one category to another are not static and are often highly uncertain. Thus it is important to set risk management thresholds keeping in mind this uncertainty and to provide information on how close the ecosystem is to these boundaries. Management actions may differ given the potential for uncertainty, however the application of precaution should increase as the degree of uncertainty increases.

[1] *The “recovery” of ecosystem components is a complex topic, some aspects of recovery of populations have been addressed in SARs on fisheries and Species At Risk issues, and some aspects of recovery of habitats have been addressed in advice for the Fisheries Protection Program. However, a full review of all aspects has not been conducted for this advisory process.*

Table 2. Boundaries representing transition points between categories (Table 2), where the incremental change in the status of the ecosystem component moves the ecosystem to a different state. Depending on objectives and levels of risk tolerance, management actions may be taken at any point along this range (and ideally before a transition point is actually reached).

Transition Point "A"	Transition Point "B"
The transition point between Category 1 (Maintaining Function) and Category 2 (Changing Function). *The ecosystem's ability to fully resist or fully compensate for lower values in the ecosystem component has been exceeded. Further degradation of the ecosystem component will reduce its capacity to contribute to the ecosystem function.* *Attributes that might help identify that position include loss of areal extent, fish condition, number of prey species, biomass of prey species, population size, etc.*	*The transition point between Category 2 (Changing Function) and Category 3 (Loss of Function).* *The ecosystem component has lost its ability to recover. The status of the ecosystem component may not yet have been reduced to a point where it no longer contributes to the ecosystem function, but because the component has lost its ability to recover it is expected that the contribution of the component to the function will continue to decline until such a point is reached. In rare cases the function is so dependent on the specific ecosystem component that it may be reduced beyond an acceptable level of impact, before the component has lost its ability to recover. Such situations can only be documented in very information rich systems.* *Attributes that may help define ability to recover include generation time, fecundity, life history, etc.*

The descriptions of these categories and transition points do not consider uncertainties in the relationship between the ecosystem component and function, risk tolerance in decision-making, or the likelihood of an ecosystem component being exposed to a pressure. The single functional relationship being represented by the line in Figure 6 *de facto* represents the "best representation" of the relationship between ecosystem component and ecological function, and the transition points are risk-neutral decision thresholds. If the uncertainty is quantified, the relationship can be represented as the probability distribution of the ecological function (y-axis), given the measured or predicted value of the ecosystem component (x-axis). If there is a stated risk tolerance for a known acceptable level of the ecological function, the transition in management decision-making from Category 1 to Category 2 can follow the specified risk tolerance along the probability distribution, rather than just the idealized line in Figure 6. However, it is stressed that this approach is only appropriate when there is sufficient information to estimate confidence intervals around the idealized relationships and where the risk tolerances are specified in advance. Following this approach with only intuitive ideas of uncertainty and risk tolerance merely creates the false impression of greater rigor without achieving it.

Sources of Uncertainty

Although much of this advice identifies uncertainty specifically associated with the approaches discussed above, and in particular the graphical relationships, other more general sources of uncertainty should also be considered:

- Although this advice is intended to be applicable to a wide range of ecosystem components, ecosystem functions, and anthropogenic pressures, there may be situations where it cannot be applied.
- The approach outlined in the Fisheries Productivity SAR (DFO 2014) is relatively new guidance that may not be readily useable in practice.
- Many processes affecting the recovery of degraded ecosystem components and functions are poorly known and multiple natural and anthropogenic pressures could affect these processes.

- Assessing impacts of anthropogenic pressures against of background of natural and wider ecosystem changes in the current context of global climate change is challenging and can result in shifting of baseline states.

CONCLUSION

This SAR provides a structured approach for assessing the impact of an anthropogenic pressure on an ecosystem component and function. The impact is assumed to result from a change in the status of an ecosystem component caused by a pressure. This approach is intended to be applicable to any anthropogenic pressure, ecosystem component, or ecosystem function, and is independent of time and space. This approach is merely one aspect of a more comprehensive risk management process that will inform management decision-making affecting the marine environment.

Integral to this advice are the Pathways of Effects (POEs) models that have been developed for major classes of anthropogenic pressures. In cases where POEs (or other similar analyses, e.g. interaction matrices) do not already exist, they will need to be developed in order to identify the interactions between anthropogenic pressures and ecosystem components of concern.

The relationship between any ecosystem component and any pressure, as well as the ecosystem function provided by any ecosystem component are assumed to follow generic shapes (non-linear and often sigmoidal).

This advice includes three categories of increasing impact that characterise the status of ecosystem function as a result of changes to an ecosystem component. The boundaries between these categories represent transition points that indicate where a change in the status of an ecosystem component affects its ability to support its function, and where management action may be appropriate.

OTHER CONSIDERATIONS

The likelihood of an ecosystem component being exposed to a pressure and the level of risk tolerance in policy and decision-making must be considered in a broader risk management process, but are not discussed in this advice.

Cumulative effects are not covered under the approach provided in this SAR and should be given consideration. No advice to date has been provided on how to combine the effects of multiple pressures on ecosystem components. However, the graphical relationships presented in this SAR would likely fit well into a cumulative effects assessment framework.

Substantial scientific analyses may be required to determine the current and baseline conditions of the ecosystem components of interest, and their potential to recover after impact from different pressures.

SOURCES OF INFORMATION

This Science Advisory Report is from the December 9-11, 2014 National Science Advisory Process titled Ecological Risk Criteria for Integrated Oceans Management. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

Cormier, R. *et al*. 2013. Marine and Coastal Ecosystem-Based Management Handbook. ICES Cooperative Research Report No. 317. 60 pp.

CSA. 2010. CAN/CSA-IEC/ISO 31010-10 Risk Management – Risk Assessment Techniques. Canadian Standards Association. 198 pp.

DFO. 2014. A Science-Based Framework for Assessing the Response of Fisheries Productivity to State of Species or Habitats. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2013/067.

DFO. 2006a. A Harvest Strategy Compliant with the Precautionary Approach. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2006/023.

DFO. 2006b. Identification of Ecologically Significant Species and Community Properties. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2006/041.

DFO. 2004. Identification of Ecologically and Biologically Significant Areas. DFO Can. Sci. Advis. Sec. Ecosystem Status Rep. 2004/006.

Freedman, J.A. and de Kerckhove, D.T. 2015. Design of Ecological Risk Criteria for the Integrated Management of Canadian Oceans. DFO Can. Sci. Advis. Sec. Res. Doc. 2015/015. v + 31 p.

APPENDIX 1: GLOSSARY

Criteria –The term "risk criteria" is used broadly across DFO, often with conflicting definitions. In the context of this advice, "criteria" is used synonymously with "category". Using a qualitative (categorical) scale, "criteria" refers to a level of impact on an ecosystem component and how that impact ultimately affects ecosystem function (see Table 1).[2]

Ecosystem Component – Any biotic or abiotic component of an ecosystem. Those of greatest relevance to this advice are ones that both respond to specific pressures and contribute to an ecosystem function of interest. Guidance on identifying such ecosystem components has been provided in previous advice, in particular those related to the identification of Ecologically and Biologically Significant Areas (EBSAs), Ecologically Significant Species (ESSs), and Community Properties (CPs). Potentially relevant ecosystem components are also provided in Environmental Effect Monitoring Guidance documents (Environment Canada).

Ecosystem Function - Any physical, chemical, or biological process or attribute that contributes to the self-maintenance of the ecosystem (e.g. productivity, biodiversity, nutrient cycling, etc.).

Impact - A measurable change to an ecosystem component or function as a result of an interaction from a pressure. Impacts of greatest relevance for this advice are ones resulting from an anthropogenic pressure that cause a change in the status of an ecosystem component and ultimately a response in ecosystem function.

Likelihood - The probability of an event occurring (e.g. the probability of a pressure resulting in a change of state of an ecosystem component).

Pathways of Effects (POE)[3] - A representation of cause-and-effect relationships between human activities, their associated sources of effects (pressures), and their impact on specific ecosystem components. POE models illustrate potential cause-effect relationships and identify the mechanisms by which pressures ultimately lead to changes in the ecosystem. POEs or similar analyses (e.g. interaction matrices) are necessary for applying this advice.

Pressure – Although there are natural and anthropogenic pressures acting on ecosystems, for the purpose of this SAR, "pressure" is defined as the manner in which a human activity changes (positively or negatively) the status of an ecosystem component. In the vernacular, "pressure" is often used to refer to the activity itself, and that interpretation is often consistent with how the term is used here within. However, any given pressure may cause several different impacts on an ecosystem which can be expressed as multiple pathways in a POE diagram. When this advice is applied technically, each individual pathway can be treated as an individual pressure.

Perturbation - Any alteration in an ecosystem component or function caused by interaction with a pressure. It is non-judgemental with regard to whether the change may increase or decrease the component or function.

Resilience - The ability of an ecosystem component or an ecosystem to return to a previous, less perturbed state following a perturbation.

Resistance - The ability of an ecosystem component or the ecosystem as a whole to buffer against pressures exerted upon it.

[2] In previous advisory documents (e.g. those related to Ecologically and Biologically Significant Areas), the term "criteria" is often used to refer to the *properties* (i.e. the combination of threats and ecosystem components) that determine which level of risk to assign specific cases. This is not the context in which it is used in this SAR.
[3] Government of Canada. 2012. Pathways of Effects National Guidelines. Fisheries and Oceans Canada. 32 pp (unpublished manuscript)

Recovery - The process of either an individual ecosystem component or an ecosystem as a whole returning from a perturbed state to a less perturbed state. Recovery often involves hysteresis, the technical term for not following the same pathways of change during a downward trend and an upward trend. Recovery can be complete (i.e. back to the original level of function, prior to exposure to pressures) or partial (i.e. back to a level below its original state, but improved from the state when the process of recovery commenced; a partially recovery state may or may not be self-sustaining).

Risk Assessment – There are diverse technical definitions and guidance to describe what is meant by "risk assessment". However, in this SAR "risk assessment" is based on the ISO 31000:2009 which generally describes a multi-step process that includes risk identification, risk analysis (that determines the likelihood and consequences of impacts to an ecosystem that may occur as a result of exposure to one or more pressures), risk evaluation (where managers and decision-makers evaluate the results of the risk analysis with consideration of risk tolerance), and risk treatment (i.e. the decision- to take action to manage the risks or not).

Risk - "Risk" has many technical definitions, but in this SAR it captures both how likely it is that a threat will impact the ecosystem component or function and how large that impact may be. Management actions can manage the risk posed by an activity by addressing the threat in ways that may reduce its likelihood, its potential magnitude, or both.

Sensitivity – The susceptibility of an ecosystem component to a change in state owing to a pressure being exerted on it.

Threat – An anthropogenic activity that may exert pressure on an ecosystem component or function.

Uncertainty - In the context of an ecological impact analysis, "uncertainty" refers to the level of confidence that the nature and magnitude of changes to an ecosystem component from an exerted pressure are known and demonstrated through science-based inquiry. Uncertainty in the context of decision-making refers to the level of confidence (i.e. certainty) that the management action taken (or not) is necessary and will lead to the desired result (i.e. alter the impact of an exerted pressure on an ecosystem component in the intended way).

THIS REPORT IS AVAILABLE FROM THE:

Canadian Science Advisory Secretariat (CSAS)
National Capital Region
Fisheries and Oceans Canada
200 Kent Street
Ottawa, ON K1A 0E6

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

ISSN 1919-5087

Correct Citation for this Publication:

DFO. 2015. A science-based approach to assessing the impact of human activities on ecosystem components and function. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2015/020.

Aussi disponible en français :

MPO. 2015. Approche scientifique pour évaluer l'impact des activités humaines sur les composantes et les fonctions écosystémiques. Secr. can. de consult. sci. du MPO, Avis sci. 2015/020.