Fisheries and Oceans Canada
Pêches et Océans Canada

Ecosystems and Oceans Science
Sciences des écosystèmes et des océans

National Capital Region

Canadian Science Advisory Secretariat
Science Advisory Report 2022/052

SCIENCE ADVICE TO THE FISH AND FISH HABITAT PROTECTION PROGRAM ON ESTIMATING IMPACTS AND OFFSETS FOR DEATH OF FISH

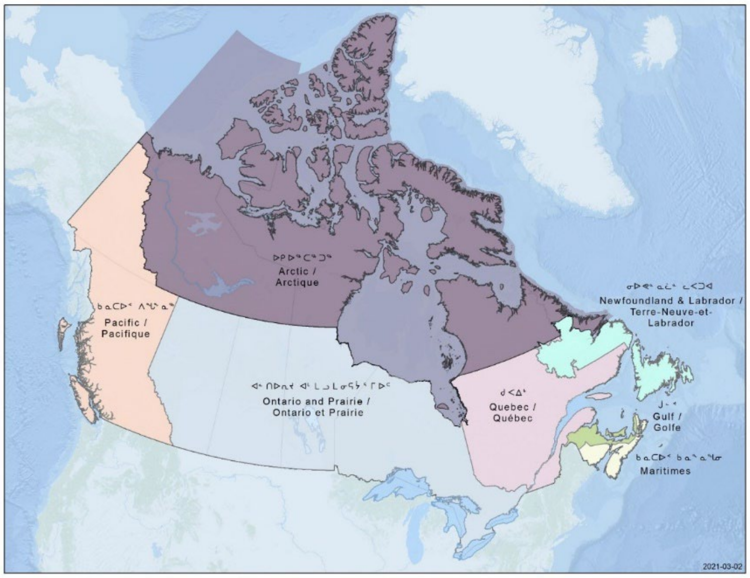

Figure 1. Department of Fisheries and Oceans' (DFO) seven administrative regions.

Context:

Works, undertakings or activities (WUAs) that are likely to cause the death of fish would contravene the Fisheries Act, as well as the Species at Risk Act (SARA) if there is also death of aquatic species at risk, unless otherwise authorized. When considering whether to issue an authorization under the Fisheries Act, the Department applies a risk-based approach to determine the likelihood and severity of potential impacts to fish and fish habitat that could result from the carrying on of a work, undertaking or activity (WUA). In doing so, the Department is guided by various principles, such as the precautionary approach and the ecosystem approach, and considers a number of criteria, including species likely to be affected, and the frequency, duration, magnitude, and extent of a WUA that can lead to the death of fish.

The Fish and Fish Habitat Protection Program (FFHPP) is seeking advice on potential consequences and how to quantify impacts from WUAs, other than fishing, that cause the death of fish and ways that death of fish associated with these WUAs can be offset. For offsetting, this includes advice on how to offset for WUAs that could result in the death of fish, information on this type of offsetting in domestic and international jurisdictions, and a summary of mechanisms and effectiveness of these practices should the information be available.

This Science Advisory Report is from the national advisory meeting April 12-16, 2021 on Science advice to the Fish and Fish Habitat Protection Program on estimating impacts and offsets for death of fish. Additional publications from this meeting will be posted on the [Fisheries and Oceans Canada (DFO) Science Advisory Schedule](#) as they become available.

SUMMARY

- This Science Advisory Report (SAR) summarizes a review of methods that can be used to quantify residual mortality (i.e. the death of fish by means other than fishing) resulting from a Work, Undertaking or Activity (WUA) for fish populations and communities and measures to offset this residual mortality.
- This advice has focused on decision making for the Fish and Fish Habitat Protection Program (FFHPP) related to fish mortality and productivity. Many of these methods can also be used in mortality situations where there are species at risk, however, the selection of methods and risk profile in these situations may be different.
- Population-level methods that evaluate the equivalency between the quantification of fish mortality resulting from a WUA, and productivity increases from any associated offsetting (including potential habitat offsets) were reviewed.
- When data exist, the 'total biomass lost' method is recommended for use as it best aligns with the 'productivity' considerations of the *Fisheries Act*. All methods have advantages and limitations, and the selection of an appropriate approach may be case dependent, based on considerations such as data availability, existing models, and the overall objective of the analysis. Consideration of jeopardy under the SARA may require the application of different methods.
- The calculation of equivalence should acknowledge, assess, and as fully as possible manage, all the sources of uncertainty including uncertainty about impact prediction, the effectiveness of offsetting, and future states of aquatic ecosystems.
- The potential time-lags and uncertainty related to the delivery and functionality of an offset, as well as uncertainty in the magnitude of harm and efficacy of proposed offsets, can be included within the calculations using time-lag and uncertainty compensation ratios. Compensation ratios in the literature generally range between 1:1.5 and 1:5.
- Mortality applied to a greater proportion of species in a community and/or an ecosystem context results in a higher likelihood that species in the network will exhibit a negative outcome. Ultimately, the outcome for any species depends on the direct and indirect effects in the network. A series of community-level methods is presented and these should be used in scenario testing when mortality is expected to impact multiple fish species.
- Simple community models suggest that the productivity of higher trophic-level species tend to be negatively affected by mortality acting at lower trophic levels. These higher trophic level species are often valued fisheries species.
- When assessing the effects of fish mortality on populations and communities the following factors should be considered: species' life-history, the size and dynamics of impacted populations, the community and ecosystem composition, the timing, duration, scale, magnitude and mechanism of mortality, and interactions with other mortality sources.
- The precautionary approach frameworks used to manage fisheries could be used to support risk-based decisions related to WUA-related fish mortality and associated offsets. The use of a common framework by fisheries and fish and fish habitat managers would allow for the leveraging of data and information across different decision-making approaches. Precautionary approach frameworks can be applied in data rich or data limited scenarios.
- A systematic review of offsetting options and methods for fish mortality events indicated that the current literature is limited on this topic but examples of offsets based on habitat

creation, habitat restoration and enhancement, and biological and chemical manipulation (including stocking) have been used in different circumstances.

- All offsetting methods reviewed have potential benefits and challenges with respect to their implementation and detailed advice on these methods exists elsewhere. With respect to fish mortality, habitat creation has mostly been studied for Salmonid species and generally has been focused on spawning/egg, larval and juvenile life stages.
- Habitat restoration and enhancement are the most commonly used offsets in cases of fish mortality. Restoration measures often provide benefits to the entire fish community while enhancement measures may be more likely to provide species-specific benefits. Habitat enhancement and restoration provides the most benefits for early life stages.
- Stocking and nutrient addition have been used to offset for fish mortality in freshwater ecosystems. While there are inherent difficulties with both approaches, they can be used in specific circumstances. Stocking can be used when the fish mortality is direct and not linked to indirect sources. Nutrient enrichment can be an interim tool to offset nutrient deficits and increase overall ecosystem productivity.
- The reviewed literature indicates no matter what method was used, offsetting projects that had a pre-impact assessment and longer monitoring programs were associated with better assessment of the effectiveness of the offset. This suggests the importance of offset planning and monitoring programs, detailed advice for offsetting program design and monitoring exists.
- In general, the scale of the models and analysis presented in this advice is usually set at the population level, in applicable situations the scale of analysis can be at a sub-population or local level.

INTRODUCTION

Mortality is one of the most important parameters determining the dynamics and productivity of fish populations and fisheries. Reductions in population abundance have been shown to increase the vulnerability of populations to local extinction. This increased vulnerability applies to both selective perturbations, such as fishing for larger individuals, and non-selective perturbation, such as catastrophes. However, this does not mean that all species / populations are equally sensitive to mortality. Instead, population sensitivity to mortality is dependent on a number of traits such as life history and body size.

Natural factors that result in fish mortality include a suite of interactions with other organisms including disease, pathogens, parasites, and predators, or lack of prey. Environmental conditions, or changes in conditions, that exceed physiological tolerances can also result in mortality. Even when environmental conditions do not directly lead to mortality, they can have sub-lethal effects that reduce the capacity for fish to withstand other stressors (e.g., reduced swimming performance). Potential environmental conditions that stress or kill fish include temperature (low, high, or rapid changes), turbidity, hypoxia, and salinity. Changes in environmental conditions can be driven by weather events (e.g., cold fronts, heat waves, flooding, drought), winter ice cover, and harmful algal blooms. Natural mortality can also occur from stress associated with completing life processes (e.g., post-migration or post-spawning stress) and from old age. While these causes of mortality occur naturally, they can also be driven by anthropogenic activities.

While there are both natural and anthropogenic causes of mortality, many works, undertakings, or activities (WUAs) that take place in or near water have the potential to directly or indirectly increase fish mortality. Many WUAs impose pressures on aquatic ecosystems (see the DFO pathways of effects diagrams) that can directly result in fish mortality, or can negatively alter habitat/or the health of individual fish in ways that can indirectly lead to fish mortality. A survey of recent cases involving fish mortality managed by the Fish and Fish Habitat Protection Program (FFHPP) across multiple regions revealed that the frequency of mortality events can range broadly from discrete or isolated instances to occasional (either regularly or unpredictably), annual, seasonal, monthly, or continuous (daily). Mortality events affect multiple species in the fish community, have the potential to affect species at risk and few fish mortality cases have been offset to date.

The *Fisheries Act* prohibits the killing of fish other than by fishing:

> **s.34.4 (1)** No person shall carry on any work, undertaking or activity, other than fishing, that results in the death of fish.

The *Species at Risk Act* further prohibits the killing of individuals of listed species:

> **s.32 (1)** No person shall kill, harm, harass, capture or take an individual of a wildlife species that is listed as an extirpated species, an endangered species or a threatened species.

Further, for listed species, the *Species at Risk Act* requires that issuing a permit or authorizing an activity that affects a listed species is only possible if the activity will not jeopardize the survival or recovery of the species (para.73(3)(c)).

The successful protection and conservation of fish and fish habitat requires managing WUAs that affect fish mortality. To achieve this, FFHPP needs science advice on the available approaches to quantifying impacts from, and offsets for, fish mortality, the factors that determine the consequences of fish mortality, and the options for offsetting fish mortality. This document aims to provide information to support answers for the following questions:

1. What approaches can be used to quantify the impacts of WUA-related residual mortality, and associated offsetting requirements?
    a. What are the advantages and limitations of the different approaches?
2. What determines local fish population or community responses to WUA-related residual mortality?
    a. Does the effect on local fish populations or communities change with respect to when and how frequently fish are killed?
    b. What criteria should be considered when quantifying or describing impacts from WUA-related residual mortality?
3. What are the current domestic and international practices for offsetting the effects of WUA-related residual mortality?
    a. What are the options for offsetting WUA-related residual mortality?
    b. What is the effectiveness of the available offsetting options?
    c. What are the rationales for selecting certain offsetting options?

The science advice provided in this document assumes that the avoidance and mitigation steps of the mitigation hierarchy (see DFO 2019a) have been applied and that it is the residual mortality that must be managed. While the expectation is that the information provided will most often be used during the *Fisheries Act* authorization process, some of the material covered will be relevant to managing accidents and monitoring and evaluating the effectiveness of offsets for fish mortality impacts. Both direct mortality (i.e., caused by the WUA and can happen immediately or following a delay) and indirect mortality (i.e., the WUA pre-disposes the fish to another mortality source such as increased predation) can be part of the residual mortality to be managed.

ANALYSIS

Quantifying losses and gains

Fish mortality that results from WUAs typically impact multiple species and life-stages simultaneously. Therefore, the death of any individual fish (e.g., a larva) may not be equivalent to the death of another (e.g., a reproductive adult). An additional complication is that the species and life-stages produced through an offset for the fish mortality may not be the same as those impacted, i.e., an “out-of-kind” offset. It is therefore necessary to quantify the losses from the mortality event in units that value the affected life-stages appropriately and allow for a direct comparison to the implemented offset. A variety of metrics have been used to quantify fish mortality events. These metrics attempt to provide a “common currency” that equates losses across species and life-stages and allows for direct comparison between the mortality and offset. The metrics differ in which population characteristic is used to equate the value of the losses to the gains from the proposed offset. The population characteristics, and therefore equivalency metric, selected should reflect specific management goals. Generally, when multiple species are affected, the metrics are applied to individual species and summed. Various metrics are summarized with the benefits and limitations of each highlighted in Table 1. Direct comparison of the metrics can be made by examining how each values fish of different age-classes (Figure 1). The Count method values each age-class equally, and it is not an appropriate metric when different age classes are exposed to mortality. Biomass and Equivalent Ages are weighted heavily towards older age-classes and likely undervalue younger fish. Reproductive Potential and Production Forgone value middle age-classes most heavily and potentially undervalue older age-classes where there is the greatest loss of standing biomass. Total Biomass Lost also values older age-classes the most but applies significantly more value to younger age-classes than Biomass or Equivalent Ages. Total Biomass Lost is the preferred metric for equivalency as it provides the most complete estimate of loss to an ecosystem and values individual age-classes most appropriately.

Inherent in the calculation and application of an offsetting plan is uncertainty. Uncertainty exists in both the initial measurement of the extent of harm to the environment, as well as in the measurement / calculation of equivalency metrics. Additionally, uncertainty exists in the efficacy of the proposed offset. Time delays in the delivery and functionality of the offset can also result in an inequality between harm and offset. These uncertainties must be accounted for in equivalency calculations and in setting the scale and type of offset that is required to achieve equivalency for fish losses.

Time delays represent delays in the implementation of offset measures and (or) when it takes time for an offset to become fully functional and effective. These time delays can be incorporated with proper accounting of the impact and offset schedules for a particular project. Time delays require a choice of a time horizon, representing the length of time the effects of the impact and offset will be measured, and application of discounting which weights past and future losses such that they are comparable. Time-lags are accounted for by calculating the time-lag compensation ratio, CR_{tl}, the multiplier (increase in size of the offset) needed to account for the time-lag such that the value of the impact and offset are equal across the time horizon.

Uncertainties are also often accounted for with compensation ratios, CR_u; however, they are less straight forward to estimate. Monte Carlo simulations can be used to estimate CR_u. This requires knowledge of the expected mean value of the magnitude of the impact and proposed offset and their uncertainties (variances). The ratio of these distributions generates a frequency distribution of potential compensation ratios. An equivalency threshold is selected representing a percentile of this distribution. The equivalency threshold represents the risk that the offset will not adequately compensate for potential impacts. An equivalency threshold closer to 1 allows for less risk but requires a greater compensation ratio.

Full accounting of the offsetting of fish mortality requires the choice and calculation of equivalency metric (to get the equivalency value), determination of the impact and offset schedule over the appropriate time horizon, quantification of the time-lag multiplier, CR_{tl}, and finally selection of the uncertainty multiplier, CR_u, to account for uncertainties. The size of the required offset is then calculated as:

$$Offset\ size = Equivalency\ Value \times CR_{tl} \times CR_u. \qquad (1).$$

Table 1. Pros and cons of various common currency metrics for quantifying fish mortality.

Metric	**Pros**	**Cons**
Counts	• Simple • Equivalency: number of fish	• Does not account for ‘value’ of different life stages • Does not account for future loss of production
Biomass	• Simple • Related to production • Equivalency: standing stock	• Does not account for future loss of production • Difficult to relate to out-of-kind offset
Equivalent Ages	• Equate losses of different age-classes • Can be measured as counts or biomass • Easily compared to stocking offset • Equivalency: age structure	• Does not credit proponent with future production when fish age > age-of-equivalence • Difficult to compare to a habitat creation offset
Reproductive Potential	• Can be converted to equivalent age-1 (EA-1) • Equivalency: egg production	• Can be difficult to measure offset as egg production • Requires fecundity values • Does not credit proponent with future production when fish age > age-of-equivalence

Metric	Pros	Cons
		• Difficult to compare to a habitat creation offset
Production Forgone	• Can be compared to habitat or stocking offset • Credits proponent with future production of offset • Equivalency: lifetime biomass production	• Does not account for direct loss of biomass from mortality • Does not account for lost reproductive production
Habitat Productivity Index	• Requires little species-specific life-history data • Equivalency: annual biomass production	• Production to Biomass (P/B) often not known and may require use of an allometric estimator • May not provide accurate species-specific estimates
Total biomass lost	• Accounts for direct loss in biomass and future production forgone • Equivalency: Standing stock and lifetime biomass production (current and future production)	• Does not account for lost reproductive production
Population models	• Can be used to estimate long-term impacts of harm • Models exist for many species	• Requires detailed species-specific life-history data • Requires estimates of harm as rates • More difficult and time-consuming to develop

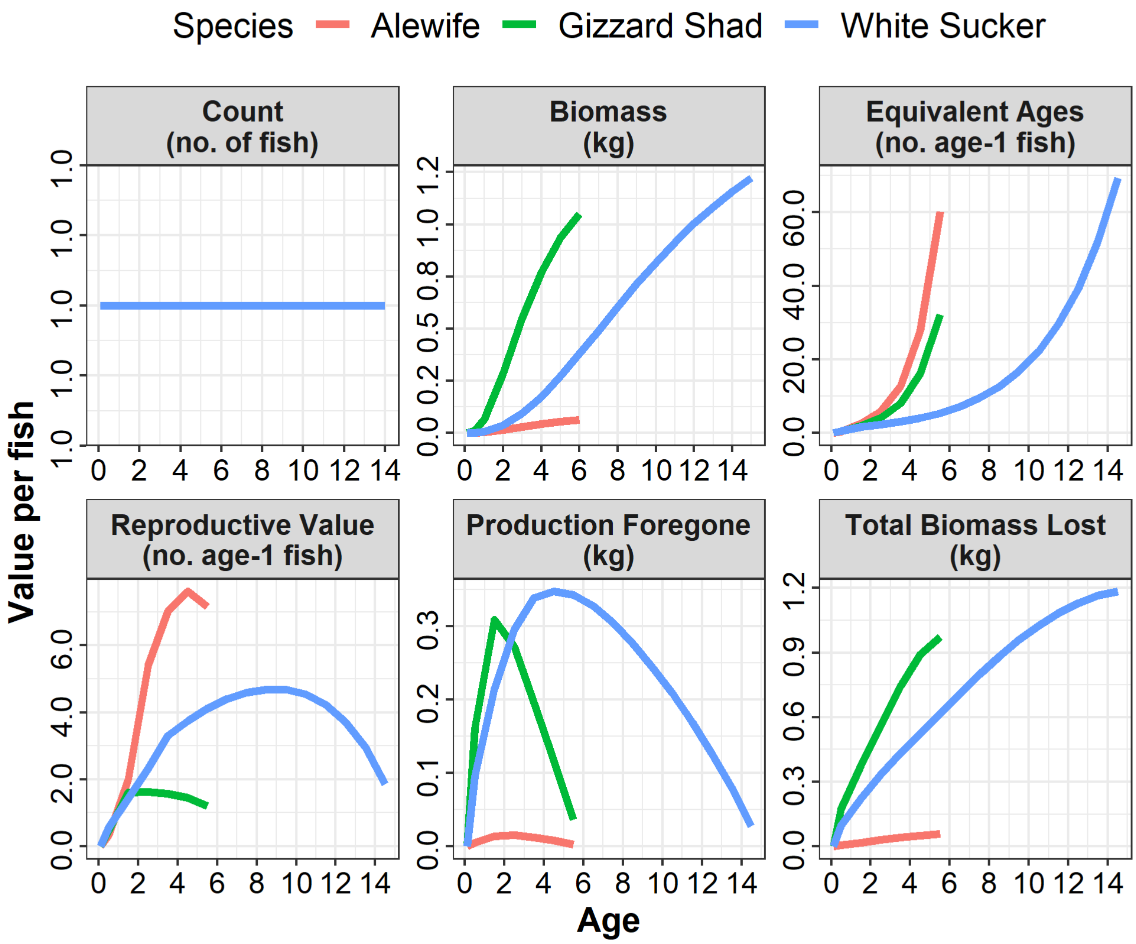

Figure 2. The amount an individual fish of each age-class contributes to the total estimate from the equivalency metric for all species in the hypothetical impingement and entrainment example for Alewife (Alosa pseudoharengus), Gizzard Shad (Dorosoma cepedianum) and White Sucker (Catostomus commersonii). Representative of how the metrics value an individual of each age-class. Units differ among figure panels and are displayed in brackets in the strip text.

Assessing community impacts

Projections of impacts of human activities on populations can often be incomplete, as harm applied to a single species can affect whole communities, sometimes with counter-intuitive results due to indirect effects (i.e., where a species has an effect on another species through an intermediary) and feedback loops (i.e., where outputs of community change are routed back on system components as causal inputs). Understanding community-level responses to fish mortality and incorporating them into decisions is a challenge for freshwater fish habitat science and management.

Community models are an essential tool to gain understanding of the impacts of fish mortality at the community level. To advance knowledge on the use of community models to applied issues involving death of fish, a number of popular modelling techniques are reviewed and their strengths and limitations are discussed. A brief summary of the reviewed models can be found in Table 2. It is important to consider that all models are abstractions of ecosystems and that different models are going to have different suitability in their application to different problems. For instance, data availability and the difficulty of implementation are major considerations when choosing the most appropriate community models to apply. Increasing familiarity with some common modelling approaches may help determine to determine the scientific information they can provide and therefore, which are most useful to inform a specific fish mortality issue.

To illustrate how one might approach investigating WUA-related fish mortality at a community level, a Qualitative Network Model (QNM) was applied to a number of simple communities that differ in strength and pattern of their linkages to seek general principles to inform decision making. The simplicity of QNM's makes them a useful tool for risk assessment and scenario testing even in data-limited cases, which is an important consideration and the typical situation for many freshwater fish applications.

The results generally showed that as community networks become larger and more complicated, it becomes more difficult to predict the outcome from harm. The effects of mortality became more uncertain when omnivores (species that feed at multiple trophic levels) were included in the community. Harm applied to a greater proportion of the community increases the chance of negative outcomes for each individual species in the network (Figure 2). Finally, top predators in a network tend to be negatively impacted when harm is applied to any lower trophic species in the community.

Table 2. A comparison of several community models which could be useful for examining WUA-related fish mortality scenarios.

Modelling Method	**Description**	**Data Requirement**	**Main Indicator(s)**	**Difficulty of Application**	**Utility of Results**
Qualitative Network Model	● A network of variables and interactions where the strength of interactions is simulated to generate qualitative predictions on the direction of response	● Direction and sign of interactions between variables	● The probability of increase and decrease for a variable or population	● Easy, require some basic programming skills ● R package *QPress*	● Useful for scenario testing and pointing out which interactions in the system has the strongest influence
Bayesian Belief Network	● A network of variables and influence pathways where the pathways are parameterized using conditional probabilities	● Possible range of values for each variable ● Influence pathways between variables expressed in terms of conditional probabilities	● The probability of each outcome state for a response variable	● Easy, require some basic programming skills ● R package *bnlearn* ● Various commercial software (e.g., *Netica*)	● Risk assessment for management decisions
Size Spectra Model	● The size spectrum represents the abundance or biomass of organisms as a function of their size	● Biomass (or abundance) and body size (e.g., weight) for all species in a food web	● The slope and (or) elevation of the size spectrum	● Require analytical and programming skills	● Diagnostic tool
Dynamic Multispecies Size Spectrum Models (e.g., Mizer)	● A dynamic size spectrum ecological model of an entire aquatic community	● Basic estimates of size, reproduction, and feeding preferences	● Biomass of species or functional groups	● Requires programming skills R package *mizer*	● Prediction of potential outcomes from alternative scenarios
Minimum Realistic Models (e.g., MSVPA)	● Models which focus on a selected group of species which are likely to have important interactions with the species of interest	● Time series data of biomass estimates, fishery catches ● Age-size composition data	● Biomass estimates with confidence intervals	● Moderate to difficult, lacks general framework and model needs to be tailored to answer specific questions	● Provide tactical fisheries management advice (e.g., total allowable catch)

Modelling Method	Description	Data Requirement	Main Indicator(s)	Difficulty of Application	Utility of Results
	● Has a focus on parameter and uncertainty estimation				
Whole Ecosystem Models (e.g., Ecopath with Ecosim; Linear Inverse Modelling (LIM); ATLANTIS)	● Models that attempt to consider all trophic levels in the ecosystem ● Predator-prey interactions often modelled using Lotka-Volterra equations	● Time series data of biomass estimates, life-history parameters, stock-recruitment relationships, total mortality, consumption, diet composition, fishery catches	● Stock and catch estimates under various scenarios	● Extremely difficult if trying to create from scratch ● Moderate if using premade software with support (e.g., Ecopath with Ecosim)	● Stock assessment ● Scenario investigation ● Theory development
Individual-Based Models (e.g., OSMOSE)	● Models that simulate the behaviour of each individual in a species	● Life-history parameters (e.g., growth, survival, reproduction, migration, etc.) for each species ● Behavioural rules for agent interactions ● Spatial data of system to be modelled and data of species distribution within the system	● A variety of ecological indicators (e.g., size structure, biomass, diversity indices) could be calculated by aggregating the data at different levels	● Difficult, requires advance programming skills ● General platforms (e.g., *NetLogo*, *MASON*) ● R package *OSMOSE*	● Implications for spatial management ● Analysis of emergent properties (e.g., stock-recruitment relationship, predator selectivity, etc.)
Bioenergetic Multispecies Models	● Models which use energy as a common currency to describe species biomass and how it is transferred between those species via differential equations	● Time series data of biomass, mortality, fishery catches ● Life-history and allometric parameters ● Diet information	● Biomass of populations	● Difficult, requires advance programming skills ● Lack premade packages	● Scenario testing

Modelling Method	**Description**	**Data Requirement**	**Main Indicator(s)**	**Difficulty of Application**	**Utility of Results**
Structural Equation Models (SE Ms)	● SEM is an approach that uses observed correlations in order to evaluate complex casual relationships. It is described as an extension of path analysis	● SEM is suited to large scale observational community or population data sets.	● SEM is typically used to test and compare *a priori* hypothesized models. Also used in exploratory analysis	● A number of software options (e.g., LISREL) and R packages available (e.g., OpenMx and lavaan)	● Useful to determine direct and indirect pathways in the structure that link ecosystem components ● incorporate "latent " variables

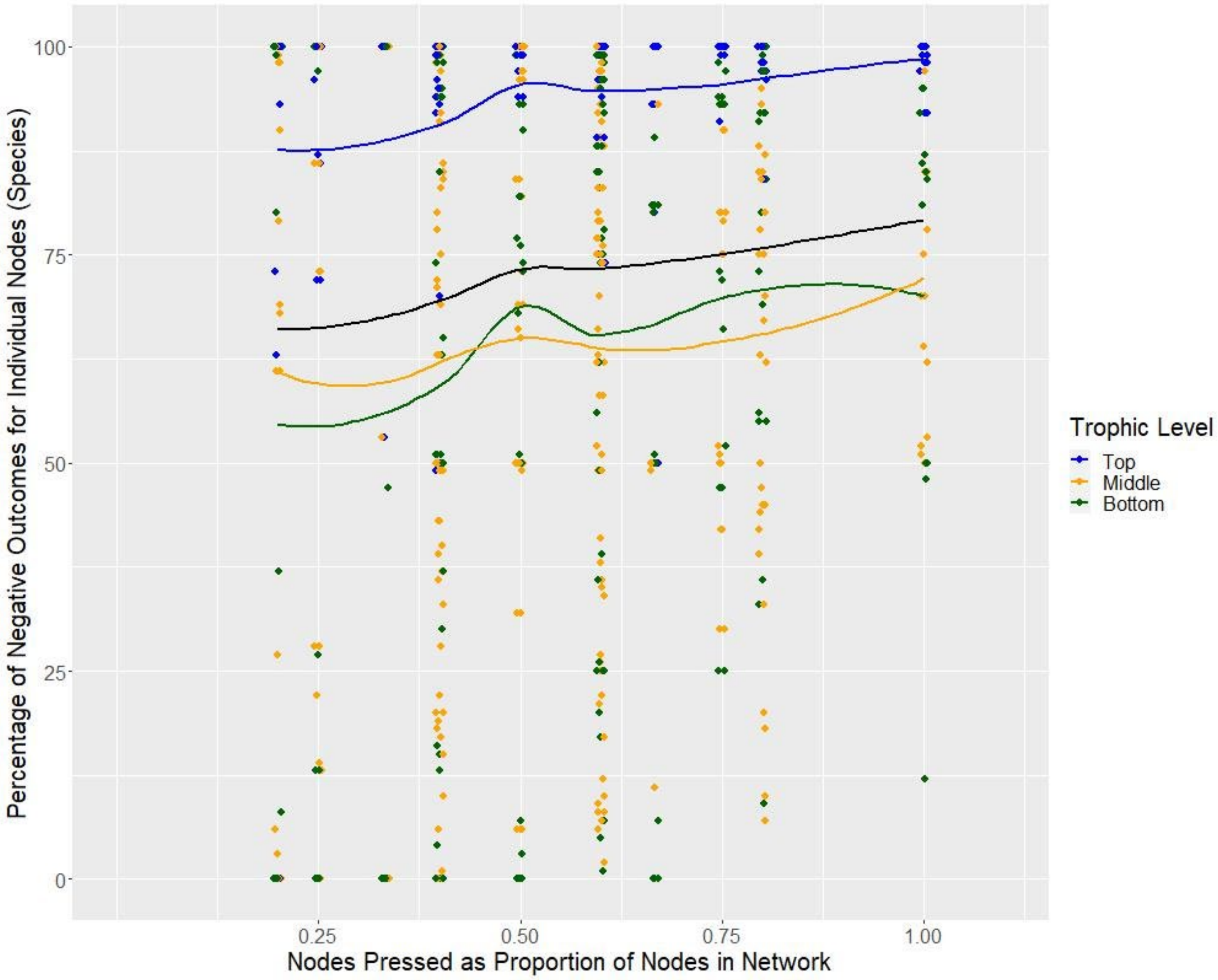

Figure 3. The percentage of negative outcomes in response to perturbations as a function of the proportion of nodes perturbed. Each point represents the proportion of negative outcomes recorded for an individual node within a particular network across 10,000 simulations. The results are divided into three groups depending on the trophic level of the response node: Top (blue), Middle (orange) and Bottom (green). The three coloured lines are loess smoothed curves corresponding to their trophic level while the black line is the curve for all data. Jittering on the x-axis was added to reduce data overlay.

Consequences of fish mortality and considerations for decisions related to the death of fish

The response of populations or ecosystems to fish mortality is dependent on a range of biological and ecological conditions. Consideration of the factors outlined below would inform decisions related to authorizing the death of fish under the *Fisheries Act* and in the application of a risk-based approach to implementing the fish and fish habitat protection provisions (DFO 2019b). These factors may also contribute to considerations concerning the effectiveness of offsetting plans, as the timing and patterns of response to fish mortality will influence the way offsetting measures support population and ecosystem recovery.

Factors to consider during decisions related to the authorization of the death of fish under the *Fisheries Act* include:

The amount of fish mortality, with greater amounts of mortality likely to have more negative impacts on populations and ecosystems (see Quantifying losses and gains, above). Importantly, some mechanisms of mortality may make the quantification of mortality challenging and increase the uncertainty related to the impacts on populations and ecosystems.

The size and trajectory of fish populations, with smaller populations, and those in decline, likely to be more negatively impacted by additional mortality

The life history of fish populations, with long-lived species typically being more impacted by mortality on adults, while short-lived species are typically more impacted by mortality on early life stages.

The duration and timing of mortality, with the susceptibility to, and impact of, mortality differing depending on fish life history and changes in behaviour across the daily or annual cycle. In addition, populations will be more sensitive to mortality if it occurs after density-dependent life-history events, rather than before, although the timing of density-dependent life history events is not known for many species.

Interactions with other sources of mortality, with the cumulative effects of multiple stressors sometimes leading to total mortality that is greater than the sum of the individual mortality effects (i.e., ‘synergistic’ stressor interactions).

Ecosystem impacts, with mortality acting on multiple species likely to lead to more severe ecosystem impacts than single species mortality

The management objectives including the social acceptability of fish mortality, and the impacts of fish mortality on fisheries, species at risk, and on the management goals of other rights holders and authorities.

Fish mortality has the potential to cause declines in fish populations and harm to ecosystems, if the amount of mortality or the sensitivity of the population or ecosystem are underestimated. Such harm can lead to a variety of negative outcomes including negative impacts to fisheries, impaired ecosystem function and resilience, and a loss of ecosystem services.

A precautionary, risk-based approach to management could help in understanding the likelihood of population collapse and ecosystem harm resulting from additional (WUA related) mortality. Such an approach could be adapted from tools used to manage fish harvest. Frameworks for managing harvest mortality are well developed and in many cases are also internationally standardized, which could provide a strong scientific and policy basis for the management of WUA-related mortality by DFO. For example, an adaptation of the International Council for Exploration of Seas (ICES) Precautionary Approach to Fisheries Management (ICES 1998, 2002) could be used to help inform decisions related to WUA-related mortality (Figure 3).

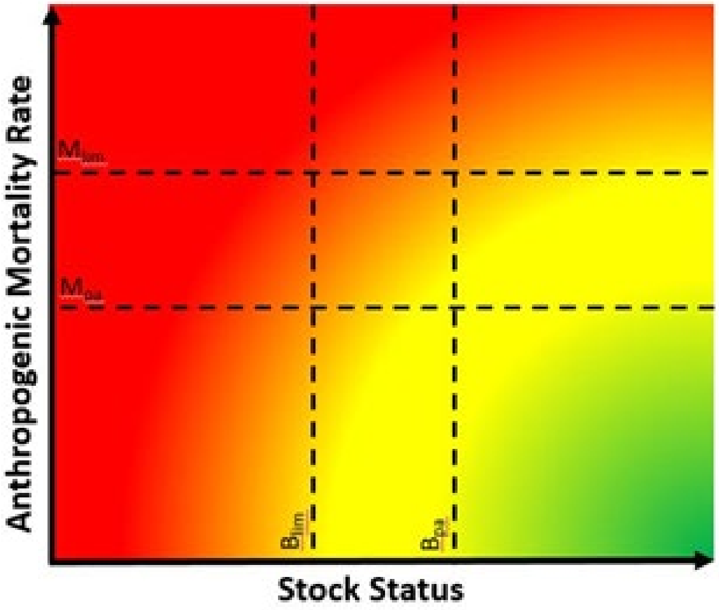

Figure 4. An adaptation of the ICES precautionary approach for supporting decision-making about WUA-related residual mortality showing the four key reference points B_{lim}*, the limit spawning population biomass;* B_{pa}*, the precautionary spawning population biomass;* M_{lim}*, the limit mortality level; and* M_{pa}*, the precautionary mortality level. Background colouration of the figure shows the relative risk of population decline and ecosystem harm, with red indicating a greater risk and green indicating a lower risk.*

Briefly, the framework is defined by the location of four reference values (B_{lim}, the limit spawning population biomass; B_{pa}, the precautionary spawning population biomass; M_{lim}, the limit mortality level; and M_{pa}, the precautionary mortality level), along two primary axes with the total instantaneous rate of anthropogenic mortality including fishing mortality *(F)* and anthropogenic mortality (*A*) on the vertical axis, and the biomass (status) of the population on the horizontal axis.

Conceptually, the B_{lim} and M_{lim} values represent the levels of degradation of the population, and the rate of mortality, that if exceeded, would have a high likelihood of resulting in population decline and ecosystem harm. These values are therefore set based on the population dynamics of the species. The precautionary values (B_{pa} and M_{pa}) represent thresholds for mortality and the status of the population that would ensure a high likelihood of maintaining the health of the population, after accounting for uncertainty in the estimation of the true mortality rate and population status. When uncertainty related to the true population status, or the amount and impact of mortality is high, the precautionary limits should be set further from B_{lim} and M_{lim}. Conversely, when uncertainty is lower, precautionary limits may be set closer to B_{lim} and M_{lim}.

In the context of use as a WUA-related mortality decision support tool, this framework would next require estimates of the stock status and total instantaneous rate of anthropogenic mortality with and without the inclusion of WUA-related residual mortality and proposed offsets. In cases where WUA cause a one-time mortality event, the initial location of the population on the framework would be shifted to the left, as the mortality event will degrade the stock status. Where WUA result in ongoing mortality to a population, WUA will cause both a degradation in the stock status and an increase in the total anthropogenic mortality rate, indicated by a shift to the upper-left space of the framework. Offsets would typically move the population to the right of the framework, by improving the status of the population without impacting the mortality rate.

The estimated position of the population would then be compared to the background colouration of the framework, to determine the level of risk for serious harm to the population (red = high risk of population collapse and ecosystem harm, green = low risk of population collapse and ecosystem harm).

Determining the size, dynamics and impacts of mortality on a population depends on defining the scope of the population under consideration. In many aquatic systems, especially larger water bodies (e.g., the Laurentian Great Lakes), fish have a patchy distribution associated with the heterogenous distribution of habitat features. Depending on their size, groups of individuals (of the same species) that are spatially separated from other groups may be described as a local population (or ‘sub population’) within a larger meta-population. However, there are no clear scientific criteria by which to define a ‘local population’ for considering the impacts of mortality. Instead, determining the scope of the population for assessing the impacts of fish mortality should depend on the goals of management. For example, if the goal of management is to maintain the presence and abundance of a species within each bay of a large lake, then the impacts should be considered relative to the size and trajectory of the population in the impacted bay. In addition, while localized mortality may be relatively less impactful when management goals are defined at larger spatial scales, it is important to understand that the number of stressors acting on larger populations is likely to be greater. As a result, it is more important to consider cumulative effects, and the impacts of interactions between different mortality sources, when populations are defined with large spatial scales.

Offsetting mortality

Scope of the review and potential limitations

A systematic review and meta-analysis were used to describe the current offsetting practices for fish mortality dividing the approaches into three main categories: habitat creation, habitat restoration, and biological and chemical manipulation. The scope of the assessment covers greater than 200,000 parsed sites and three scientific databases. Advice is based on 98 extracted documents (30 with usable data) validated through a critical appraisal based on Before-After-Control-Impact (BACI) study design, assessment bias, and temporal and spatial scales. Studies were skewed towards salmonid species (~66%) and density was the most common assessment metric (~50%). Approximately 25% of the studies had less than three offset sites that could be considered ‘treatment’ replicates that could be compared to reference sites. Studies covering offsets for whole communities had a low evidence base (n = 6) and offsets for small-bodied fish species were rare (n = 1). Structural enrichment through placement of large woody debris, logjam, boulder weir, and substrate tend to have a large number of offset ‘treatments’ but were represented by fewer studies compared to dam removals, stocking, and habitat creation, which by their very nature is hard to replicate in an experimental sense.

Habitat creation

Habitat creation refers to the practice of creating entirely new habitat to offset fish mortality by increasing productivity, abundance, density, and fish survival in the newly created habitat while simultaneously providing ecosystem wide benefits. Assessed projects applying created habitat to offset fish mortality used off-channel habitat construction to provide habitat for essential life-history components, mostly for salmonid species. Off-channel habitat can take the form of side channels, sloughs, ponds, floodplains, and wetlands (Table 3). Habitat creation is often applied for salmonid species and provides long-term benefits at both a habitat and population level. Thus, habitat creation can be suitable to offset mortality events that happen on longer temporal scales or relate back to detrimental habitat effects in addition to residual mortality (e.g., larval mortality through flow reduction and sediment accumulation during spawning season).

Habitat restoration

Habitat enhancement and restoration for projects used to offset fish mortality can be divided into distinct categories based on objectives of those projects, which include structure and cover, connectivity, substrate, and riparian restoration. Adding structure and cover to existing aquatic ecosystems can take many forms, from creating riparian cover, constructing boulder weirs, adding pools and riffles, and introducing large woody debris. Adding structure and cover can be cost-efficient, especially in cases with smaller impacts or urbanized systems that do not offer the space for habitat creation; benefits are documented and supported by the current literature (Table 3). Restoration and enhancement measures can fall into all spatial and temporal categories. For instance, restored connectivity in most instances benefits a whole fish community over a relatively long period of time, while spawning gravel addition often targets a single salmonid species and deteriorates over time without maintenance.

Biological and Chemical Manipulation

Biological and chemical manipulation of habitats and ecosystems is commonly used to either enhance productivity of nutrient poor systems or to control nutrient inputs and eutrophication (e.g., algal blooms). It also refers to the practice of increasing fish abundance through stocking, (re)introduction, and transfer of fish. Biological and chemical manipulation cover a wide range of aspects ranging from the simple addition of physical specimens to influencing specific trophic levels or whole food webs through nutrients (Table 3).

Commonly used compensation ratios and benefit time

Compensation ratios comparing impact to offset varied across the three major types of offsets. Assessed projects involving habitat creation applied mean ratios of 1:5.7 for side channel creation and 1:5.4 for off channel pond and floodplain creation. Early benefits require at least 1 year post construction to manifest. Riparian restoration projects had a mean compensation ratio of 1:1.2. Structure and substrate addition commonly applied a ratio of 1:1.6 and 1:2.1. Increasing or re-establishing connectivity used a 1:4.6 ratio but was highly variable depending on the size of the connected or reconnected habitat. Restoration benefits were first detectable as early as within a few months but normally required 1 year post construction. There were no commonly applied ratios for nutrient manipulation and addition, while stocking commonly used ratios of 1:3.1. Stocking has been used as an effective replacement for lost or harmed fish, given a stable and unimpaired ecosystem and no significant bottlenecks. Stocking may not be considered as a viable offsetting technique for use with all populations given potential risks to wild populations. Hatchery fish tend to have lower survival rates than wild fish and are more vulnerable to harm and mortality sources (e.g., impingement). Stocking and enrichment effects have short to immediate timeframes for first benefits (3 months to 1 year) but require long term monitoring, management, and frequent adjustments to ensure benefits and to reduce negative impacts. Ratios for all three general offset categories coincide with commonly accepted uncertainty and time-lag related considerations.

Pre-impact assessment and monitoring in relation to offset success and unintended consequences

Pre-impact assessments and monitoring timeframes play a vital role in offsetting success. Results from the literature review suggest that monitoring time can be related to offsetting success. A minimum timeframe, including pre-assessment, of 4 years is linked to a significant increase in project success. Projects with pre-assessment studies also have higher success ratios compared to projects without a proper pre-impact assessment. Planning strategies for residual mortality offsets, like planning strategies for HADD-related offsets, should incorporate an assessment of potential unintended and adverse effects. The self-sustaining nature of habitat offsets also needs to be considered in the planning process. Most major offsets require maintenance to adhere to the in-perpetuity requirement of their benefits. Maintenance and long-term adaptive management are needed to compensate and adjust for adverse and unintended effects. Long-term monitoring will further reduce the potential bias of annual fluctuations and aid the decision-making process as well as help adjust offset benefits and targets (e.g., habitat amounts, stocking amounts).

Table 3. Types of offsets used in cases of fish mortality in aquatic ecosystems. Results and classifications are based on a literature review and meta-analysis.

Type	**Subtype**	**Measure**	**Associated benefits/ goals**
Habitat creation	Off channel habitat creation	Side channel creation Overwintering pond creation	Spawning habitat provision, rearing habitat provision, overwintering habitat
Habitat restoration and enhancement	Restoration	(Riparian) restoration, rehabilitation	Buffer zone creation, reduction of environmental impacts, food availability, habitat coupling
	Structure and Cover	Bank stabilization Riparian heterogeneity LWD & logjams Boulders & rock weirs Pools & riffles	In-stream habitat provision (shelter or refugia, food availability), flow regime, flow diversity
	Connectivity	Dam and barrier removal Fish passage enhancements Reconnection within floodplain	Lateral & longitudinal habitat connection, migration corridors, nutrient and sediment exchange and transport, flow regime
	Substrate	Channel dugouts Substrate addition Substrate removal	Spawning substrate provision, channel morphology changes, temperature refugia, climate refuges

Type	Subtype	Measure	Associated benefits/ goals
Bio and Chemical Manipulation	Stocking	Stocking (Re)Introduction Translocation	Direct addition of individuals and biomass, potential increase in productivity
	Nutrients	Nutrient enrichment	Productivity boost for biotic production, compensation for nutrient loss through lack of anadromous fish/ carcasses

Sources of Uncertainty

There are three main pieces of information about species and populations that are generally lacking to inform decision making about fish mortality: population abundance, population trajectory, and mortality rates. Population abundance and trajectory provide information about the current status of the population. Risk is elevated when populations have low abundance and (or) are exhibiting a declining trajectory. Mortality rates are challenging to measure in natural systems but are needed for many of the metrics to quantify equivalence of fish mortality and offsets. Pre-impact assessments can help to provide these important pieces of information but understanding population trajectory requires long-term data collection.

The described metrics for quantifying mortality losses provide an accounting of individual species losses that are then summed across the affected species to achieve an estimate of total losses from a WUA. While this provides an accounting of direct impacts, it does not consider the complexity of communities and ecosystems with the potential for indirect effects. This suggests the need for an ecosystem approach to managing fish mortality. The described community and ecosystem modelling approaches can assist with explorations of these potential indirect effects, but there is no clear direction on how to account for these indirect effects when estimating mortality losses.

Non-stationarity in environmental conditions (e.g., because of climate change) can impact the consequences of mortality for fish populations, and the performance of offsets. Management uncertainty resulting from environmental non-stationarity is caused by (i) uncertainty in estimating the future environmental conditions themselves, and (ii) uncertainty in the relationships between offset performance, population consequences of mortality, and future environmental conditions.

A variety of anthropogenic and natural stressors can impact fish populations in a way that interacts with fish mortality. Stressors such as fisheries, other WUA, extreme environmental conditions, invasive species, or pollutants can co-occur with WUA-related residual mortality and may be either chronic or acute in nature. Importantly, mortality resulting from multiple stressors can combine to have effects that are different from the sum of the individual mortality effects. Theory predicts that factors such as the mechanism of action of the stressors, the ecological context, and the form of density-dependence acting within a population, can all impact the total mortality resulting from multiple stressors. However, there is currently a poor ability to predict the impacts of multiple stressors on mortality in most natural systems. Multiple stressors and cumulative effects will add uncertainty to the management of fish mortality.

CONCLUSION AND ADVICE

Most of the examples provided in this advice focused on freshwater systems but the methods should be transferrable to marine systems as well.

There are various metrics proposed for the quantification of fish mortality that provide equivalency for different life-history characteristics between the impact of fish mortality and any potential offset. Maintaining standing stock levels and ensuring future production are most consistent with the conservation and protection objective of the *Fisheries Act* and the FFHPP principle that offsets should balance adverse effects. Therefore, total biomass lost is recommended as the preferred equivalency metric under most circumstances.

Projections of fish mortality impacts on populations can be incomplete, as harm applied to a single species can impact whole communities and may cause counter-intuitive results due to indirect effects and feedback loops. Community-level impacts can be considered through a number of community modelling approaches. Even simple community models can improve understanding of how fish communities may respond to fish mortality events.

Decisions related to authorizing the death of fish should consider the biological and ecological factors that determine the sensitivity of populations to mortality. Even if offsets fully account for a given source of mortality, serious harm to fish populations can still occur when there are differences between the timing of mortality and the implementation of offsets, when populations are highly sensitive to decreases in abundance, or by changes in the ecosystem that interact with WUA-related residual mortality in a synergistic manner.

A precautionary fisheries management framework can be adapted as a risk management framework for decisions about fish mortality impacts and offsets. Given the similarity between the population consequences of fisheries mortality and other anthropogenic sources of mortality, and the fisheries protection objectives of the *Fisheries Act* and the Fish and Fish Habitat Protection Program, the use of a common framework by fisheries and habitat managers would allow for the leveraging of data and information across different decision-making contexts.

The review of the literature on offsets for fish mortality demonstrated that habitat creation, habitat restoration and enhancement, and biochemical manipulation can all be feasible options for offsetting fish mortality given caveats and general monitoring timeframes. All three offsetting types can be potentially detrimental when an out-of-kind replacement or a species versus community effect takes place on a magnitude that disrupts or alters community structure and food web composition.

OTHER CONSIDERATIONS

Cumulative effects and multiple stressors can result in outcomes that differ from the sum of individual effects. Stressors can interact, and the total mortality resulting from multiple stressors can be affected by factors such as the mechanism of action, ecological context, and form of density-dependence. However, there is currently a poor ability to predict the impacts of multiple stressors on mortality in most natural systems. A recent CSAS process was conducted to provide science advice for assessing cumulative effects (See CSAS website for updates, meeting March 8-12, 2021), which should be a starting point for considering cumulative effects stressors in management decisions about the death of fish, though additional research and science advice will be needed to fully include the potential interactions of stressors and sources of mortality.

Most WUAs that involve fish mortality also have the potential to produce sub-lethal effects with implications for population status and resilience to other stressors (see DFO 2021). Despite this, sub-lethal effects were not be dealt with here. The occurrence of sub-lethal effects can lead to additional fish mortality or have consequences for population responses. Specific science advice is needed on the integration of sub-lethal effects into management decisions.

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SOURCES OF INFORMATION

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Koops, M.A., Dey, C.J., Fung, S., Theis, S., Tunney, T.D., and van der Lee, A.S. 2022. Estimating impacts and offsets for the death of fish. DFO Can. Sci. Advis. Sec. Res. Doc. 2022/080. v + 94 p.

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