ASSESSMENT OF THE DEPENDABILITY OF FISHERY CATCH MONITORING PROGRAMS

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

Context

Fisheries and Oceans Canada (DFO) is currently developing a national fishery monitoring policy to ensure that DFO has dependable, up-to-date, and accessible fishery information to manage fisheries sustainably. Implementation of the policy will involve evaluating the degree to which data on removals in individual Canadian fisheries are appropriate for determining whether the fishery removals are sustainable for target and incidentally captured stocks / populations. DFO (2019) provided a method and tool (Quality Assessment Tool; QAT) for assessing the quality of monitoring programs. The next step involves the development of an approach to set the required level of dependability for monitoring programs, with the level of dependability commensurate with the degree of potential risk to sustainability caused by fisheries. A Risk Screening Tool (RST) is being developed to facilitate and standardize these risk assessments. The RST defines seven Conservation Risk Factors, consequence descriptors for each risk factor, and methods for determining a risk level for each risk factor scored during the screening. In applying the new policy, the Risk Screening Tool and the Quality Assessment Tool will be used in combination to help guide decisions about the type and level of monitoring that is required in a fishery to meet the data needs to support sustainable fisheries.

This Science Advisory Report is from the May 14 to 16, 2019 national meeting on the Assessment of Dependability of Catch Monitoring Programs for a National Policy on Fishery Monitoring. Additional publications from this meeting will be posted on the [Fisheries and Oceans Canada (DFO) Science Advisory Schedule](#) as they become available.

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SUMMARY

- The productivity and susceptibility traits in the consequence descriptors of the reviewed Risk Screening Tool (RST) are considered sufficient to characterize vulnerability of stocks / populations for the purpose of establishing the consequences of fisheries removals to long-term sustainability. Advice on revised consequence descriptors related to removals is provided.
- The Quality Assessment Tool (QAT) can assess quality of monitoring activities at the stock / population level, for a single fishery or a combination of fisheries. The results of the RST and QAT are used together to determine dependability.
- The results of the RST and QAT are not prescriptive in how specific fisheries monitoring programs should be conducted, rather they determine which fisheries monitoring program changes could be considered with the objective of improving the quality scoring associated with reducing bias and / or uncertainty and assessing cost-efficiencies.
- Minimum values for quality from the QAT, as a function of conservation risk from the RST, are provided as guidance rather than absolute values and the choice of threshold values may change as new information is obtained on performance and improvements are made to monitoring programs.
- The process of determining, evaluating and revising fishery monitoring programs involves the RST and QAT in a recursive process aimed at aligning conservation risk and data quality for estimation and/or limit compliance applications.
- The assessment of the adequacy of fishery monitoring needs to account for many aspects of the fishery assessment and management systems. The assessment of catch monitoring could be incorporated within the population assessment process, including the subsequent advisory committee meetings. The review of monitoring programs under the new policy could be phased in as part of the existing multi-year stock assessment cycle.

INTRODUCTION

Fisheries and Oceans Canada (DFO) is finalizing a national fishery monitoring policy to ensure that it has dependable, timely and accessible information to manage fisheries sustainably and to minimize harm to non-harvested incidentally captured taxa and to habitats. The policy seeks to implement an objective and consistent approach for setting the type and degree of monitoring employed across fisheries managed nationwide by DFO under the *Fisheries Act*.

The fishery monitoring policy seeks to align the level, frequency and type of fishery monitoring with the degree of risk associated with the fishery, including risks to the conservation of aquatic populations, species, biotic communities and habitat, and compliance of fishers to fishery regulations. The policy aims to take a precautionary yet pragmatic approach to establishing monitoring needs by recognizing that the quality of estimates of removals should be commensurate with conservation risks posed by the fishery.

Dependability describes the ability of an estimation process (e.g. estimation of the total landing for a given stock) to reach the objectives for which it is intended (e.g. evaluation of whether the quota has been reached). It is in effect a measurement of whether a monitoring program is fit for purpose. The fishery monitoring policy also recognizes the need to consider cost-effectiveness, in addition to quality and risk, and provides flexibility in defining a suitable monitoring program. A monitoring program with lower cost monitoring options that results in lower-quality estimates may remain dependable provided that conservation risks are also lower.

Implementation of the fishery monitoring policy will follow a number of steps to ensure consistent application and a high likelihood of achieving conservation, monitoring and compliance goals. Three key steps are:

- the screening of conservation risks and the quality assessment of the existing monitoring programs, which comprise one or more monitoring tools;
- the determination of monitoring objectives related to conservation, compliance and other factors to address identified gaps where they exist in the assessment; and
- the specification of monitoring requirements, i.e. the cost effective combination of monitoring tools and sampling (coverage) levels that will provide estimates that are dependable.

Two policy implementation tools have been developed to aid in the retrospective assessment and, if required following the gap analysis, the determination and specification of new or additional monitoring requirements. The first, termed the Quality Assessment Tool (QAT), comprises a unified method for estimating quality of the catch estimation process, that is whether estimates are of sufficient quality to conclude, with a predetermined level of certainty, whether catch limits or data quality standards are reached (DFO 2019b; Allard and Benoît 2019). The QAT applies to estimation of a value (e.g. catches) and to compliance to a limit (e.g. an allowable catch), whether a stock / population is captured as a target or incidentally, by one or several fisheries, and whether catches are retained or discarded. In this approach, the level of certainty should be commensurate with the degree of potential risk to sustainability caused by fisheries, such that higher risk fisheries should be monitored in such a way as to produce low uncertainty in the estimations of removals. The second tool, termed the Risk Screening Tool (RST), provides a means to characterize risk in a semi-quantitative manner, and specifies minimum quality thresholds required from the monitoring program(s) for each of three risk classes.

In applying the national fishery monitoring policy, the RST and the QAT will be used in combination to help guide decisions about the type and level of monitoring that is required in a fishery to meet the data needs of the Department.

Outstanding gaps in the RST and QAT needed to be resolved such that the consequence descriptors, which characterize the impacts of the fisheries to resource sustainability, and quality thresholds from the RST can better align with the quality conclusion from the QAT.

This science advisory report addresses the following objectives in response to a request from the DFO National Fishery Policy directorate:

- Review the descriptors and methods within the draft RST for assessing and categorizing the risk to target catch and bycatch (both landed and discarded) species through the prosecution of Canadian fisheries.
- Provide guidance on quality thresholds obtained using the QAT that are appropriate for each of the risk categories in the RST.
- Provide advice on how the RST and QAT can be used to inform decisions on modifying catch monitoring programs so that the required dependability can be achieved.

These objectives respectively relate to characterizing risks to conservation, aligning quality and conservation risks, and outlining options to ensure consistency in the rigour of catch monitoring programs.

The following terms, as defined in the national fishery monitoring policy and in DFO (2019), are used in this report:

- Retained catch: portion of the catch that is retained including landed catch and catch that is used in some way but not landed, such as catch that is used for bait (DFO 2019a).
- Non-retained catch: consists of any catch that is handled, not retained, and returned to the water, whether alive, injured or dead. This includes catch brought on board and thrown back, catch released from gear before it is brought on board (such as catch released from a purse seine before the seine is fully pursed), and catch that becomes visibly entangled in fishing gear, such as entangled whales, birds and sea turtles. This does not include catch that escaped the fishing gear, that was removed by predators and scavengers, or that dropped out dead from the gear (DFO 2019a).
- Bycatch: includes a) retained catch of a target species, such as specimens of a particular sex, size or condition, that the harvester is not licensed to direct for but may or must retain, and b) all non-retained catch, including catch released from gear and entanglements, whether alive, injured or dead, and whether of the target species or the non-target species (DFO 2019a).
- Target catch: retained catch that consists of the species that the harvester is licensed to direct for, in other words, the target species of the fishery. In a multispecies fishery, this includes any species that the licence holder is licensed to direct for on a given fishing trip regardless of whether the licence holder did so or not (DFO 2019a).
- Removals: in a fisheries context, removals include all documentable losses to the population or species resulting from fisheries activities, whether due to retention in targeted and bycatch fisheries (also termed landings) and estimated mortality associated with release from the fishing gear.
- Stock / population: refers to spatially and temporally distinguishable aggregations of a species that are exploited by fisheries. The stock / population level is generally smaller than but may include a species group.
- Quality of an estimation process: refers to measures of how close to the true value the estimate is expected to be, considering its accuracy (converse is bias) and precision (converse is variability).

Risk to target catch and bycatch species in Canadian fisheries

The RST determines the risk that fisheries pose to fisheries specific conservation factors, including risk to the target and bycaught fish stocks, risk to fish habitat, as well as the incidence of non-compliance and other factors that need to be considered in determining monitoring requirements. The RST can also examine the overall risks to conservation objectives for stocks / populations resulting from multiple fisheries targeting or intercepting a stock / population (Figure 2).

RST (by fishery)

Proportion of fisheries related lossed for each species								
	Fisheries							
Species	a	b	c	d	e	...	F	Conservation status of species
1.00	0.90	0.08	0.01		0.01			Healthy
2.00			0.95	0.05				Critical
3.00	0.20	0.70			0.10			Unknown
4.00	0.90	0.05			0.05			Critical
5.00							1.00	Cautious
...								
S				0.80			0.20	Healthy

QAT (by species)

Figure 2. Direction of assessments for the Risk Screening Tool (RST) and Quality Assessment Tool (QAT) in the assessment of dependability of monitoring programs, with fictitious examples for illustration. The status of the species being assessed in the RST, and the state of removals relative to sustainable levels must be known, considering losses from all fisheries. The QAT assesses the quality of the monitoring programs of fisheries that interact with the species. The dependability of each program is determined for the corresponding risks to the species over all fisheries that produce losses of the species.

Essential to the characterization of risk to the stock / population of a fishery is the establishment of a status level for the stock / population, in the context of the PA, species at risk consideration or other status assessment. The consequence descriptor criteria related to catch in the existing draft RST are based on management frameworks under the Precautionary Approach (PA; reference points and harvest control rules) or risk-based considerations for determining sustainable mortality levels of bycatch species (DFO 2012). For any stock / population for which there is no PA, five elements are considered in the assessment of risk to the population associated with a fishery:

- Magnitude of catches relative to estimated exploitable biomass using a F_{proxy} reference value defined by natural mortality (M) based reference points;
- The portion of the exploitable population distributed within the area being fished;
- Trends in post-recruitment (exploitable biomass) abundance;
- For species assessed as “at risk”, the risk that fishing pressure is an impediment to recovery; and
- For bycatch species, risk could be considered low if the inferred M of the bycatch species is higher than the M of the target species, provided the bycatch species has equal or lower catchability to the gear, and provided that the target species is not being over-fished.

Productivity and susceptibility

DFO (2012) considers that the vulnerability of populations to overexploitation can be assessed as a function of their productivity (related to resilience which is the capacity to withstand overexploitation or to recover if depleted) and susceptibility to capture and mortality. Vulnerability appears to be most accurately predicted with a few characteristics that include the intrinsic rate of population increase, the availability and selectivity to the fishing operation, and the discard mortality (Hordyk and Carruthers 2018).

Natural mortality (M) has been used as a proxy for productivity; species with higher M are likely to be more productive and hence able to sustain higher exploitation rates. As such, M is a key parameter that has been used to develop benchmarks for management of bycatch and other data poor species. Inherent in the use of M for sustainable fishing proxies is the assumption that M represents values for populations at non-depleted equilibrium. However, M may vary temporally and in particular can vary inversely with abundance resulting in depensation (decline in per capita productivity) at low abundance; this can occur for example when predation rates on the population increase as abundance declines. For populations for which this is suspected to be the case, lower benchmark values should be used in the RST.

The draft RST presently assesses susceptibility to capture and mortality based only on the relative distributions of the population and the fishery, i.e. availability. The level of consequence is assumed to be low when a substantial portion of the population is not exposed to fishing mortality.

- On one hand, this metric may overstate the consequence because relative distributions need to be considered with respect to time (diurnally, seasonally, etc.) to correctly describe availability. Catchability and selectivity should also be considered since even at high availability, there may be little catch if the catchability of the gear is low. Finally, even if animals are captured, the consequence may be low if there is a high likelihood of survival post-release.
- On the other hand, the metric may understate the consequence as for the case of aggregative behaviour of a population which can contribute to risk of overexploitation by fisheries targeting aggregations. This is of particular concern as the distribution of most fish species tends to contract as abundance declines, increasing catchability, and therefore vulnerability to overfishing.

Noting that the intrinsic rate of population increase is a function of age-dependent M and reproductive schedule, the productivity and susceptibility traits in the current RST are considered sufficient to characterize vulnerability for the purposes of establishing the consequences of catch to long-term sustainability.

DFO (2012) indicates that trends in adult abundance can provide an indication about whether present catch levels might be impairing the productivity of the stock / population. This indicator is employed in the RST. Caution is advised if these trends are based on fishery-dependent information as changes in fishery management and objectives, markets, or other factors may bias the indicator. The vulnerability of a stock / population can be established via age-structured population simulations, rather than by using proxies or indicators. Simulation-based approaches more accurately reflect the interplay of life-history characteristics affecting productivity, and the effects of susceptibility characteristics. Simulation-based methods should therefore be considered as part of the RST toolbox.

The RST includes tables that provide descriptors and criteria associated with each consequence level for the seven factors related to catch (target retained, target discard, retained and / or discarded bycatch of non-target species), community and habitat, and compliance. The descriptors for conservation factors related to all catch categories, now termed removals, were reviewed and revised (Appendix 1).

ASSESSMENT

Aligning quality and risks to conservation

The QAT is designed to assess quality. To reiterate, quality refers to how close the estimate is to the true value. The assessments for both measurement and compliance to a limit objectives in the QAT are founded on a common assessment of quality. The QAT can simultaneously assess the contributions of one or more monitoring programs to a removal estimation process and it facilitates the evaluation of trade-offs in estimation process quality among fisheries and monitoring tools.

Allard and Benoît (2019) separated the statistical objectives of fishery monitoring programs into two classes, measurement and compliance, each requiring a different approach for assessing dependability. Measurement objectives are related to scientific (e.g. stock assessment and recovery potential assessment) and administrative activities (e.g. reporting on removals and economic value). Compliance to a limit objectives are relevant when the management scheme involves some sort of limit (e.g. total allowable catch, the allowable percentage of undersized catch) and the estimate of the parameter is used to determine if the limit has been respected or not.

The RST provides threshold quality values as guidance rather than absolute values and the choice of threshold values may change as new information is obtained that reduce uncertainty and bias in the operational characteristics. The specific values were chosen based on a mixture of considerations related to effect or signal detection and achievability (details in Benoît and Allard 2020).

Quality for measurement objectives

Measurement objectives are assessed by comparing the statistical quality of an estimate with pre-specified scientific or administrative requirements. Following on further work, the evaluation of quality defined in DFO (2019) has been changed to consider bias and variability separately (Benoît and Allard 2020). This change is motivated by the fact that estimation process errors caused by variability and bias have different consequences to conservation risk. Variability comprises random errors resulting in parameters, such as total catch, that are equally likely to be underestimated or overestimated in a given year. In contrast, bias comprises systematic errors resulting in a repeated under or overestimation. Over time the errors caused by bias will compound, leading either to systematic loss of fishing opportunities or undue conservation concerns (associated with overestimation of the role of fishing mortality to population abundance trends or status in exclusion of other factors) in the case of positive bias, or to systematic over-fishing in the case of negative bias.

The following notation is used.

θ: The true value of the parameter being estimated by the parameter estimation process, for example, the total catch.

$\theta_{anticipated}$: The typical or anticipated true value of the parameter.

b_{ep} and s_{ep}: Respectively, the estimation process bias and estimation process variability as defined in Benoît and Allard (2020).

$\hat{\theta} = \theta_{anticipated} + b_{ep}$: The typical estimate of the parameter obtained in the estimation process.

The two QAT measures of quality for an estimation are the relative estimation process bias and the relative estimation process variability:

$$rb_{ep} = b_{ep}/\theta_{anticipated}$$

$$rs_{ep} = s_{ep}/\theta_{anticipated}$$

rb_{ep} is a signed value: a negative value indicates that the estimation process tends to underestimate the value while a positive value indicates the opposite.

rs_{ep} is similar to the coefficient of variation and does not have a sign.

For variability (rs_{ep}), the derived values are assessed relative to guidance threshold values corresponding to the three risk categories for the objectives defined in the RST. As per the RST, monitoring programs should provide adequate information to estimate catch when risk is low, have a reasonable likelihood of ‘correctly’ estimating catch when risk is medium and a high likelihood when risk is high (Table 1). The proposed threshold values for rs_{ep} in Table 1 reflect pragmatic considerations based on available analyses matched to descriptors in the RST.

Table 1. Parameter estimation variability (rs_{ep}) thresholds corresponding to the risk categories in the RST. The values shown are for situations where the sampling distribution of the estimator is approximately symmetrical and the sample size is greater than approximately 20. Threshold values are provided as guidance rather than absolute values.

Component	High conservation risk	Medium conservation risk	Low conservation risk
Expectation as per RST	High likelihood of determining if objective is met	Reasonable likelihood of determining if objective is met	Adequate to determine if objective is met
Threshold values	$rs_{ep} \leq 15\%$	$rs_{ep} \leq 30\%$	$rs_{ep} < 50\%$

Errors due to bias may be very difficult to detect and their impacts will accumulate over time. Since this could be much more detrimental to conservation, thresholds of quality for bias (rb_{ep}) are stricter than those on variability. The consequences of the direction of bias also differ depending upon the risk to conservation of the fishing activity (Table 2). A negative bias, for example, underestimating the catch, can have more important consequence to conservation under a high risk situation than if the bias is positive. As such, the direction of bias must be considered in concert with the risk evaluation. The threshold values are in-line with the RST, which indicates that at high risk, a monitoring program should have a design that is theoretically, and presumably also in practice, unbiased in the direction that is detrimental to conservation while at medium risk, bias should be limited.

Table 2. Parameter estimation bias (rb_{ep}) thresholds corresponding to the risk categories in the RST. The values shown are for situations where the sampling distribution of the estimator is approximately symmetrical and the sample size is greater than approximately 20. Threshold values are provided as guidance rather than absolute values. A value of 0% is desirable at high conservation risk and it should be theoretically unbiased for the parameter estimation in the direction that is detrimental to conservation.

Risk	High conservation risk	Medium conservation risk	Low conservation risk
Expectation as per RST	Theoretically unbiased	Bias should be limited	Not specified
Direction of bias relevant to conservation risk			
Negative (most frequent case)	$0\% \le rb_{ep}$	$-10\% \le rb_{ep}$	$-25\% \le rb_{ep}$
Positive (rare case)	$rb_{ep} \le 0\%$	$rb_{ep} \le 10\%$	$rb_{ep} \le 25\%$

Asymmetrical sampling distribution, rare events, presence-absence

There are some situations when the sampling distribution of the estimator is not symmetrical, as for example, with rare events. In the rare event cases, it may to be more appropriate to use absolute values (e.g. the number of events or animals) rather than the relative values to describe precision and bias. In these situations, the quality assessment would be performed using confidence interval values (68.3% confidence interval, approximately one standard error as in the symmetrical case above), and choosing the maximum variability range from the left-hand-side and the right-hand-side intervals (Allard and Benoît 2019). In some cases, the confidence interval can be computed using analytical or numerical methods, in others, it can be estimated using simulation.

Quality for compliance with a limit

A monitoring program is a component of a decision making process which may involve several elements including a limit on a component of the fishery of interest and a procedure for managing the fishery. The limit can be on target species catch, on the bycatch of specific species, on the proportion of specific components of the catch (e.g. undersized individuals), or in respect to resource sharing agreements or international treaties. In many situations, a limit to the catch or to some fishery characteristic is implemented in order to meet a conservation goal and a decision process is established, such as to close the fishery if the estimate of the total catch given by the monitoring program has reached the limit (e.g. the total allowable catch). The dependability of the decision process depends in part on the quality of the parameter estimation process.

Quality objectives for compliance with a limit

It is proposed that the assessment of quality for compliance with a limit be based on a hypothesis testing framework, with the primary goal of controlling risk to conservation of fish stocks / populations (Allard and Benoît 2019). For upper limits, the fishery will be compliant with the conservation objective if the limit is not exceeded (conversely for lower limits, if such cases exist). Given that conservation of aquatic populations is the primary concern, management should aim to minimize the chances of concluding incorrectly that the total removals do not exceed the limit when it actually does, a conclusion known as a false-negative.

Regarding the compliance to a limit, the quality is specified with respect to the probability of false-negative conclusions; a false-negative conclusion being that the limit is estimated to have not been exceeded when in fact it was.

The quality of the parameter estimation process, in the context of a decision on compliance with a limit, is defined heuristically as:

- the probability of avoiding a decision detrimental to conservation, i.e. 1 – probability of a false negative.

Consider the previous notations (θ, $\theta_{anticipated}$, b_{ep}, s_{ep}, and $\hat{\theta}$) and

- L: the true upper limit required to meet the objective, for example, the total removals corresponding to the management objective for the population, and
- $\varphi(\,)$: the cumulative distribution function of the standard normal distribution.

If $\theta_{anticipated} < L$, the quality of the parameter estimation process is equal to 1.

If $\theta_{anticipated} \geq L$, the quality of the parameter estimation process is:

$$1 - \varphi\left(\frac{L-(\theta_{anticipated}+b_{ep})}{s_{ep}}\right).$$

When $\theta_{anticipated} \geq L$, the quality of the parameter estimation process can be high when either the variability, i.e. the imprecision, of the estimation process s_{ep} is sufficiently small and / or the bias of the estimation process, b_{ep}, is zero or is in the positive direction, e.g. if the estimation process tends to overestimate the total removals. The quality of a parameter estimation process will be low when the limit has been exceeded but the estimation process has a high probability of reporting a value below the limit, due to the its bias and/or variability.

The estimation process is assessed as either dependable or not, according to its quality and the level of risk prescribed by the RST. The thresholds for quality are defined for each level of conservation risk, noting that the measure of quality is between 0 and 1 (Table 3). A more general definition taking into account uncertainty in the limit is available in Benoît and Allard (2020).

Table 3. Thresholds for quality (0 to 1) of compliance to a limit for three conservation risk levels defined from the RST.

Risk	High conservation risk	Medium conservation risk	Low conservation risk
Required quality	≥ 0.95	≥ 0.75	≥ 0.50

Options for monitoring programs with respect to dependability

The assessment of dependability consists of relating the quality assessment of the monitoring program with the risks posed by fisheries to stocks or populations. In practical terms, the quality assessment can be used at the fishery level to ensure monitoring programs are of sufficient quality to attain fishery objectives. Dependability can only be determined with respect to the risk to stocks and populations and will often involve the cumulative impacts of multiple fisheries.

When assessing collective risk to a conservation objective and risk to a limit compliance from more than one fishery, the advantage of considering dependability across fisheries is that it allows for the possibility of trading-off requirements for quality between fisheries (Figure 2). The calculation would involve weighting fishery-specific acceptable parameter estimation bias and variability values by fishery-specific anticipated catch and ensuring that the variability and bias of the combination meets overall requirements for the assessed level of risk.

When a single fishery is relevant to several conservation objectives and/or limit compliance objectives, the quality of the monitoring program(s) must satisfy the requirements for all the objectives.

The process of determining, evaluating, and revising fishery monitoring programs involves the RST and QAT in a recursive process aimed at aligning conservation risk and estimation process and compliance dependability (Figure 3). The typical implementation process normally begins with an assessment of risk for a specific conservation objective (e.g. a population biomass declining below a certain critical level). The RST will be used to assess the impact of individual fisheries that capture individuals from that population as target catch or bycatch or that otherwise meaningfully interact with that population (e.g. capture of prey, destruction of spawning grounds). The RST will be applied to compute the contribution of each relevant fishery to the risk for the specific conservation objective, i.e. each fishery risk score for the specific conservation risk factor. In turn, each fishery's risk score will inform the quality required from monitoring tool(s) in that fishery.

When only one or only a few fisheries are relevant, the required quality can be compared directly to the results of the QAT for the monitoring of these fisheries. When many fisheries are relevant, it may be necessary to use the QAT to assess the quality of the monitoring tools jointly, using the QAT's ability to assess quality with respect to one or more monitoring programs across all fisheries that capture a species.

In certain cases assessors may begin with a monitoring program assessment followed later by a risk screening to determine if the assessed data quality is sufficient. This could be the case where a monitoring program is well understood while, conversely, key inputs to the scoring of fishery risks such as stock status reports or research into discard mortality are not available. The two assessment tools are independent of one another; the QAT does not need input from the RST in order to assess quality of a monitoring program.

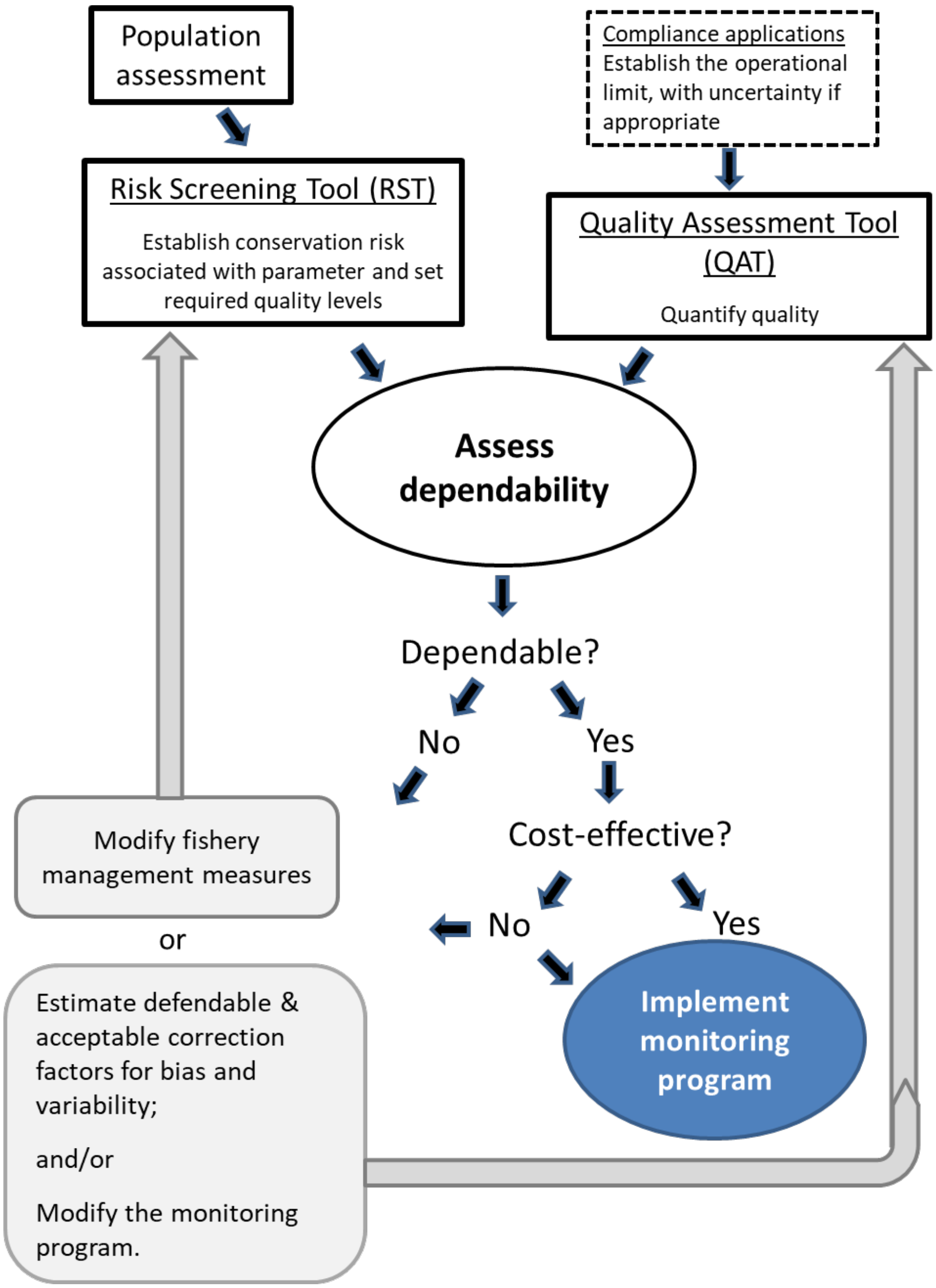

Figure 3. Flow diagram for the implementation of the Fishery Monitoring Policy with respect to conservation risk. The diagram illustrates the principal flows, however, in practice many of the processes will be more integrated. The process begins with the establishment of conservation risk using the Risk Screening Tool, followed by the application of the Quality Assessment Tool. Results from the dependability assessment may motivate modifications to the fishery management plan and/or the monitoring program, followed by a re-assessment of dependability and possibly quality or conservation risk.

Dependability outcomes

There are two possible determinations for monitoring programs that result from assessing dependability via the QAT and the RST, dependable and not dependable (Figure 3).

Dependable

A monitoring program that is found to be dependable can be implemented as designed. A future reassessment of dependability should be considered if:

- there is a change in the assessed status of the population that results in a change in conservation risk;
- change in the fishery management plan that results in a change in conservation risk;
- there is a desire or need to modify the type or sampling intensity of one or more monitoring program; or,
- there is new or better information to inform the assessment of estimation process quality, for example to specify the effects of operational characteristics on bias and variability.

Monitoring programs that exceed the RST quality requirements may be cost-inefficient from the perspective of conservation risk to only the population that was assessed. Fishery managers and stakeholders may consider alterations to the monitoring programs that reduce costs for that population objective while not undermining estimation process quality requirements for other parameters monitored by that program. This could involve reducing sampling (coverage) rates or changing the monitoring tools employed to favour lower cost options that do not unduly compromise quality (see Beauchamp et al. 2019).

Not dependable

There are two principal options for the fishery monitoring policy when a monitoring program is deemed not dependable: modify the monitoring program to improve quality or decrease the conservation risk and therefore lower the quality requirements for the estimation process (Figure 3). These options are not mutually exclusive.

Options for improving the quality and therefore dependability include:

- Reducing the bias of the parameter estimation process, and
- Decreasing the variability of the parameter estimation process.

Furthermore, because the choice of the conservation limit involves error, due among other things to errors in stock assessment, reducing the bias and uncertainty associated with the limit will improve quality.

The evaluation of monitoring programs in the QAT provides a detailed accounting of the contribution of statistical and operational factors affecting the variability and bias of an estimation process. Results from the QAT can therefore guide the selection of monitoring options. These are discussed in DFO (2019), Beauchamp et al. (2019), and Benoît and Allard (2020).

Monitoring tools that depend on data supplied by resource users are susceptible to biases resulting from biased reporting and missing values due to intentional factors (Allard and Benoît 2019). Bias in monitoring tools that rely on data supplied by resource users may be reduced or eliminated by adding auditing tools (e.g. 100% video monitoring) or by switching to accredited independent monitoring.

Similarly, certain independent monitoring tools, most notably at-sea observer surveys, can be associated with biases resulting from observer effects (Benoît and Allard 2009). For both resource-user dependent and independent monitoring tools, biases are likely to be most effectively addressed by providing incentives for compliant behavior, as assessed through routine auditing.

In some cases, improvement to the monitoring program may be impossible or excessively costly or other sources of uncertainty too large to allow a reduction of the conservation risk. In those cases, the fishery management decision process may have to be revised.

Decreasing conservation risk to lower quality requirements is the most likely option when resource users are unwilling to undertake monitoring program changes that would lead to sufficient improvements in quality. Conservation risk can be reduced by setting removal limits that are lower than would otherwise be proposed based on stock status and the Precautionary Approach for the stock, or in the case of bycatch, by reducing catches by increasing gear selectivity, by avoiding locations and times where bycatch is most probable or decreasing fishing effort. Conservation risk can also be reduced in some circumstances by improving the science underlying the stock assessment to improve the accuracy (decrease bias and variability) of reference points, the determination of stock status and the estimation of risk of different management options. However, changes to the scientific process are outside the scope of DFO’s fishery monitoring policy.

Options for new monitoring programs

The implementation of the fishery monitoring policy is likely to lead to a requirement to establish monitoring programs where none existed previously. There are three complementary approaches that can be used to design and assess a new monitoring program with respect to dependability.

First, the assessment of conservation risk will determine the broad requirements for bias and variability, which in turn help to identify the monitoring tools that might be appropriate. For example, at high risk, many catch monitoring programs will have to support estimates that are unbiased and of high precision. The intolerance to bias for determining removals may render insufficient many monitoring tools which cannot be reasonably assumed to be unbiased (Benoît and Allard 2009; Faunce and Barbeaux 2011). The requirement on precision will motivate a monitoring program with a high sample size, potentially a census. Beauchamp et al. (2019) and Mangi et al. (2015) discuss elements that can inform on the potential bias and variability associated with different monitoring tools.

Second, it may be possible to borrow information from monitoring programs on similar fisheries and to assume, as an initial step, that the profile for bias and variability across statistical and operational factors would be the same should an identical program be implemented. In addition, it may be possible to use spatial and temporal variability in catches in scientific surveys in the area to inform the statistical variability assumed in the initial evaluation of potential dependability and to help plan sampling stratification for catch monitoring (Figus and Criddle 2019).

The third option is to conduct a pilot monitoring program. This would allow for an estimation of the statistical variability in the estimated parameter and may provide information that can be used to optimize sampling.

Regardless of the approach that is adopted, new monitoring programs should be reassessed within a few years of implementation to ensure that they meet dependability objectives.

Sources of uncertainty

Proxy values for F_{msy} related to M are not available for many invertebrate species so alternatives will need to be considered in the characterization of population status when assessing conservation risk in the RST.

Information on which to base risk considerations related to the distribution and the extent of overlap of species with fisheries may be limited seasonally which increases the risk from the fisheries activities.

Apportioning total removals across a suite of fisheries employing different gears, fishing practices, locations and seasons is challenging. Losses associated with discarding are the most uncertain. For many fisheries, there is limited information on the extent of bycatch and discarding and frequently less information on the mortality rates of released fish.

It is generally agreed that uncertainty exists on the reference values used for fisheries management, such as harvest decision rules. Although the QAT can theoretically take into account this uncertainty, it is rarely included in the decision making process.

Measurement objectives for monitoring programs typically involve estimation for scientific or reporting purposes. However, fishery management objectives may include the desire to change the magnitude of one or more parameters, such as reducing the total catch or total effort directed to a particular species or area over a short time frame. The measurements obtained from the monitoring programs can be used to assess the likelihood that the management objectives are met using a hypothesis testing framework akin to the one used to assess quality for compliance to a limit applications. This has not yet been incorporated in the QAT.

Completing an evaluation of quality using the QAT requires specifying anticipated values or ranges of values for the variability and bias elicited by 15 operational characteristics (DFO 2019b). In many cases, this process must rely on informed opinions. There is a clear need for additional methods and approaches to streamline the process and to ensure national consistency in application, given the large number of Canadian fisheries and populations of interest for which an assessment of quality will be required under the fishery monitoring policy.

CONCLUSIONS AND ADVICE

There is further work required to integrate the RST and the QAT for the categorization of conservation risk of fisheries with respect to stocks / population status and to assess the dependability of monitoring programs.

- The QAT can assess quality of monitoring activities for a stock / population for a single fishery or for a group of fisheries thus informing fisheries specific and stock / population objectives.
- Characterizing risks to populations from fisheries for multiple species and catch categories (targeted species, bycatch) requires the consideration of total removals from the stock / population across several fisheries.
- Completion of the catch monitoring assessment requires the quantification of fisheries specific removals which may require information from all fisheries that interact with the stock / population.
- The requirement that risk be assessed at the population level may be challenging as this may involve coordination with timing of stock assessments, inputs for multiple fishing fleets,

and coordination within DFO. Species of particular concern or for which there is information may have to be prioritized in the application of the RST and QAT.

Overall risks of fisheries to conservation of a stock / population would be best determined when individual population (stock) assessments are conducted and this information would be used to characterize the risk using the RST components (consequences and likelihood) related to fishing removals. For stocks / populations which are infrequently or not assessed, a different process to quantify cumulative effects of fisheries may be required.

The assessment of quality for both estimation and limit compliance objectives in the QAT is founded on a common assessment of variability and bias. To estimate a parameter of interest, such as the total removals from a fishery or multiple fisheries, estimation process variability and bias are calculated separately within the QAT.

Threshold quality values for assessing dependability for three conservation risk categories are provided as guidance rather than absolute firm values.

- For overall monitoring programs to be considered dependable for the estimation of a parameter, both the variability and bias must be within the thresholds corresponding to the assessed risk to conservation by the RST. Failure of one of the two components would result in an assessment of not dependable leading to considerations of options in management plans (to change the risk to conservation of the fishing activity(ies)) or to modify monitoring plans to reduce uncertainty and/or bias according to the need.
- For a monitoring plan developed for the purpose of assessing limit compliance, the quality score is compared to the threshold values corresponding to the conservation risk as established by the RST.
- When a monitoring program is relevant to several conservation objectives or limit compliance objectives (e.g. for several populations caught in a fishery or fisheries), the monitoring program should satisfy the quality requirements for all objectives.
- The choice of threshold quality values would be expected to change and be improved as new information is obtained on gains (reduction of bias and variability quality) achieved from directed and assessed modifications to practices to address the suite of operational characteristics of monitoring programs.

The process of determining, evaluating and revising fishery monitoring programs involves the RST and QAT in a recursive process aimed at aligning conservation risk and the quality of estimation and/or limit compliance applications.

- When only one or only a few fisheries are relevant, the required quality thresholds can be compared directly to the results of the QAT for the monitoring of these fisheries (Tables 1 to 3).
- When the population under consideration is affected by many fisheries, it may be necessary to use the QAT to assess the quality of the monitoring tools jointly, using the QAT's facility to evaluate quality with respect to one or more monitoring programs across all fisheries that capture a stock / population.

The combined output of the RST and QAT is not prescriptive in how fisheries specific monitoring programs could be modified to achieve the overall desired level of dependability for catch monitoring. The QAT can determine which fisheries monitoring program changes could be considered with the objective of improving the quality scoring associated with reducing bias and / or uncertainty and to assess cost-efficiencies.

If the conclusion is that the monitoring program is not dependable, the monitoring program may be improved and several options for consideration are available (DFO 2019b). In cases for which improvement to the monitoring program may be impossible or excessively costly or other sources of uncertainty too large to meet quality requirements, fishery management measures may have to be modified to lower the conservation risk and to align with achievable quality.

The implementation of the fishery monitoring policy is likely to lead to a requirement in some fisheries to modify current monitoring programs, and in a number of fisheries, to establish new programs where none existed previously. There is a suite of approaches available in previous advice and supporting documents. For these revised programs and new programs, they should be reassessed within a few years of implementation to ensure that they meet quality thresholds corresponding to the conservation risk categories of the RST.

The assessment of the adequacy of fishery monitoring needs to account for many aspects of the fishery assessment and management systems, and in itself catch monitoring constitutes an integral part of that system. It therefore seems appropriate to incorporate the assessment of catch monitoring within population assessment processes (stock assessments, recovery potential assessments, allowable harm and potential biological removal assessments). Furthermore, most assessment processes are followed by (management) advisory committee meetings that also involve DFO Fisheries Management, Science and a broader group of stakeholders. Together, the science advisory and management advisory meetings provide a venue for assessing the quality of monitoring programs, ensuring that the population assessments best account for the quality, assessing conservation risk and establishing quality with respect to risk. The management advisory meetings may be the appropriate venue for establishing fishery monitoring plans that match quality and risk, with respect to monitoring costs. The review of monitoring programs under the new policy could be phased in as part of the existing multi-year stock assessment cycle.

The assessment of dependability is currently undertaken as a distinct process that requires input from population assessments and information from existing monitoring programs and related studies, and for which the outputs affect monitoring and perhaps fishery management plans. An alternative to this approach is to evaluate dependability in the context of the population dynamics, assessment and fishery management systems, as structured within a management strategy evaluation (MSE; Punt et al. 2014). Undertaking MSE can be a long and complex process and will not be feasible for a large number of fisheries or populations under DFO's responsibility. Considering that the inputs required for the assessment of quality using the QAT would also be used within the MSE process, efforts related to the application of the RST and the QAT would be of benefit to MSE initiatives that may be undertaken in the future.

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SOURCES OF INFORMATION

This Science Advisory Report is from the May 14 to 16, 2019 national peer review meeting to review the risk screening tool developed to assess and categorize the risk to target catch, bycatch and discards from the prosecution of Canadian fisheries. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

Allard, J., and Benoît, H.P. 2019. Unified framework for the statistical assessment of fishery monitoring programs. DFO Can. Sci. Advis. Sec. Res. Doc. 2019/013. vi + 63 p.

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APPENDICES

Appendix 1. Revised descriptors associated with each consequence level for factors related to removals (all categories of catch) for the Risk Screening Tool (RST).

Nominal	Consequence	Descriptors
1	**Fisheries cause negligible impacts** to population size, recruitment range or dynamics (including trophic relationships), generally within the variation due to natural variability.	**Precautionary approach in place** The management framework (e.g. decision rules) is such that the realized and target fishing mortalities (F_{target}) are **well below** the fishing mortality reference point (F_{lim}) when the stock is in the Healthy Zone, or the fraction of F_{lim} believed to be sustainable when the stock is in the Cautious Zone. Furthermore, there is **no expectation** that F_{target} may be exceeded by a relatively large amount due to quota overruns or unreported catches that would cause fishing mortality to approach unsustainable levels. The stock is most likely to be in the Healthy Zone, though it may be in the Cautious Zone due to natural variability.
		No precautionary approach in place i) A proxy for F_{lim} can be defined: The inferred fishing mortality rate is **well below** the proxy for F_{lim} with the proxy for F_{lim} = 1.5 x proxyF_{MSY}, and • proxyF_{MSY} = 0.87 x natural mortality for teleost fish, or • proxyF_{MSY} = 0.41 x natural mortality for elasmobranchs. ii) A proxy for F_{lim} cannot be defined: In the absence of a proxy for the fishing mortality reference point there is a reasonable expectation that removals will be **negligible** with respect to the size of the stock and its productivity. Evidence in support includes more than one of the following: • negligible catches relative to fishable biomass estimates from surveys; • convincing evidence that the catchability of the population in the fishery is very low; • convincing evidence that the fishery selects only for highly abundant juvenile stages associated with high natural mortality; • the fishery occurs in a marginal portion of the population distribution and outside any biologically sensitive time periods for the population; the population does not display an aggregative behavior that could accidentally result in overfishing in any given year; and • there is an increasing trend in post-recruitment abundance, provided the stock is not severely depleted and the index of abundance is reliable and is tracking abundance well.
		Additional Considerations i) In the case of a population caught only as bycatch: • additional evidence is an inferred natural mortality rate of the bycatch species that is **much higher** than the natural mortality of the target species (thus indicating higher productivity under natural conditions), unless the bycatch species is suspected of having higher catchability to the gear. ii) In the case of a principally discarded species: • post-release survival is expected to be **very high**. iii) For species assessed as “at risk” by COSEWIC: • recovery potential assessment of species at risk **does not indicate** fishing pressure as an obstruction to recovery.

<table>
<tr><th>Nominal</th><th>Consequence</th><th>Descriptors</th></tr>
<tr><td rowspan="3">2</td><td rowspan="3">Fisheries cause minor impacts to population size, recruitment, range or dynamics (including trophic relationships) beyond variation due to natural variability. The population’s capacity to increase from a depleted state is not impacted.</td><td>Precautionary approach in place
As above, realized and target fishing mortalities (F_{target}) are well below F_{lim} for stocks in the Healthy Zone, or a fraction of F_{lim} for stocks in the Cautious Zone. Furthermore, it is unlikely that F_{target} may be exceeded by a relatively large amount due to quota overruns or unreported catches that would cause fishing mortality to approach unsustainable levels.</td></tr>
<tr><td>No precautionary approach in place
i) A proxy for F_{lim} can be defined:
The inferred fishing mortality rate is well below the proxy for F_{lim} with the proxy for F_{lim} = 1.5 x proxyF_{MSY}, and
• proxyF_{MSY} = 0.87 x natural mortality for teleost fish, or
• proxyF_{MSY} = 0.41 x natural mortality for elasmobranchs.
ii) A proxy for F_{lim} cannot be defined
In the absence of a proxy for the fishing mortality reference point there is a reasonable expectation that removals will be small with respect to the size of the stock and its productivity. Evidence in support includes more than one of the following:
• small catches relative to fishable biomass estimates from surveys;
• convincing evidence that the catchability of the population to the fishery is low;
• convincing evidence that the fishery selects mainly for highly abundant juvenile stages associated with high natural mortality;
• the fishery occurs in a small portion of the population distribution and outside any biologically sensitive time periods for the population;
• the population generally does not display an aggregative behavior that could accidentally result in overfishing in any given year; and
• there is an increasing trend in post-recruitment abundance, provided the stock is not severely depleted, the index of abundance is reliable, and is tracking abundance well.</td></tr>
<tr><td>Additional Considerations
i) In the case of a population caught only as bycatch:
• additional evidence is an inferred natural mortality rate of the bycatch species that is higher than the natural mortality of the target species (thus indicating higher productivity under natural conditions), unless the bycatch species is suspected of having higher catchability to the gear.
ii) In the case of a principally discarded species:
• post-release survival is expected to be high.
iii) For species assessed as “at risk” by COSEWIC:
• recovery potential assessment of species at risk indicates fishing pressure as an unlikely obstruction to recovery.</td></tr>
</table>

<table>
<tr><th>Nominal</th><th>Consequence</th><th>Descriptors</th></tr>
<tr><td rowspan="3">3</td><td rowspan="3">Fisheries cause moderate impacts to population size, recruitment, range or dynamics (including trophic relationships) beyond variation due to natural variability. The population's capacity to increase from a depleted state may be adversely impacted.</td><td>Precautionary approach in place
As above, realized and target fishing mortalities (F_{target}) are near or below F_{lim} for stocks in the Healthy Zone, or a fraction of F_{lim} for stocks in the Cautious Zone. Furthermore, F_{target} may be exceeded by a relatively large amount in some years due to quota overruns or unreported catches that would cause fishing mortality to exceed sustainable levels.</td></tr>
<tr><td>No precautionary approach in place
i) A proxy for F_{lim} can be defined:
The inferred fishing mortality rate is close to, yet below the proxy for F_{lim} with the proxy for F_{lim} = 1.5 x proxyF_{MSY}, and
• proxyF_{MSY} = 0.87 x natural mortality for teleost fish, or
• proxyF_{MSY} = 0.41 x natural mortality for elasmobranchs.
ii) A proxy for F_{lim} cannot be defined
In the absence of a proxy for the fishing mortality reference point there is a reasonable expectation that removals will be moderate with respect to the size of the stock and its productivity. Evidence in support includes more than one of the following:
• moderate catches relative to fishable biomass estimates from surveys;
• evidence that the catchability of the population to the fishery is moderate;
• the fishery selects mainly for life-history stages whose loss may hinder productivity (e.g. mature individuals);
• the fishery occurs in a moderate portion of the population distribution and/or during a time that may overlap with a biologically sensitive period for the population;
• the population displays an aggregating behaviour that could result in accidental overfishing in some years; and
• there is a stable trend in post-recruitment abundance, provided the index of abundance is reliable, and is tracking abundance well.</td></tr>
<tr><td>Additional Considerations
i) In the case of a population caught only as bycatch:
• additional evidence is an inferred natural mortality rate of the bycatch species that is similar to the natural mortality of the target species.
ii) In the case of a principally discarded species:
• post-release survival is expected to be moderate.
iii) For species assessed as “at risk” by COSEWIC:
• the recovery potential assessment of species at risk indicates fishing pressure as a possible obstruction to recovery.</td></tr>
</table>

<table>
<tr><th>Nominal</th><th>Consequence</th><th>Descriptors</th></tr>
<tr><td>4</td><td>Fisheries cause significant impacts to population size, recruitment, range and/or dynamics (including trophic relationships) leading to eventual population depletions and/or range contractions, and possibly enhanced risk of local extirpation. Species capacity to increase from a depleted state is adversely impacted.</td><td>Precautionary approach in place
The management framework is such that there is a high likelihood that the realized fishing mortality could exceed levels deemed sustainable in some years, by design (e.g. $F_{target} \approx F_{lim}$) or F_{target} is likely to be exceeded by a relatively large amount in some years due to quota overruns or unreported catches that would cause fishing mortality to exceed sustainable levels.

No precautionary approach in place
i) A proxy for F_{lim} can be defined:
The inferred fishing mortality rate is at or above the proxy for F_{lim} with the proxy for F_{lim} = 1.5 x proxyF_{MSY}, and
• proxyF_{MSY} = 0.87 x natural mortality for teleost fish, or
• proxyF_{MSY} = 0.41 x natural mortality for elasmobranchs.
ii) A proxy for F_{lim} cannot be defined
In the absence of a proxy for the fishing mortality reference point there is a reasonable expectation that removals will be large with respect to the size of the stock and its productivity. Evidence in support includes more than one of the following:
• large catches relative to fishable biomass estimates from surveys;
• evidence that the catchability of the population to the fishery is moderate to high;
• the fishery selects for life-history stages whose loss may hinder productivity (e.g. mature individuals);
• the fishery occurs in a large portion of the population distribution and/or during a time that may overlap considerably with a biologically sensitive period for the population;
• the population displays an aggregating behaviour that is expected to result in accidental overfishing in a some years; and
• there is a declining trend in post-recruitment abundance, provided the index of abundance is reliable, and is tracking abundance well.

Additional Considerations
i) In the case of a population caught only as bycatch:
• additional evidence is an inferred natural mortality rate of the bycatch species that is lower than the natural mortality of the target species.
ii) In the case of a principally discarded species:
• post-release survival is expected to be low.
iii) For species assessed as “at risk” by COSEWIC:
• recovery potential assessment of species at risk indicates fishing pressure as a likely contributor to continued population decline.</td></tr>
</table>

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