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Ecosystems and Oceans Science | Sciences des écosystèmes et des océans

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SCIENCE GUIDELINES TO SUPPORT DEVELOPMENT OF REBUILDING PLANS FOR CANADIAN FISH STOCKS

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

Context:

Under Canada's recently modernized Fisheries Act*, the Minister of Fisheries and Oceans Canada (DFO) is required to develop and implement rebuilding plans for major fish stocks prescribed in regulation that decline to or below their limit reference point, taking into account the biology of the fish and the environmental conditions affecting the stock. Science advice was requested by Resource Management, National Fisheries Policy, and Fish Population Science to establish recommendations for science guidelines to support the development of rebuilding plans. These recommendations will guide the DFO Ecosystems and Oceans Science Sector in developing advice required for key elements of rebuilding plans that meet the requirements of the legislation and proposed regulations, the policy requirements of the Fishery Decision-Making Framework Incorporating the Precautionary Approach, and the Guidance for the Development of Rebuilding Plans under the Precautionary Approach Framework.*

This Science Advisory Report is from the January 14-16, 2020 National Peer Review meeting on Science guidelines to support development of rebuilding plans for Canadian fish stocks. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

SUMMARY

- Under the revised *Fisheries Act* a rebuilding plan is required when a stock falls to or below its Limit Reference Point (LRP). The LRP should be avoided with high probability to reduce the risk of serious harm and management actions to prevent further decline in stock status should be implemented before this point is reached.
- Unless otherwise defined in stock-specific precautionary approach frameworks, the LRP should be considered breached if the terminal year stock status indicator is estimated to be at or below the LRP with a greater than 50% probability or if the projected stock status indicator falls below the LRP with a greater than 50% probability under a zero catch scenario in a 1 year projection.
- Stock status and fishing mortality should be expressed in a probabilistic manner with respect to reference points and targets. Where probabilities cannot explicitly be estimated, qualitative likelihood approaches may be required.
- A rebuilding plan requires the establishment of a rebuilding target. There should be a high probability that the stock is above the LRP when the target is achieved. Furthermore, there should be a low probability of the stock falling below the LRP in the short to medium term.
- Measurable rebuilding objectives should be defined, including objectives related to the rebuilt state. Where possible, environmental conditions and biology should be taken into account when setting objectives.
- Rebuilding objectives may include outcomes other than those related to biomass, such as expanding or maintaining spatial distribution, subpopulations and age structure, and creating the conditions that are expected to promote such outcomes. Consideration should be given to prioritizing among objectives to facilitate decision-making, with stock growth being a high priority.
- Based on scientific literature, actions to rebuild a stock should be taken as soon as possible to avoid further deterioration of stock status and increase the likelihood of rebuilding success.
- A minimum rebuilding timeline should be established against which alternative management actions can be evaluated. The standard is to estimate the time to reach the rebuilding target with zero fishing mortality (T_{min}). In the absence of T_{min}, alternative metrics of rebuilding time can be used, such as generation time.
- Where possible, future stock states should be projected for a range of plausible scenarios and candidate management measures. Scenarios are hypotheses about stock and fishery dynamics that may be affected by various factors including environmental conditions. Projections should include a zero fishing mortality and status quo scenario to serve as a benchmark for comparison with alternative strategies.
- Attribution of stock depletion to environmental factors should not be taken as an indication that fishing mortality has little or no effect without evidence that is the case. Where rebuilding prospects appear to be poor even in the absence of fishing mortality, this prognosis should be explicitly described.
- Advice on whether habitat loss or degradation has likely contributed to the stock’s decline is required.

- Rebuilding strategies need to be evaluated relative to defined objectives and associated performance measures. Evaluation should occur during development and implementation of the plan. Advice should be provided on the frequency of evaluation and the monitoring information that is needed to evaluate rebuilding performance.

INTRODUCTION

Prior to the 2019 modernization of the *Fisheries Act*, Fisheries and Oceans Canada (DFO) did not have a legal requirement to implement rebuilding plans; however, the need to do so was outlined in policy and guidelines. In 2009, DFO published the *Fishery Decision-Making Framework Incorporating the Precautionary Approach* (PA Policy) which indicates that once a stock is below its limit reference point (LRP), a rebuilding plan must be in place with the aim of having a high probability of growing the stock above the LRP within a reasonable time frame (DFO 2009). The LRP is defined as the stock status, usually in terms of biomass (or abundance), below which serious harm to the stock may occur. Serious harm is considered to include recruitment overfishing or other impairment to stock productivity (Shelton and Rice 2002) and may also have resultant impacts to the ecosystem and a long-term loss of fishing opportunities. The PA Policy states that below the LRP, management actions must promote stock growth, removals from all sources must be kept to the lowest possible level, there should be no tolerance for preventable decline, and that conservation considerations prevail over other considerations (e.g., socio-economic). The PA Policy also notes the need to initiate development of a rebuilding plan in advance of when it is needed, to ensure that there is a plan ready if a stock declines to or below its LRP. Subsequently, guidelines were developed in the *Guidance for the Development of Rebuilding Plans under the Precautionary Approach* (DFO 2013a).

In 2019, the *Fisheries Act* was revised, including the addition of the Fish Stocks provisions (Section 6). Section 6.2 of the *Fisheries Act* outlines new requirements to develop and implement rebuilding plans for major fish stocks that have declined to, or below their LRP, while taking into account the biology of the fish and the environmental conditions affecting the stock. The provisions only apply to major fish stocks prescribed by regulation. The provisions further indicate situations where rebuilding plans may be amended to mitigate adverse socio-economic or cultural impacts, additional considerations for rebuilding plans, or exceptions that may apply (such as if a stock is an endangered or threatened species under the *Species at Risk Act*).

Regulations are being developed to support the new Fish Stocks provisions which will outline the minimum requirements for the contents of rebuilding plans. The proposed regulations indicate that a rebuilding plan will contain (DFO 2018):

- A description of stock status, and stock trends,
- Reasons for the stock's decline,
- Measurable objectives aimed at rebuilding the stock and associated timelines,
- A description of the desired rebuilt state or target,
- Management measures aimed at achieving the objectives,
- A method to track progress to achieve the rebuilding plan's objectives, and
- An approach to review the objectives and adjust them if the objectives are not being achieved.

This Science Advisory Report provides recommendations on key science-based elements to support development of rebuilding plans that meet legal obligations and are aligned with departmental policies. The recommendations are intended to promote consistency by applying a common interpretation of science advice for rebuilding. While a consistent approach is desired, some adaptation to meet the circumstances of individual stocks and fisheries is expected. It is expected that these recommendations will need to be updated periodically over time as experience with their application accumulates and international practice evolves.

ANALYSIS

Implementing rebuilding plans for stocks that fall to or below their LRP is central to DFO's efforts to sustainably manage Canadian fisheries. The main roles and responsibilities of the Ecosystems and Oceans Science Sector (hereafter Science Sector) in supporting the development of rebuilding plans relate to estimating stock status and productivity parameters, identifying limit reference points, and evaluating the expected consequences of management choices (e.g., management measures and associated risks). Science advice may also inform various other elements of rebuilding plans. However, the responsibility for making decisions on management measures, targets, and risk tolerance is not Science Sector remit. These decisions are informed by socio-economic and cultural considerations, input from Indigenous groups, the fishing industry, and other stakeholders, as well as science advice. Developing rebuilding plans is led by the Fisheries and Harbour Management Sector (hereafter Fisheries Management). However, given the considerations noted above, there is a need within the Department for Sectors to work together throughout the development of rebuilding plans.

A management strategy is defined by stock and fishery objectives and the management measures or procedures that are intended to achieve those objectives. Rebuilding should be regarded as an integral part of an overall management (or harvest) strategy. In other words, management strategies should anticipate periods of stock declines to low levels, and the need to pre-specify actions intended to arrest a decline before a rebuilding plan is required. Viewing a rebuilding strategy as separate from the overall management strategy can lead to deferral of action to prevent stock decline until thresholds to serious or irreversible harm have been passed (e.g., LRP) and conflict between rebuilding measures and those measures intended to provide harvest opportunities. This can result in delayed rebuilding to target levels. Ideally, rebuilding objectives and supporting actions are identified prior to the need for stock rebuilding (i.e., before a stock falls to or below its LRP) so that decision-makers and resource users can anticipate the management measures that will be required. The transition from a depleted state where rebuilding is required to an improved state at target levels should be achieved via a continuum of measures defined in a management strategy.

The LRP represents a biological threshold to possible serious harm, below which rebuilding prospects are uncertain, and as such declines of the stock to or below its LRP should be avoided. Therefore, to avoid breaching the LRP, management actions to prevent further decline in stock status should be implemented before this point is reached. When it has been determined that a stock needs rebuilding, actions to rebuild should be taken as soon as possible to increase the likelihood of rebuilding success. Case studies reviewed in the scientific literature strongly suggest that rebuilding success requires reduction of fishing mortality early in the rebuilding period (Hutchings 2015; Milazzo 2012; Murawski 2010; Sherzer and Prager 2007). Therefore, taking management action should not be delayed during the period of time needed to develop and implement a formal rebuilding plan.

Identifying the requirement for a rebuilding plan

A rebuilding plan is required when stocks fall to or below their LRP under s. 6.2(1) of the Fish Stocks provisions and the PA Policy. When determining if an LRP has been breached, uncertainty should be taken into account. Unless otherwise defined in stock-specific precautionary approach frameworks, the LRP should be considered breached if the terminal year stock status indicator is estimated to be at or below the LRP with a greater than 50% probability, or if the projected stock status indicator falls below the LRP with a greater than 50% probability under a zero catch scenario in a 1 year projection. This should be used to determine stock status relative to the LRP. However, the LRP should be avoided with high probability to avoid serious harm. Projections are further described below in the section ‘Projections and model scenarios’ and should not be limited to the zero catch scenario described here that may be used to assign stock status relative to the LRP.

For situations where it is not possible to estimate the probability that the current or projected biomass is below the LRP, an agreed upon means of assigning status relative to limits is required and should be defined and clearly documented. This may include expert judgement or weight of evidence approaches (Health Canada 2018). To the extent possible, risk-equivalency of breaching LRPs should be maintained across stocks.

There may be cases where a change in model assumptions or the data used to determine stock status results in revised reference points that change the status determination. Determination of stock status should always be based on the best available information and most recent science advice.

Recommendation:

- Unless otherwise defined in stock-specific precautionary approach frameworks, as general guidance, the LRP should be considered breached if the terminal year stock status indicator is estimated to be at or below the LRP with a greater than 50% probability or if the projected stock status indicator falls below the LRP with a greater than 50% probability under a zero catch scenario in a 1 year projection.

Description of stock status and trends

The PA Policy elements include status-based reference points including the LRP, upper stock reference (USR), and target reference point (TRP) as well as a limit fishing mortality rate (removal reference). Status-based reference points are usually expressed as biomass (abundance) terms or their proxies, however other units may be used to indicate stock status where appropriate (e.g., yield for effort-controlled fisheries). Stock status should be reported relative to both status and fishing mortality reference points and targets when possible. Other stock attributes, such as stock trends (e.g., decreasing, stable, increasing over a given time period), spatial distribution, density, sub-populations, and age structure, may also be important to describe stock status and to better quantify or qualify rebuilding prospects.

Recommendations:

- Report the stock status relative to the LRP. This should include the biomass estimate (or proxy), and the probability, or qualitative likelihood, that the stock is below the LRP.
- Report the fishing mortality status relative to the removal reference, including the probability, or qualitative likelihood, that fishing mortality is greater than the removal reference.
- Describe stock trends and/or trajectories (e.g., trends in biomass and fishing mortality).

- Report on other stock attributes that have been identified as important to describe stock status, such as spatial distribution, density, sub-populations, and age structure and indicate how those attributes relate to defining status and stock trajectory.

Describing reasons for the stock's decline

The relative impacts of fishing, environmental factors, and other anthropogenic factors on the productivity and dynamics of a stock can change over time and with abundance. For example, fishing may have initiated or contributed to stock decline to a state where environmental conditions may maintain a compromised stock state even if fishing pressure is reduced. The reverse is also true; environmental drivers may create conditions where fishing at a level deemed "sustainable" in the past is now precluding stock rebuilding by removing available surplus production. In some cases, resolving the relative roles of various factors contributing to stock decline over time, both in the past and future, may be difficult. Changes to fish habitat can also contribute to stock decline and is considered in a separate section.

Recommendation:

- Describe potential drivers of stock trends, specifically any anthropogenic and/or environmental factors that may have contributed to or caused the decline and/or that may impede rebuilding.

Rebuilding target

Defining a point at which rebuilding is considered achieved and the stock rebuilt, the rebuilding target, is needed to transition from a rebuilding plan to an Integrated Fisheries Management Plan. Targets for rebuilding are established by Fisheries Management, however general advice is provided here to support development of these targets. A rebuilding target should be set at a level that is far enough above the LRP to have a high probability of the stock being above it, taking uncertainties into account. A rebuilding target should also be set far enough above the LRP so that there is a low probability of falling below the LRP in the short to medium term. Biomass at maximum sustainable yield (B_{MSY}) is used as a rebuilding target in some jurisdictions (e.g., United States and New Zealand; NOAA 2018; MF 2008), and in international agreements such as the United Nations Fish Stocks Agreement (United Nations 1995), and has the advantage of likely being far enough above the LRP to meet the conditions described above. Other jurisdictions, such as Australia, require that rebuilding strategies aim to rebuild the stock to above its LRP with a reasonable level of certainty (DAWR 2018).

Recommendation:

- A rebuilding target should be set at a level that is far enough above the LRP to have a high probability of the stock being above it, taking uncertainties into account. The rebuilding target should also be set far enough above the LRP so that there is a low probability of falling below the LRP in the short to medium term.

Rebuilding objectives

The identification of objectives for a stock and fishery depends upon collaboration between scientists, decision-makers, and resource users. The Science Sector has a role in helping to translate legal and policy intent as well as translating the goals of decision-makers and resource users into measurable objectives. Rebuilding objectives can be made measurable by including: an outcome of interest (e.g., biomass greater than the LRP), a desired probability of achieving the outcome, and the timeframe within which the outcome should be achieved. A statement of how to interpret the probability in the context of time should be provided. For example, objectives that include reference points or targets should clearly specify how time should be interpreted, e.g., a 90% probability of avoiding a limit breach may mean a 1-in-10 year chance of a breach, or 90% in each and every year.

Rebuilding objectives related to abundance or biomass should provide some assurance that the rebuilt state is achieved to avoid ending rebuilding measures too early. In addition, interim objectives may be defined which allow evaluation of rebuilding progress and create process steps to allow for adaptation of the rebuilding strategy, and possibly the rebuilding objectives, using new information and updated analyses. Objectives in a rebuilding plan may also include requirements for increased data collection and additional analyses (e.g., to develop or improve a model).

Rebuilding objectives should ideally also account for other biological metrics of stock condition that may relate to stock sustainability, such as age or size structure, sex ratios, density, spatial distribution and spatial occupancy of spawning locations. However, setting objectives for these metrics may be challenging. In some cases, it may be possible for these metrics to be accounted for explicitly by setting specific objectives, or implicitly by setting rebuilding objectives for abundance or biomass at levels that are sufficiently high to result in a high likelihood of restoration of these other metrics of condition. Objectives related to non-biological considerations may also be included (e.g., socio-economic and cultural objectives). However, objectives related to biological stock preservation and stock growth should be prioritized.

The PA Policy specifies that when a stock is below the LRP “management actions must promote stock growth and removals from all sources must be kept to the lowest possible level […] There should be no tolerance for preventable decline” (DFO 2009). Preventable decline can be interpreted as a decline that is induced by human activities (e.g., fishing or habitat disturbance) or those causes that can be mitigated by humans, such as natural habitat erosion. While no tolerance literally means zero probability of a decline, this statement is associated with “should”, admitting possibility. The Science Sector does not have the purview to determine what possibility should be admitted for tolerating preventable decline. However, a decline tolerance objective and performance statistic given the specified risk tolerance and time period for evaluation, should be included in the rebuilding plan, when possible. To be consistent with policy, rebuilding objectives should avoid preventable decline and promote growth above the LRP in a reasonable timeframe and with high probability (i.e., 75-95% defined using draft Table B in Annex 2 of DFO 2009).

Recommendations:

- Define measurable rebuilding objectives. These should include reaching a rebuilt state, defined as being above the rebuilding target with a specified probability or qualitative likelihood. Include a decline tolerance objective and performance statistic, where possible, given a risk tolerance and time period for evaluation. Other objectives, including interim objectives may also be defined. Where possible, take into account environmental conditions and biology.
- When defining objectives, a statement of how to interpret the probability in the context of time should be provided.
- Consideration can be given to attributes other than those related to biomass, such as expanding or maintaining spatial distribution, density, subpopulations and age structure, and creating the conditions that will promote this.

- If there are multiple objectives, consideration should be given to prioritizing among them, with stock growth being a high priority.

Timelines for rebuilding

The timeline for rebuilding is the expected time to reach the rebuilding target, generally expressed in years. The choice of timeline for rebuilding is a Fisheries Management decision, based on a variety of factors. However, regardless of the timeline, actions to rebuild should be taken as soon as possible to increase the likelihood of rebuilding success. Early reduction of fishing mortality is associated with increased likelihood of successful rebuilding outcomes.

The PA Policy indicates that “a rebuilding plan must be in place with the aim of having a high probability of the stock growing [above the LRP] within a reasonable time”. A reasonable time to achieve a level above the LRP is indicated to be 1.5 to 2 fish generations, with allowance for variance in life history (e.g., long-lived species). However, generation time does not take into account the level of stock depletion or environmental conditions which impact the speed at which rebuilding may be possible.

It is recommended that where possible, the minimum time to reach the rebuilding target with zero fishing mortality (T_{min}) be calculated to inform rebuilding timelines. T_{min} has the advantage that it takes into account current estimates of stock depletion, generation time, and productivity, and is used in other international jurisdictions with well-developed rebuilding policies and guidelines. The Science Sector can also support the selection of rebuilding timelines by calculating the time to reach the rebuilding target under status quo and alternative management actions and for alternative plausible hypotheses about stock response to preventable and/or ecosystem factors. As a general guideline, a maximum rebuilding time of 2-3 times T_{min} could be considered based on international practice. Once selected, the rationale for the choice of rebuilding time should be provided.

Where T_{min} cannot be calculated, estimates of generation time should be provided to inform rebuilding timelines. While the PA Policy suggests that the time to reach the LRP should be between 1.5 to 2 times the generation time, a longer time may be needed to reach a higher rebuilding target or to recover a highly depleted stock.

Recommendations:

- Actions to rebuild depleted stocks should be taken as soon as possible to increase the likelihood of rebuilding success, including during the period when the rebuilding strategy and plan are being developed.
- When possible, calculate T_{min} (time to reach the rebuilding target with zero fishing mortality).
- Calculate the time to reach the rebuilding target under status quo and, when available, alternative management actions.
- Calculate the time to reach the rebuilding target under alternative plausible hypotheses about stock response to preventable and/or ecosystem factors.
- Provide estimates of generation time, in particular when T_{min} cannot be calculated.

Probability and communicating uncertainty and risk

Stock and fishery dynamics are uncertain; future outcomes cannot be predicted exactly. Measurable objectives should therefore identify the desired certainty (probability) of avoiding undesirable states or achieving desired states, wherever possible. While exploratory analyses might help inform the selection of probabilities by estimating what is feasible given current knowledge about the fisheries system, probabilities in objectives more often reflect legal or policy obligations or the risk tolerance of decision makers for particular management outcomes given a choice of potential management actions. Where probabilities cannot explicitly be estimated, qualitative likelihood approaches may be required.

When communicating uncertainty, such as the probability of an event or outcome occurring, standard and consistent terminology should be used. Standard terms used to define likelihood have been defined by the Intergovernmental Panel on Climate Change (IPCC 2007 and revised in Mastrandrea et al. 2010) which could be adopted by the department for describing and communicating uncertainty.

Performance measures

Performance measures are statistics used during retrospective or prospective evaluation of management (rebuilding) strategies; for prospective evaluation they can be used to compare the performance of alternative management options relative to stated objectives. Performance measures can be calculated from simulated future states of nature and represent how closely a suite of objectives is likely to be met when making choices among alternative rebuilding strategies. These differ from empirically-based indicators of stock status that may be used retrospectively to monitor realized rebuilding performance over time.

Performance measures used to inform rebuilding plans should be directly linked to stated objectives. Each objective should have at least one performance measure. Within the context of rebuilding plans, performance measures are likely to be focused on estimating projected abundance or biomass (or proxy) relative to a desired rebuilt state, as defined in rebuilding objectives. Definition of performance measures should be specific, describing how the performance measure will be calculated over multiple years and replicates when simulation methods are used for prospective evaluation. Examples of performance measures related to rebuilding objectives may include the probability that biomass will be above the LRP at some future time period, or the probability that the stock will experience a decline in abundance over a specified period. However, additional performance measures, including those related to socio-economic and/or cultural objectives, can also be used to inform the selection of a management strategy, subject to the strategy meeting higher priority rebuilding objectives. Performance measures should be easy for stakeholders and decision-makers to interpret; similarly, to simplify decision-making, the number of objectives and matching performance measures should be limited to the extent possible, while still representing key rebuilding goals.

Recommendations:

- Performance measures should be quantifiable and directly linked to stated rebuilding objectives.
- Differentiate performance measures used to evaluate how well specific rebuilding objectives are met versus those used to inform trade-offs among management options, subject to meeting imperative rebuilding criteria.

Management strategies

Management (or rebuilding) strategies define stock and fishery objectives and what, and when, management actions are to be made in response to perceived changes in stock status (e.g., changes in biomass levels). In addition to objectives, a strategy includes the data and assessment methods used to inform and trigger the management measures. The data, assessment method and management measures are collectively referred to as a management procedure. Harvest Decision Rules (HDRs) are a component of management procedures. A HDR is an algorithm or well-defined set of rules that specify a harvest-related management output (e.g., Total Allowable Catch, total effort, or target removal rate). HDRs are an essential component of a PA Policy harvest strategy (DFO 2009). The description of HDRs should be explicit enough to allow quantitative evaluation.

The iterative relationship between estimated stock status and management response allows the outcome of a stock assessment to feed back into the fishery management system, to influence the future stock trajectory in response to perceived changes in stock status. This feedback relationship only develops when control rules are applied consistently to a stock and fishery over multiple rounds of decision-making. If the basis for harvest decisions (e.g., the objectives and priorities among objectives) shifts annually, feedback will not develop. Feedback control rules do not need to be restricted to quantitative output controls such as harvest limits. They may include specification of area or seasonal closures, gear restrictions, fishing effort controls, size-limits, or other management tactics used as part of a management strategy; however, many of these types of management measures are harder to evaluate through simulation. For stocks in which data limitations prevent the evaluation of feedback control rules, a plan should be developed outlining the steps for increased data collection to support the development and application of feedback control rules in the future. For some data-poor stocks where reference points and biomass are more challenging to estimate, empirical rules that reduce fishing mortality via input controls may be more effective than those based on catch limits and biomass targets (NRC 2014).

In the context of rebuilding plans, the Science Sector has a role to play in helping to design and evaluate management strategies that have a high likelihood of avoiding undesirable outcomes and promoting stock growth towards pre-specified targets over a range of hypotheses about stock and fishery dynamics. This can be done through closed-loop simulation modelling.

Recommendations:

- In general, HDRs should include feedback control mechanisms such that updates to perceived stock status are used to adjust harvest impacts in a way that helps move the stock towards objectives.
- When possible, closed-loop simulation modelling should be used to design feedback control rules demonstrated to avoid undesirable outcomes under hypotheses about future dynamics.
- Management measures other than harvest limits should also be considered.

Stock enhancement

Stock enhancement, in which a subset of individuals from a population are bred and reared in captivity for part of their life cycle and then released into the wild, can be used as part of a rebuilding plan. Stock enhancement can also include captive breeding programs, in which a part of a population is reared in captivity for one or more complete life cycles in order to prevent possible extirpation. If survival through early life history stages is higher in captivity than in the wild and survival of released fish to maturity is sufficiently high, stock abundance with enhancement will increase faster than in the absence of enhancement. For stocks that are at extreme low levels of abundance, enhancement can also help safeguard against the risks of extirpation and genetic drift.

Hatchery production can present both benefits and risks to rebuilding. Risks may include undesirable genetic effects on the natural population, disease, deleterious ecological implications, and increased harvest pressure on co-migrating wild stocks (reviewed for Pacific salmon in DFO 2013b). Despite these risks, the use of hatchery-based stock enhancement may still be appropriate when the potential benefits to rebuilding outweigh the risks. Stock enhancement options should be quantitatively evaluated in the context of the broader management framework that includes options for harvest reduction and habitat restoration where applicable. Rebuilding objectives linked to enhancement should be explicit about the long-term level of acceptable hatchery influence on natural production and performance relative to these objectives should be used to inform enhancement decisions. Recommendations included here are specific to the development of rebuilding plans and may not necessarily apply to enhancement actions linked to Species at Risk Recovery Strategies and/or Action Plans.

Recommendations:

- The scientific rationale for enhancement should be clearly developed and supported by an analysis of the ability of the stock to meet rebuilding and harvest objectives in the absence of enhancement.
- Stock enhancement options should be quantitatively evaluated in the context of the broader management framework that includes options for harvest reduction and habitat restoration where applicable.

Projections and model scenarios

The use of quantitative population models that project trajectories of future stock size under alternative management actions can be an informative component of advice in support of selecting a rebuilding strategy. For example, projections can be used to identify management procedures likely to meet rebuilding objectives adequately. They allow comparison of likely stock and fishery outcomes as a result of applying different sets of management measures and can be used to inform on timelines for rebuilding. They can also be used to inform socio-economic analyses by communicating trade-offs between biological and socio-economic outcomes. Projections should be parameterized using the best available knowledge and to represent key uncertainties in future biological and management processes (e.g., recruitment, growth, maturity, natural mortality, implementation error). However, projections should not be viewed as predictions of future stock status. Instead, they should be viewed as a test of whether a given rebuilding strategy is likely to fail under the modelled hypothesis about future conditions so that options that perform poorly can be eliminated from consideration.

While some sources of uncertainty are incorporated into stock projections through specification of probability distributions for model parameters (i.e., parameter uncertainty), structural uncertainties in the underlying data or mathematical model formulation will need to be represented through the use of alternative model scenarios. Each scenario is intended to represent a plausible hypothesis about future stock and fishery dynamics. By applying the same set of candidate rebuilding procedures to each model scenario, procedures that fail to meet required rebuilding objectives under one or more plausible scenarios can be identified and removed from consideration. Examples of structural uncertainties that have been explored through scenarios include: stock structure, the form of spawner-recruit relationship, and non-stationarity in biological processes such as recruitment, productivity, natural mortality, growth, and maturity. Alternative models or scenarios may not be considered to be equally probable. In some cases, model-averaging with pre-specified weighting schemes may be used to simplify advice by combining results from multiple scenarios into a single set of performance measures. In such cases a rationale should be provided for the choice of model weights.

Closed-loop simulation modelling is the preferred tool to evaluate future performance of candidate management procedures so that annual data collection, stock assessment, and decision-making processes, as well as their associated errors, are represented in performance measures. This allows for better representation of the management system and associated uncertainties such as assessment errors and lags in feedback effects. Projections and/or simulations are most often used for data-rich and data-moderate stocks. However, simulation testing of candidate management strategies can also be useful in data-limited cases. This approach can lead to robust management choices even in data-poor situations and allows value of information analyses to identify what data would be most useful in resolving reducible uncertainties (Carruthers et al. 2014; Carruthers and Hordyk 2018).

Data limitations may be severe enough to prevent plausible hypotheses about stock dynamics from being developed. In these cases, rebuilding plans should emphasize ways to improve data collection to support future analyses. For example, changes to indicators based on available data for data-poor situations (e.g., fishery footprint, catch, species composition of the catch, etc.) may be explicitly tied to requirements for increased data collection if fishing activities are to continue (Dowling et al. 2015).

Recommendations:

- Where possible, projections should be aligned with the time horizons identified in rebuilding objectives, recognizing that projections become more uncertain the longer they are. When possible, alternative model scenarios should be employed.
- Closed-loop simulation modelling is the preferred tool to evaluate future performance of candidate management procedures so that annual data collection, stock assessment, and decision-making processes, as well as their associated errors and lag effects, are represented in performance measures.

Evaluating rebuilding strategies

Rebuilding strategies should be evaluated relative to the defined objectives and performance measures. The Science Sector can assist with evaluating and communicating trade-offs in management outcomes that result from management choices. These trade-offs can be described for a range of plausible hypotheses about stock and fishery dynamics. Trade-offs may include possible costs (e.g., persistent or worsening stock and fishery states) and benefits (e.g., stock growth in support of attaining desired stock states, shorter rebuilding times, and restoration of benefits to resource users). Analyses of changes in trade-offs among management outcomes that result from enhanced data collection can also be investigated (i.e., value of information analyses). Where possible, a zero fishing mortality and status quo scenario should be completed for each hypothesis under consideration to serve as benchmarks for comparison with alternative strategies. It is not possible to guarantee that management procedures will perform as intended, but simulation analyses help to eliminate procedures that perform poorly and identify those that may perform adequately in practice.

Recommendations:

- Rebuilding strategies should be evaluated relative to defined objectives and performance measures.

- Best practice for designing rebuilding strategies includes simulation-testing of management options, against a range of plausible hypotheses for uncertain stock and fishery dynamics.
- Simulation testing should include a zero fishing mortality and status quo scenario.

Taking into account environmental conditions

Section 6.2(1) of the *Fisheries Act* includes the requirement to take into account environmental conditions affecting the stock when developing rebuilding plans. Environmental conditions can impact stock rebuilding by affecting dynamics and productivity by influencing attributes such as life history characteristics, spatial distribution, or predator-prey dynamics. Environmental variables include physical (climatic) and ecological (e.g., species interactions, habitat) drivers that may vary over short or long time scales. DFO continues to work towards an ecosystem approach to fisheries management (EAFM). National and regional working groups are developing a framework for incorporating environmental variables into science advice. It is expected that science guidelines for accounting for environmental variables will be revised as EAFM work progresses.

In the case of stocks requiring rebuilding plans, fishing may have initiated or contributed to stock decline to a state where environmental factors are maintaining the stock in a compromised state even if fishing pressure is reduced or removed. Alternatively, environmental drivers may create conditions where productivity is reduced and therefore harvest levels considered to be sustainable in the past are no longer so. Attributing stock depletion to environmental conditions should not be taken as an indication that fishing has little or no impact, or that there is no need to reduce or remove fishing mortality. Evidence must be provided to evaluate the impact of fishing on the rebuilding likelihood of the stock over the short, medium, and long term. In some cases, even in the absence of fishing mortality, stocks may be very unlikely to return to former levels due to unfavourable environmental factors. Where possible, projections at current and hypothesized future environmental conditions should be provided to evaluate the likely effects on rebuilding performance. Where projections are not possible, a description of how current and hypothesized future environmental conditions may impact rebuilding should be provided.

In some cases, rebuilding prospects may be poor even in the absence of fishing mortality. If this is the case, it should be explicitly described (quantitatively where possible). Suggested text with examples are provided below. However, actual wording must be specific to the context.

- Rebuilding appears to be unlikely under current ecosystem conditions, even with no fishing mortality (e.g., F=0 in projections).
- Rebuilding appears to be unlikely at current [insert appropriate factor] (e.g., predator abundance), even with no fishing (e.g., projections with zero fishing mortality and strong evidence that the lack of recovery is due to predation).
- It is likely that the stock will continue to decline at current [insert appropriate factor(s)] (e.g., predator abundance, environmental conditions), and surplus production is not expected. Local extinction of the stock is possible (or likely), (e.g., evidence that the stock is experiencing a strong Allee effect).

Recommendations:

- Attribution of stock depletion to environmental factors should not be taken as an indication that fishing mortality has little or no effect without evidence that is the case.
- Where rebuilding prospects appear to be poor even without fishing mortality, this should be explicitly described.

- Where possible, projections at current and hypothesized future environmental conditions should be provided to evaluate the likelihood of rebuilding. Where projections are not possible, a description of how current and hypothesized future environmental conditions may impact rebuilding should be provided.

Allee Effects

Based on classical population-dynamics theory, per capita rates of population increase are postulated to be negatively density dependent, increasing as population abundance declines (Nicholson 1993). However, in some cases, the opposite relationship is observed, with population productivity decreasing as abundance declines below some threshold. This positive density-dependence is termed an Allee effect or depensation (Courchamp et al. 1999; Stephens and Sutherland 1999, Hutchings 2014). Allee effects can delay or prevent rebuilding from low abundance and increase the risk of extinction.

Prospects for rebuilding populations experiencing Allee effects are limited and these situations should be avoided with high probability. Where possible, the likelihood that productivity has decreased or is decreasing should be evaluated, especially if predator abundance is increasing or stock (i.e., prey) abundance is decreasing. Because it may not be possible to rebuild populations experiencing strong Allee effects, it is imperative to prevent population declines to levels where these effects are triggered. The LRP should be set above the Allee-effect threshold, the abundance where density dependence switches from negative to positive (Hutchings 2015). In situations where Allee effects are occurring, it is all the more important for fishing mortality to be reduced to promote rebuilding.

Predation can be an important cause of Allee effects (Gascoigne and Lipcius 2004). As prey abundance declines, the per capita predation mortality on prey can increase resulting in reduced productivity and a potential for local extinction of the prey. Predation can cause Allee effects as a result of low prey abundance or because of an increase in predator abundance. Predators may also shift to alternative prey when a particular prey species declines to very low levels. This can result in a predator pit where, in the event that abundance increases, this prey again becomes an attractive prey resource, driving the prey species back to very low abundance.

Recommendation:

- Prospects for rebuilding populations experiencing predation-driven Allee effects or predator pits are limited and these situations should be avoided with high probability. Where possible, the likelihood that productivity has decreased or is decreasing should be evaluated, especially if predator abundance is increasing or stock (i.e., prey) abundance is decreasing.

Non-stationary reference points

Stock assessments often include the assumption that demographic processes underlying the dynamics of populations are stationary over time (e.g., the rate of natural mortality, the nature of the stock-recruit relationship). However, it is increasingly clear that a number of such processes change through time, affecting productivity and dynamics, and in turn affecting many aspects of management and rebuilding plans such as the determination of reference points and the anticipated reaction of populations to management actions (Szuwalski and Hollowed 2016, Britten et al. 2017).

Consideration has been given to determining whether reference points might need to change with stock productivity, concluding that non-stationary reference points may be considered under certain scenarios. It may be appropriate to consider non-stationary reference points where there is high certainty that productivity change is not believed to be reversible in the short or medium term (DFO 2016). Science guidance is needed on the sustainable application of non-stationary reference points.

Fish habitat considerations

Section 6.2(5) of the *Fisheries Act* requires that "in the management of fisheries, if the Minister is of the opinion that the loss or degradation of the stock's fish habitat has contributed to the stock's decline, he or she shall take into account whether there are measures in place aimed at restoring that fish habitat". In section 2(1) of the *Fisheries Act*, fish habitat is defined as "water frequented by fish and any other areas on which fish depend directly or indirectly to carry out their life processes, including spawning grounds and nursery, rearing, food supply and migration areas".

For some stocks, habitat availability and suitability may play an important role in rebuilding, particularly for freshwater and diadromous species where various life stages are tightly linked to habitat. Rebuilding plans should incorporate anticipated population consequences of fish habitat restoration and enhancement when fish habitat is linked to stock declines or potential lack of rebuilding of a depleted stock. The Science Sector can play a role in evaluating the contribution of loss or degradation of fish habitat to stock decline and evaluating anticipated biological outcomes of rehabilitation measures. Assessing fish habitat is a complex challenge that requires input from other sectors and groups, including but not limited to Fish and Fish Habitat Protection Program, Fisheries Management, Species at Risk, and Oceans Programs. Where information is limited, the assessment of habitat loss or degradation (and potential restoration measures) may rely heavily on expert opinion. Further guidance is needed on how to provide science advice related to habitat to support rebuilding plans.

Recommendation:

- Provide advice on whether habitat loss or degradation has likely contributed to the stock's decline. If it is unlikely, if there is no evidence to suggest it, or if it is uncertain, include a statement to that effect.

Mixed-stock fisheries

The majority of fisheries worldwide are mixed-stock (multi-species). Harvesting productive stocks to maximize sustainable yield will likely result in overfishing of less productive stocks unless their vulnerability to the fishery is low. Conversely, implementing management measures aimed at allowing less productive stocks (i.e., weak stocks) to rebuild within recommended timelines may result in substantial forgone yield from more productive stocks.

The mixed-stock problem is recognized internationally (e.g., DAWR 2018). Some jurisdictions allow for longer rebuilding times for weak stocks in mixed-stock fisheries to accommodate some fishery benefits to other stocks. Lower rebuilding targets or higher risk tolerance for unfavourable stock outcomes may also be contemplated. However, specific guidelines on acceptable trade-offs between fishery benefits from healthy stocks and rebuilding times and/or risks for depleted weak stocks are lacking. Theoretical considerations and empirical evidence indicate that the potential for rebuilding following reductions in fishing mortality is negatively related to the extent and the duration of depletion (Hutchings 2015). Lengthening rebuilding times or lowering rebuilding targets for weak stocks, to allow some fishing on more productive stocks, may increase the risk of failing to rebuild for the weak stock. Tolerance to this risk needs to be established by Fisheries Management before defining acceptable and consistent standards for extended rebuilding times for weak stocks.

In some cases, it may be possible to implement management measures to mitigate harm in mixed fisheries by altering fishing selectivity to reduce capture of specific stocks (e.g., using spatial and temporal closures, including encounter protocols, or changes in fishing gear) or by employing mandatory live release where feasible. In all cases it is critical that these measures be demonstrated (via research and adequate monitoring) to be effective and to not create negative indirect effects (e.g., increase the mortality on other vulnerable stocks, post-release mortality).

Recommendations:

- Lengthening rebuilding times or lowering rebuilding targets for weak stocks in mixed-stock fisheries, to allow some fishing on more productive stocks, may increase the risk of failing to rebuild for the weak stock. These risks should be evaluated and clearly stated.
- Any management tools implemented to mitigate harm in mixed fisheries should be well documented and defensible based on the best science available.

Evaluation of rebuilding progress

Rebuilding is not a predictable process and a lack of rebuilding or not meeting objectives does not in itself represent a failure. Rather, failure can be characterized by the absence of process that allows adaptation of the plan in light of new data, altered understanding of stock and fishery dynamics, updated analyses, or revised objectives. It is expected that rebuilding prospects will in general evolve from initial expectations through the lifespan of the plan. The Science Sector has a role in helping to set realistic expectations of stock rebuilding by identifying those management actions unlikely to produce desired rebuilding outcomes over a range of possible stock conditions. The Science Sector also has a role in providing advice on adapting a rebuilding strategy based on the stock response over time.

Progress against rebuilding objectives should be evaluated periodically to determine if the rebuilding plan is on track, and in light of new information that may have been gathered. The Science Sector should advise on frequency of evaluation based on stock biology, level of depletion, the environmental conditions affecting the stock, the degree of uncertainty associated with projections, and the rate at which new knowledge is acquired. As a general guideline, rebuilding plan objectives may be re-evaluated at least every five years or at intervals defined by a multi-year assessment schedule for the stock. A review may be required more frequently than planned under exceptional circumstances such as unexpected observations, new understanding of the stock and fishery or divergence between realized and expected performance of management actions. The Science Sector should also provide advice on stock and fishery monitoring needed to evaluate performance. Reporting on progress should generally use the same methods as those used in the original development of the plan. Reporting on progress should include a review of performance relative to the rebuilding objectives and advice on adjustments if the rebuilding objectives are not being achieved.

Recommendations:

- Provide advice on frequency of evaluation and monitoring information that is needed to evaluate performance and link to an existing or recommended multi-year assessment cycle.

- Provide advice on adapting the rebuilding strategy based on stock response over time, new data or information, new understanding of stock and fishery dynamics, revised objectives, and departures from expected performance.

Sources of Uncertainty

This science advisory meeting is the first formal advisory process to support the development of national operational guidelines for the Science Sector in support of the broader Departmental implementation of the Fish Stocks provisions. Additional science advisory processes to support implementation of the Fish Stocks provisions are anticipated.

These recommendations were developed to support current policies and proposed regulations. Therefore, the recommendations presented here may need to be revised based on updated science advice, policies, and regulations and as domestic experience and international practice evolve.

CONCLUSION

The Science Sector provides advice required for key elements of a rebuilding strategy used to inform rebuilding plans. The advice presented here will be used to develop science guidelines that support development of rebuilding plans that align with legislative obligations and policy intent. The recommendations are intended to include sufficient flexibility for case-specific details to be applied.

This advice also identifies topics where more science research and guidance are required to advance guidelines.

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This Science Advisory Report is from the January 14-16, 2020 National Peer Review meeting on Science guidelines to support development of rebuilding plans for Canadian fish stocks. 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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