# SCIENCE ADVICE ON THE EFFECTIVENESS OF SPAWNING HABITAT CREATION FOR SUBSTRATE SPAWNING TEMPERATE FISH

*Figure 1. Volunteers preparing to place substrate in Windebank Creek, Mission B.C. Photo credit: Joanne Neilson.*


*Figure 2. Gravel placement for Chinook salmon spawning in the Campbell River, 2018. Photo credit: Shannon Anderson (DFO)*

## Context:

*DFO's Fish and Fish Habitat Protection Program (FFHPP) is interested in science advice on the effectiveness of commonly applied fish habitat enhancement, restoration or creation practices (collectively termed habitat manipulations) to inform both regulatory decision making (e.g. offset negative impacts on fish and fish habitat; Figure 1), and funding decisions under partnership programs (e.g. providing funds to external groups for habitat manipulation projects; Figure 2). As a starting point, DFO Science used the findings of a systematic literature review focused specifically on rigorously evaluating existing evidence on the effectiveness of fish spawning habitat manipulations for a suite of biological end points. Two additional literature reviews assessing the effectiveness of habitat manipulations were also considered as part of the evidence base in this science advisory process.*

*The objectives of this science advisory process were to: 1) provide FFHPP with advice on whether commonly applied spawning substrate manipulation techniques are effective at offsetting the impacts of destroyed or degraded fish habitats for substrate spawners; 2) identify how to best collect information from spawning habitat restoration projects to evaluate their effectiveness; and, 3) outline whether there is guidance for habitat manipulation projects that could guide their review in terms of whether proposed projects are likely to provide effective spawning habitat for substrate spawning fish.*

*This science advisory process provided science advice on the effectiveness of specific spawning habitat manipulations in temperate zones. At the same time a systematic literature review was adapted for use within a science advisory process, and resulted in lessons learned for future processes that may wish to take this approach. This process focused specifically on spawning habitat manipulations, but the methods followed herein could be followed for other habitat types targeting other life stages as needed. The systematic literature review included marine search terms, however there was not a* *sufficient evidence base of marine substrate spawning habitat manipulations to provide definitive advice in marine systems.*

*This Science Advisory Report is from the January 22-24, 2019 Science advice to the Fisheries Protection Program on the effectiveness of spawning habitat creation for substrate spawning temperate fish. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.*

## SUMMARY


- Literature reviews and meta-analyses were conducted on the effectiveness of creation, restoration, and enhancement of fish spawning habitat (hereinafter referred to as manipulation of spawning habitat) in temperate zones. In the context of manipulating freshwater spawning habitat, the evidence suggests that these actions can: 1) attract substrate spawning fishes, 2) result in spawning, 3) result in egg survival, and 4) produce age-0 fish. Whether these manipulations and their results translate to population-level productivity improvements was not directly explored.
- The reviews considered marine spawning habitat manipulation, but because few targeted spawning habitat manipulations occurred in the marine environment, limited evidence was available for review. Future reviews could focus on evaluating the effectiveness of manipulations more common in marine habitats (e.g. nursery function).
- There were only a few groups of fish (e.g. salmonids) and some intervention types where the evidence base was sufficient to reach quantitative conclusions on effectiveness. There is greater uncertainty for other groups of fish. Nonetheless, if careful consideration is given to the habitat attributes and the biology and life history of the focal species, substrate spawning manipulation techniques that were reviewed may attract substrate spawning fishes, result in spawning, result in egg survival, and produce age-0 fish (Table 1).
- The success of manipulating spawning habitat for substrate spawning fish is dependent on physical attributes of the site, such as: hydrology, fluvial geomorphology, fetch, water level dynamics, shoreline energy characteristics, water quality, and accessibility, as well as biological attributes of the site, for example, if spawners are available.
- Changes to flow and water level are recognized as an important component of spawning habitat manipulation but were not included in this advice as they are the subject of a separate ongoing systematic literature review.
- There was recognition that there are thousands of spawning habitat manipulation projects conducted by governments of various levels, environmental non-governmental organizations (ENGOs), and industry that were not captured in this review because the effectiveness of these interventions was either not assessed, not assessed appropriately, or the data were not available in accessible formats.
- The magnitude of benefits differed between reviews and was dependent on the quality of studies included in the reviews, with higher quality studies (e.g., appropriate controls, replication, more rigorous planning, etc.) demonstrating a greater effectiveness of the habitat manipulation. The cause of this result is uncertain, however, the higher level of planning at all stages (i.e. from concept, to build, to monitoring) that likely accompanied more robustly designed monitoring programs may be a contributing factor to effectiveness.
- Monitoring is essential to understand the effectiveness of spawning habitat manipulations. The appropriate level or type of monitoring can be project dependent and more information is found in DFO (2012) (effectiveness monitoring Science Advisory Report), Smokorowski et al. (2015), and DFO (2019) (functional monitoring Science Advisory Report).
- Many monitoring programs provide low-value information despite the collection of large amounts of data, as was evidenced by the many number of studies excluded from the systematic review. Minimum evaluation criteria for monitoring programs are presented herein that would allow the data’s inclusion in systematic reviews and meta analyses, allowing a broader understanding of effectiveness of spawning habitat manipulations.

- To evaluate the contribution (beyond the effectiveness discussed above) of the spawning habitat manipulation projects to population-level productivity of fish, other information is required. For example, whether manipulating fish spawning habitat results in population-level effects depends in part on whether spawning habitat is a limiting factor to a population, amongst other factors, presented below.
- Spawning habitat manipulations often have impacts on ecosystem components (e.g., other fish species and life stages, habitat functions and physical attributes) beyond the targeted spawning habitats and species, and should thus be considered when determining the overall effectiveness of habitat manipulation.
- Given the understanding that there are significant amounts of information that were not included in the syntheses due to lack of accessibility, it is strongly recommended that a comprehensive system, based on the advice herein is established to provide standardized data collection, reporting, management and accessibility for further analysis of effectiveness.

# BACKGROUND

DFO's Fish and Fish Habitat Protection Program (FFHPP) requested science advice on the effectiveness of spawning habitat enhancement, restoration and creation (hereinafter referred to as manipulation) at offsetting impacts of destroyed and degraded fish habitats for substrate spawning fish in temperate systems. The purpose of this science advice is to help FFHPP in their overall understanding of the effectiveness of these habitat manipulations, and to provide information that is useful for decision making for both regulatory processes and the administration of habitat-oriented funding programs. For example, FFHPP may use this specific advice when evaluating effects of projects on fish and fish habitat and associated offsetting plans (both in terms of evaluating whether a proposed offset is likely to be effective, requesting information and when setting monitoring program requirements). FFHPP also funds partnership programs to remediate historical impacts of fish habitat degradation through restoration projects. While these programs have existing proposal evaluation criteria, science advice is needed to ensure that comprehensive evaluation criteria can be created and consistently applied across programs to identify the extent to which project proposals are scientifically defensible with respect to restoring spawning habitat for substrate spawning fish.

The objectives of this science advisory process were to: 1) provide advice on the effectiveness of commonly applied spawning substrate manipulation techniques at restoring or offsetting destroyed and degraded fish habitats and fish productivity losses in regions of varying productivity and across habitat types; 2) identify information that should be collected from spawning habitat manipulation projects that would allow for improved evaluation of their effectiveness, and; 3) provide guidance on how to evaluate offset and partnership proposals in terms of criteria for evaluating the likelihood of effectiveness of habitat manipulations to achieve the offset and restoration objectives. Note that the science advice produced from this science advisory process was not able to address the question of regions of varying productivity from Objective 1.

The science advisory process used three working papers. The first paper was a systematic literature review and meta-analysis that focused specifically on spawning habitat manipulations for substrate spawning fish, following methodology approved by the Collaboration for Environmental Evidence (CEE; Taylor et al. (2019)). The second report built on the data included in the systematic review but also included literature containing valuable information on the effectiveness of manipulating spawning habitat for substrate spawning that did not meet the robust statistical and experimental design requirements of the systematic review (Rytwinski et al. (2019)). The third review, Theis et al. (2019), took a different approach and assessed relationships between compliance with regulatory requirements and functional effectiveness of habitat offsetting projects in general. Participants of the science advisory process also discussed the benefits of using a systematic versus conventional forms of knowledge review and synthesis.

## ASSESSMENT OF THE EFFECTIVENESS OF MANIPULATION OF SPAWNING HABITAT FOR SUBSTRATE SPAWNING TEMPERATE FISH

The use of systematic literature reviews (see Glossary for more information on terminology and Appendix A for more resources on systematic reviews and associated methodology) to support evidence-based decision making in environmental management and conservation communities in Canada is a relatively new practice. Systematic reviews differ from traditional literature reviews in their level of reliability, transparency and repeatability, and help ensure that the best available evidence feeds decisions instead of risking a potentially biased selection of empirical evidence, or relying on the use of personal experience or input from peers to make decisions. When following the strict protocols produced by the CEE, a large amount of confidence can be placed in the summarization of quantitative information and the strength of evidence available for decision making. There are, however, limitations to systematic reviews in terms of sources of information that are not accessed, or studies that are excluded from the evidence base because results are not available, or excluded because the reported information does not hold up to the requirements of a systematic review.

Not all relevant and valuable information is available/accessible via the systematic literature gathering process (e.g., unpublished or proprietary monitoring reports). Because of this, even (rigorous) systematic reviews may rely on an incomplete evidence base. Moreover, when referring specifically to habitat manipulation, many real-world spawning habitat manipulations are conducted at one site only. While these single interventions may be monitored in a way that is scientifically defensible, the single intervention weakens or eliminates the inclusion of any monitoring information gathered from quantitative meta-analysis. Additionally, many real-world spawning habitat manipulations, whether single or multiple interventions, are not monitored in a scientifically defensible way, resulting in the elimination of that evidence from consideration in the systematic review.

To gauge the amount of information gained from including available reports/literature initially excluded from the Taylor et al. (2019) systematic review (i.e. they were relevant but susceptible to bias and/or had inadequate study designs), a second review (Rytwinski et al. 2019) was conducted to produce additional evidence for consideration in this Canadian Science Advisory Secretariat (CSAS) process. The systematic review (Taylor et al. 2019) used formal meta-analysis techniques to calculate effect sizes for various spawning habitat interventions. These effect sizes were based on the standardized mean difference between intervention and control groups (in this case, represented as a statistic known as Hedges' *g*), with individual studies weighted according to their standard error. For the second review, it was not possible to use Hedges' *g* to represent effect sizes because of data limitations resulting from the expanded inclusion of lower quality studies. Therefore, in Rytwinski et al (2019), the statistic used was percent change. Percent change is a more basic, less robust statistic not traditionally used in meta-analysis though it does provide some useful information that was otherwise excluded from the systematic review.

While the two reviews covered a broad cross-section of literature, it remains impossible to quantify the amount of information that was not included because it was either not found, or was not accessible. It is suspected that this information could be quite vast, greatly reducing the value of such monitoring efforts where data is used only for site-specific decisions, and results only known to a limited audience.

The Terms of Reference for this process had three main objectives that were discussed sequentially:

i) Are the commonly applied spawning substrate restoration techniques effective at restoring or offsetting destroyed and degraded fish habitats and fish productivity losses, in regions of varying productivity and across habitat types?

ii) Is there information that should be collected from spawning habitat creation/enhancement projects (or other restoration projects) that would allow for improved evaluation of effectiveness?

iii) Is there restoration/offset project assessment guidance (e.g. a habitat restoration project assessment tool) for spawning habitat creation/enhancement that could be developed for FFHPP staff to use as follows:

    a. To evaluate proposals for authorizing spawning habitat offset/restoration projects;

    b. To evaluate proposals for habitat restoration program funding (pre-construction, approval stage) and;

    c. To provide criteria for evaluating the effectiveness of spawning habitat to achieve the offset and restoration functional objectives?

**Terms of Reference Objective 1 – Are commonly applied spawning substrate restoration techniques effective at restoring or offsetting destroyed and degraded fish habitats and fish productivity losses, in regions of varying productivity and across habitat types?**

The overall conclusion of this advice is that if careful consideration is given to the habitat attributes and the biology and life history of the focal species, the reviewed substrate spawning manipulation techniques may: 1) attract substrate spawning fishes, 2) result in spawning, 3) result in egg survival, and 4) produce age-0 fish. It was recognized that examples of failed habitat manipulations exist, but that these failures were predominantly the result of poor planning as well as poor assessment and consideration of the biophysical attributes of the manipulated sites. In the context of this advice, we define ‘biophysical attributes’ as follows (also see Glossary):

> The biotic and abiotic elements, characteristics and processes of a subject area and the interactions among them. For example, in a fluvial environment, any area within the channel is subject to abiotic processes (e.g., flow, sediment transport, debris, ice, solar radiation, etc.) and biotic processes (e.g., spawner redd excavation, nutrient processing by periphyton, beaver dam building, woody and plant material, etc.) and the predictable interaction among these processes is of biological significance.

There are only a few groups of fish (e.g. salmonids) and some intervention types where the evidence base was sufficient to reach firm conclusions. In the systematic review (Taylor et al. 2019), the effect size statistic of interest is Hedges’ *g*. In Rytwinski et al. (2019), the effect size statistic is percent change. In cases where the weighted-mean effect size estimated from either of these metrics are positive and their associated confidence intervals (CIs) do not overlap zero, this means that a) the response variable (e.g., abundance, survival or body size) was higher/larger on average in the manipulated habitat than in areas with no intervention (Hedges’ *g* or percent change), and b) the mean of the effect size is likely to be accurate (confidence interval contains the true population mean). In no case was a specific intervention found to be harmful where the weighted-mean effect sizes were negative with negative confidence intervals that did not overlap zero. In other words, the analysis did not show any cases where the estimated weighted-mean effect size statistics (using either Hedges' *g* or percent change) indicated that the response variable was smaller on average in the manipulated habitat. This finding was verified by the confidence interval. For Rytwinski et al. (2019), the only exception to a) and b) above are for cases where the goal was to restore degraded impact sites to natural conditions or to create artificial streams/spawning channels similar to natural conditions (control sites). For these cases, having a summary effect size at or near 0 would be the desired outcome (<0% may still be an improvement in the degraded sites but not relative to control site). However, it was not possible to statistically show that an effect is exactly 0. Therefore, CIs are included to provide an indication of the precision of the estimate (i.e. width of the interval) but are not used to infer statistical significance.

Both reviews (Taylor et al. 2019; Rytwinski et al. 2019) included data robust enough to quantitatively report on the effectiveness of rock and plant material interventions (Table 1). In addition, Rytwinski et al. (2019) was able to provide more information regarding non-salmonid groups of fish, albeit by including lower validity studies and with small samples sizes. In general, the inclusion of low to medium validity (high to medium bias) studies in the analysis reduced the magnitude of benefit from the habitat manipulation. While the cause of this result is uncertain, the higher level of planning at all stages (i.e., from concept, to build, to monitoring) that likely accompanied more robustly designed, high quality (low bias) studies may be a contributing factor to effectiveness. This could also be indicative of the importance of investing in careful and thorough planning up front to increase the chances of success.

Table 1 summarizes the results from both the systematic review (Taylor et al. 2019) and Rytwinski et al. (2019), and can be used to examine those interventions where data were adequate for quantitative analysis. The use of rock material (primarily gravel/cobble additions for salmonids), plant material, and plant material along with waterbody modification can be considered effective manipulations to spawning habitat for substrate spawning fish because these manipulations demonstrate a positive Hedges *g* and confidence intervals that excluded zero. However, the resolution of the data used in the systematic review does not allow for specific science advice to be given on the implementation of the effective intervention types (e.g. interventions that involve rock material can, on average, have a statistically significant effect on the abundance of nests, eggs or age-0 fish, survival of nests or eggs, and presence of spawning adults but the results cannot illuminate specific composition and configuration of rock material to use). Nonetheless, the effectiveness of particular interventions (e.g. addition of rock material for salmonids) depend on the suitability of the substrate type for the target species, and the application location. Species-specific information should be sought for appropriate planning. The positive results from the systematic review for rock material, plant material and plant material with waterbody modification are further reported in Rytwinski et al. (2019).

While the results from Rytwinski et al. (2019) are not as statistically robust as the systematic review and cannot be used with the same degree of certainty, the additional literature included in Rytwinski et al. (2019) did allow for a more detailed analysis of specific intervention types and other family groups, and other effective interventions emerged. Specifically, gravel intervention for salmonids and rock combinations showed high positive percent change; in contrast, there was no detectable evidence for the effectiveness of gravel washing and cobble only interventions. Other specific interventions that were found to be effective included the addition of logs for creation of spawning habitat for both salmonids and non-salmonids, the specific water body creation involving the extension of an existing water body (e.g. augmenting an existing water body with a bay), and a number of treatment combinations where more than one intervention was applied at one site (Table 1). In all cases, these categories remain broad, so for the purposes of decision-making, attention should be paid to details in the specific individual projects included in each analysis (Rytwinski et al. 2019).

It is important to note that while it was recognized that altering water flows and levels to improve fish spawning habitat is a common habitat manipulation practice, that topic is the subject of a separate systematic literature map (protocol: Rytwinski et al. 2017, map: “What are the impacts of flow regime changes on fish productivity in temperate regions? A systematic map” as requested by the FFHPP) and was not considered here. Although marine spawning habitat manipulations were included as part of the search terms for the systematic review, very little documented evidence was found, likely because coastal zone marine habitat manipulations were more commonly applied to other life stages (e.g. juveniles requiring nursery habitat). Thus, the advice provided in this SAR does not apply to the marine environment and we recommend that future reviews be conducted to evaluate the effectiveness of common coastal marine habitat manipulations.

*Table 1. Comparisons between the Taylor et al. (2019 systematic review and Rytwinski et al. (2019) analysis. H: high study validity (low bias); M: medium study validity (moderate bias); L: low study validity (high bias); SMD: standardized mean difference effect size measure used in the formal meta-analysis (i.e., Hedges' g). CI: 95% confidence intervals. Refer back to the Background section for more information on interpreting study validity and the use of effect sizes.*

| **Review aspect** | **Taylor et al. (2019) systematic review** | **Rytwinski et al. (2019) analysis** |
| --- | --- | --- |
| No. of articles (studies) | 64 (75) | 100 (134) |
| No. of data sets in narrative (quantitative synthesis) | 183 (53) | 359 (228) |
| Quantitative synthesis | | |
| Methods<br>Study validities included | M, H | L, M, H |
| Effect size metric(s)used | SMD (Hedges' *g*); weighted-mean % change in intervention effectiveness | weighted-mean % change in intervention effectiveness |
| Results*<br>Rock material | Hedges' *g*: 1.16 (CI: 0.59, 1.73); 90% (CI: 75.02, 105.43) (n=6) primarily salmonids (5/6) | 18% (CI: 1.32, 35.23; n=78) mixture of salmonids & non-salmonids L validity: 13% (CI: -15.42, 41.95; n=29) M/H validity: 31% (CI: 0.26, 62.04; n=21) |
| *Gravel* | | 75% (CI: 54.15, 95.01; n=20) primarily salmonids & L validity studies |
| *Cobble* | | 5% (CI: -19.41, 25.56; n=43) salmonids: -1.34% (CI: -35.54, 32.86; n=23) non-salmonids: 22% (CI: -6.69, 51.48; n=20) |
| *Gravel washing* | | -12% (CI: -58.52, 34.34; n=6) |
| *Rock Combinations (gravel + cobble)* | | 81% (CI: 59.50, 102.94; n=5) |
| Plant material | Hedges' *g*: 0.45 (CI: 0.09, 0.80); 49% (CI: 30.34, 67.98) (n=4) | 45% (CI: 30.41, 60.34; n=26) primarily M validity studies based on indirect outcome metrics and/or short-term monitoring |
| *Log* | | 50% (CI: 35.74, 64.97; n=14) mixture of salmonids & non-salmonids primarily M validity studies |
| *Brush* | | 33% (CI: -50.15, 115.09; n=4) primarily centrarchid nests and serranid spawners & L validity studies |

| Review aspect | Taylor et al. (2019) systematic review | Rytwinski et al. (2019) analysis |
|---|---|---|
| Waterbody creation** | B: Hedges' *g*: 0.61 (CI: -0.05, 1.27); 39% (CI: 0.48, 76.97) (n=14) | A: 44% (CI: -30.45, 118.06; n=4) primarily low validity studies; B: 46% (CI: 16.35, 75.45; n=22) primarily M validity studies |
| *Stream A*** | | 44% (CI: -30.45, 118.06; n=4) |
| *Stream B*** | | 75% (CI: 46.02, 103.40; n=12) primarily Brown & Rainbow Trout |
| *Bay B*** | | 26% (CI: -20.99, 73.37; n=10) primarily cyprinids |
| Waterbody modification (alteration/excavation, etc.) | | 100% (CI: 100.00, 100.00; n=3) |
| Human-made structure (addition of non-organic materials: PVC pipes, bricks, ceramic tiles, etc.) | | 28% (CI: -31.44, 86.64; n=5) |
| Rock material + Human-made structure | | 59% (CI: 7.21, 111.38; n=7) |
| Rock + Plant material*** | Hedges' *g*: 0.19 (CI: -0.75, 1.14); 6% (CI: -45.00, 56.50) (n=7) | 54% (CI: 19.49, 87.92; n=20) |
| Rock + Plant material + Waterbody modification | | -3% (CI: -76.95, 71.55; n=4) |
| Plant material + Waterbody modification | Hedges' *g*: 0.45 (CI: 0.12, 0.78); 78% (CI: 66.60, 89.48) (n=7) | 79% (CI: 67.68, 89.29; n=8) |

*Results are for abundance outcome metrics only (i.e., survival and body size outcomes are not compared here).

**For the analyses that involved waterbody creation, 'type A' (e.g. Stream A) refers to stream creation where the comparator is a natural waterbody; 'type B' refers to stream or bay creation where the comparator is a reference site within the same waterbody as where the creation occurs (e.g. the existing waterbody is expanded).

*** In the Taylor et al. (2019) systematic review, to increase sample size, included any rock + plant material combination within this category (i.e., rock material + plant material, rock material + plant material + human-made structures, and rock material + plant material + waterbody modifications) but only rock material + plant material were combined for Rytwinski et al. (2019).

### Terms of Reference Objective 2 - Is there information that should be collected from spawning habitat creation/enhancement projects (or other restoration projects) that would allow for improved evaluation of effectiveness?

Monitoring is essential to understand the effectiveness of habitat manipulations. The level or type of monitoring that is appropriate is often project dependent, but detailed science advice in this regard can be found in CSAS Science Advisory Reports on effectiveness monitoring (DFO 2012) and on functional monitoring (DFO 2019), and in a DFO technical report that expands on the advice produced from the effectiveness monitoring CSAS process (Smokorowski et al. 2015). Many monitoring programs provide low-value information despite the collection of large amounts of data, as was evidenced by the large number of studies excluded from the systematic review.

The systematic review (Critical Appraisal Tool (Table 2 in Taylor et al. (2019)), copied into Appendix B below for reference) provides criteria for well-designed, low bias monitoring programs for spawning habitat manipulations, and if applied appropriately, would help ensure high value, robust information results, contributing to the evaluation of effectiveness beyond the site scale. Critical considerations for ensuring a high quality study include establishing criteria related to design, replication, measured outcome, control matching and consideration of confounding factors (Appendix B). Keeping these factors in mind, recommended *minimum* criteria for the description and monitoring of effectiveness of spawning habitat manipulations include:

- Description of the pre- and post-intervention conditions sufficient to be able to locate the site and assess change (e.g., location, dimensions, materials used; similar to the information contained in an 'Applicant's Guide to Submitting an Application for *Fisheries Act* Authorization').
- Intervention site must have a comparator (e.g., the site before manipulation, a control site, etc.).
- The comparator must be suitable (e.g. appropriate site/data), or there must be evidence (e.g. similar biophysical conditions) that the comparator is suitable.
- The minimum criteria for evaluating effectiveness of spawning habitat manipulation does not require an intervention replicate (though this can be useful).
- Sampling design (and replication) must be appropriate to yield a reliable estimate of each metric (i.e. you may be able to achieve an accurate estimate either with very reliable sampling or sampling replication). Reporting variance at a single intervention does yield valuable information about the precision of the outcome. However, unless there are multiple interventions (i.e. intervention replicates), there is not a reliable estimate of the variance of the outcome. However, pooling among similar single interventions could provide an estimate of the outcome variance.
- If multiple interventions are not possible, the sampling design might include multiple sampling locations at a single intervention/treatment site. This type of replication is termed 'pseudoreplication' (See Glossary), since the intervention is not truly replicated and the reported variance is not for truly replicate means. In cases where pseudoreplicated studies are included in a meta-analysis, the pseudoreplication should be acknowledged and accounted for to ensure that such data are not over-weighted relative to a truly independent replicated intervention.
- Results must be quantitative measurements (i.e. numerical) and not qualitative descriptions (e.g. anecdotal observations).
- The metric(s) that are measured are an appropriate and reliable representation of desired outcome (e.g., depth, velocity, substrate size, plant type and density, egg to fry survival, etc.). For example, where age-0 fish are used as a metric, that there is a reliable indication that individuals came from the restored habitat, versus simply being sampled there after hatching elsewhere.
- Duration, timing and frequency of monitoring is appropriate to the species (e.g. spawning intervention monitored at correct season), setting, intervention type and objective of intervention type (permanent vs. temporary function).
- Any confounding factors are recorded and reported (e.g. extreme weather events).

While the above criteria represent minimum requirements for monitoring, manipulated spawning habitat has the potential to appear effective through the redistribution of reproductive effort from other sites instead of increasing reproductive contributions at the manipulated site, and this will not necessarily be observed using minimum criteria alone. To assess the effectiveness of spawning habitat manipulations, consideration should be given to the following:

- Population level/abundance (e.g., estimate of local spawning adults and/or carrying capacity).
- The movement and distribution of adult fish during spawning.
- Increase in productivity at the habitat versus attraction of fish from other habitats.
- Habitat manipulation stability in dynamic environments (e.g., high energy or variable environments, across seasons, over appropriate time periods to demonstrate resilience).
- Fixed structures in dynamic fluvial systems.
- Site access and connectivity.
- Discussion of suitable habitat conditions for the target species (e.g., flow, substrate type/size/composition/depth, water depths, water velocities).
- Temporal evolution of creation or enhancement of habitat (re-sampling sites after a period of time is recommended) until stability of the intervention is expected.
- Expected outcomes, with attention paid to alternative hypotheses and the data needed to distinguish among these potential outcomes.
- Survival of eggs and age-0 fish produced in created or enhanced habitat for target species as appropriate.
- Recruitment to the targeted life stage.
- Habitat limitations for all life stages and determination of the population bottlenecks relevant to the intervention.
- Spatial information on the changes to the impacted and intervention habitats and equivalency calculations if done (e.g. Habitat/Ecosystem Assessment Tool).
- Additional, more detailed descriptions of the intervention above and beyond minimum criteria (e.g., engineering drawings, hydraulic modeling).

In all cases of assessing or monitoring spawning habitat manipulations (and regardless of the level of monitoring criteria, i.e. minimum or beyond), it is strongly recommended that information be collected and reported in a standardized and accessible way to allow for increased ability to evaluate effectiveness, and provide better data for systematic review across programs.

**Terms of Reference Objective 3 – Restoration/offset project assessment guidance for spawning habitat creation/enhancement that could be developed for FFHPP staff use.**

The criteria described for Objective 2 are relevant for the assessment of proposals to undertake spawning habitat manipulation projects, regardless of the rationale for the project (e.g. whether the proposal is to apply for funds to support habitat restoration, or required under a regulatory context). Proposals should also be assessed to ensure that they contain or consider the following information:

- A description of applicable fisheries management objectives (as referenced in FFHPP's Fish and fish habitat protection policy statement; section 8.6).

- Identification of threats and limiting factors at project site (e.g., land use, invasive species, species at risk, climate change, other pressures).
- Identification of other uncertainties or constraints that may exist (e.g., cumulative effects, future potential developments, spawning population limitations, density dependent factors, etc.).
- The project's timeline.
- Meaningful and relevant evaluation criteria (e.g. biological endpoints) for assessing project success.

Three overall categories may be helpful when developing evaluation criteria for spawning habitat manipulation projects: 1) the project context and objectives; 2) project methodology; and 3) post project monitoring (see Appendix C). In terms of project context and objectives, project evaluators can ask questions relating to the: physical and biological characteristics of the site; how the project is expected to conserve or enhance fish populations/communities/guilds/life stages; how projects will create or restore natural features; and uncertainties or constraints associated with the project. Questions related to project methodology may include questions related to the project's timeline, project site/location, replication and comparators for monitoring, and how well known the success rate is for a specific restoration type/species combination. To assess the effectiveness of a habitat manipulation, questions should focus on the project's monitoring and data collection plan, the evaluation criteria for assessing a projects effectiveness (biotic and abiotic), and evidence of the project's ecological benefits.

If a goal of any habitat manipulation project is to understand the value of the work in terms of contribution to the specified resource management objectives, then monitoring is essential. Since there are costs associated with monitoring, it may be necessary that financial resources are available for monitoring (in cases where a proposal is to receive funding in order to undertake a spawning habitat manipulation project). Similarly, given the importance of careful planning to the success of the project, supporting a planning component in habitat manipulation proposals is recommended. Project proposals may also benefit from being assessed in the context of national coordinated research networks or partnerships with diverse knowledge bases on spawning habitat manipulations, where broader experimental design and data analysis across the landscape, regionally or nationally can be applied to gain broader information beyond individual projects (i.e. 'big science').

## Sources of Uncertainty

While the calculation of a percent change in Rytwinski et al. (2019) provides useful supplementary information, the effect size and confidence interval information contained in the systematic review is the most definitive source of rigorously collected information regarding the effectiveness of spawning habitat manipulation. It is recognized that the results of the systematic review are based on data available for analysis, which necessarily omitted unavailable but potentially relevant data representing significant past investments in monitoring spawning habitat manipulations. It is uncertain how the results may have differed with the inclusion of such data. These data were unavailable as a result of lack of accessibility (e.g. non-digital formats or held by individuals not reached by or responding to the call-outs), or by unavailability due to the proprietary nature of the reports holding the data (e.g. consultant reports prepared for industry, with industry not able to release to the public). To ensure that future systematic reviews are able to include these data in quantitative analyses, consideration must be given towards ensuring that future monitoring efforts are accessible and available to improve the evidence base and subsequent scientific advice.

If only the minimum criteria above are included in a monitoring program, there will be an ongoing uncertainty as to whether increases in productivity detected at the site of the intervention resulted in population level improvements, or resulted from a shift of productivity from elsewhere in the waterbody or from another unknown factor (e.g., climate, long-term variability, etc.). Furthermore, the end results of habitat manipulations often include additional results over and above the intended goal, and these may not be detected with the minimum monitoring criteria (e.g. one species spawning habitat may be another species nursery or rearing habitat).

There may be interest in extending the advice on the effectiveness of spawning habitat manipulation to decisions on offset ratios (i.e. the amount of habitat required for offsetting compromised or destroyed habitat). Where an offset project enhances existing spawning habitat and the harm was the destruction of spawning habitat (i.e. a like-for-like scenario) then evidence from effect sizes and confidence intervals presented here provide support for a greater than 1:1 offset to impact area ratio. However, while these effect sizes should not be used to directly determine the ratio, broader confidence intervals indicate greater uncertainty, which supports a higher offset ratio. Keeping this in mind, there should be more confidence in applying these results to species and interventions well represented in the reviews. Additional information in Rytwinski et al. (2019) could inform expectations of productivity gains from other offsetting scenarios (e.g., habitat creation or restoration of degraded habitats).

Over time, as better planned, monitored, and assessed projects accumulate and there is greater confidence in the effectiveness of various interventions, offset ratios may be able to be prescribed with greater certainty.

# CONCLUSIONS AND ADVICE

Both Rytwinski et al. (2019) and Taylor et al. (2019) provide information that can be useful when considering whether a proposed spawning habitat manipulation is likely to be effective attracting substrate spawning fish, or result in spawning, egg survival, and the production of age-0 fish. The systematic review (Taylor et al., 2019), provides the most definitive information regarding the effectiveness of various manipulations because it included only studies that met stringent screening criteria that allowed for the calculation of an effect size, but only a limited number of studies were included.

### Objective 1

When careful consideration is given to the habitat attributes and the biology and life history of the focal species or community, then the reviewed substrate spawning habitat manipulations may result in successful spawning. More robust and specific advice is only available for salmonids because there were more studies with high quality information for salmonids that could be included in the systematic review. Overall, the use of rock material, plant material, and plant material with waterbody modification can be considered effective spawning habitat manipulations for substrate spawning fish.

### Objective 2

Minimum criteria have been described and recommended that would improve the evaluation of effectiveness for a spawning habitat manipulation. Minimum criteria are the necessary criteria that allow for the creation of a defensible monitoring program. These are ‘must-haves’ such as a project requiring a comparator to be effectively monitored for effectiveness. However, criteria are also described that lead to a more thorough understanding of the effectiveness of manipulations. These secondary criteria are important to determine whether a manipulation is increasing spawning success, or just appearing to do so through the re-distribution of reproductive effort from other sites. These types of criteria include estimating population level abundance, or tracking the movement and distribution of adult fish during spawning.

**Objective 3**

The minimum and additional criteria outlined under Objective 2 are appropriate for the evaluation of a manipulation to spawning habitat, regardless of the reason for the manipulation (e.g., required as part of an offsetting plan, proposed as part of restoration project by an ENGO, etc.). However, FFHPP also requested more information on questions that could be considered/asked in the situation where a project proposal is being evaluated for funds that DFO has available for external organizations to undertake habitat manipulation projects. An additional set of questions/considerations are provided under Objective 3 and in Appendix B. These additional questions can be applied to any spawning habitat manipulation (whether it be for a regulatory or non-regulatory context), but may be more useful when dealing with proposals for funding outside of a regulatory context (i.e. not for a *Fisheries Act* authorization or offsetting plan) because the considerations can also be used to shape a call for proposals.

It is also important to note that the criteria outlined in Appendix C could be adaptable for the monitoring of other types of habitat (e.g., nursery, adult) with slight modification.

## OTHER CONSIDERATIONS

The most definitive advice provided in this SAR is based on studies that could be included within the systematic review of the effectiveness of spawning habitat manipulation. There is recognition that there are likely other effective manipulations but the evidence base did not permit their inclusion in this review.

The following key factors lead to knowledge gaps that should be addressed to facilitate the implementation of successful spawning habitat manipulations and monitoring of these manipulations:

- Accessibility of data.
- Funding for planning and monitoring habitat manipulation projects.
- The importance of landscape-level research to inform the evaluation of effectiveness of smaller scale spawning habitat manipulations

## LIST OF MEETING PARTICIPANTS

| | |
|---|---|
| Smokorowski, Karen (Co-chair) | DFO Science, Central & Arctic (C&A) |
| Winegardner, Amanda (Co-chair) | DFO Science, National Capital Region (NCR) |
| Anderson, Shannon | DFO Salmonid Enhancement Program (Community Involvement and Restoration Unit), Pacific (PAC) |
| Bradford, Mike | DFO Science, Pacific |
| Cooke, Emma (Rapporteur) | DFO Science, NCR |
| Cooke, Steven | Carleton University |
| Clarke, Keith | DFO Science, Newfoundland and Labrador (NL) |
| Depaiva, Alex | DFO Ecosystems Management Policies and Practices (EMPP), NCR |
| Doka, Susan | DFO Science, C&A |
| Enders, Eva | DFO Science, C&A |
| Fisher, Neil | DFO EMPP, NCR |
| Fleet, Terry | DFO FFHPP, NL |
| Jacobi, Carol | DFO FFHPP, Maritimes |
| James, Joanna | DFO Science, NCR |
| Jonsson, Alan | DFO Salmonid Enhancement Program (Community Involvement and Restoration Unit), Pacific (PAC) |
| Koops, Marten | DFO Science, C&A |
| Lapointe, Nicolas | Canadian Wildlife Federation |
| Makkay, Kristina | DFO Species at Risk (SAR), NCR |
| Melanson, Terry | DFO FFHPP, Gulf |
| Midwood, Jon | DFO Science, C&A |
| Poesch, Mark | University of Alberta |
| Ponader, Karin (Rapporteur) | DFO Science, NCR |
| Roberts, Karling | University of Alberta |
| Robichaud, Lisa | DFO FFHPP, NCR |
| Runciman, Bruce | DFO FFHPP, PAC |
| Rytwinski, Trina | Carleton University |
| Stanley, David | Ontario Power Generation (OPG) |
| Taylor, Jessica | Carleton University |
| Theis, Sebastian | University of Alberta |
| Wong, Melisa | DFO Science, MAR |

## SOURCES OF INFORMATION

This Science Advisory Report is from the January 22-24, 2019, Science advice to the Fisheries Protection Program on the effectiveness of spawning habitat creation for substrate spawning temperate fish. 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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## GLOSSARY

| Term | Description | Reference |
|---|---|---|
| **biophysical attributes** | The biotic and abiotic elements, characteristics and processes of a subject area and the interactions among them. For example, in a fluvial environment, any area within the channel is subject to abiotic processes (e.g., flow, sediment, debris, ice, solar radiation, etc.) and biotic processes (e.g., spawner redd excavation, nutrient processing by periphyton, beaver dam building, woody and plant material, etc.) and the predictable interaction among these processes is of biological significance. | Jonsson, A. and Runciman, B. (Personal communication) |
| **confidence interval** | An interval estimate that indicates the probability that the true population mean μ falls within the interval. If a 95% confidence interval does not include zero then there would be high confidence that the effect of an intervention on a response variable is not zero. In the case of the reviews used here, 95% confidence intervals were included to provide an indication of the precision of the estimate (i.e. width of the interval), but not to infer statistical significance. | Gotelli and Ellison (2004)<br><br>Harrison (2011) and Rytwinski et al. (2019) |
| **effect size** | "Statistics that provide a standardized, directional measure of the mean change in the dependent variable in each study". An effect size can be "weighted by the variance of the estimate, such that studies with lower variance are given more weight in the dataset". | Harrison (2011) |
| **Hedges' g** | A measure of effect size that is appropriate for continuous or ordinal data from two or more groups (e.g. control site and restored habitat site). The raw difference in means is standardized by using pooled standard deviation. | Harrison (2011) |

| Term | Description | Reference |
|---|---|---|
| **percent change** | Metric used in Rytwinski et al. (2019) to assess the effectiveness of a spawning habitat intervention. Percent change is calculated as: $$= \frac{\bar{X}_{G2} - (\bar{X}_{G1} + q)}{\bar{X}_{G1} + q} * 100$$ where $\bar{X}_{G1}$ and $\bar{X}_{G2}$ are the means (or total count if n=1) of group 1 (G1 = comparator group) and group 2 (G2 = intervention group). Since percent change cannot be computed when $\bar{X}_{G1}$ = 0, a small constant $q$=0.01 to $\bar{X}_{G1}$ is added for each data set. Thus, a positive percent change indicates that the outcome (abundance, survival, or body size) was higher/larger in the enhanced spawning habitat areas than in areas with no intervention, and a negative percent change indicates that the outcome was lower/smaller with spawning habitat enhancement. | Rytwinski et al. (2019) |
| **pseudoreplication** | Occurs when multiple sampling locations are sampled at a single intervention/treatment site. While the samples are replicated, the intervention is not truly replicated and the reported variance is not for truly replicate means. | Taylor et al. (2019) |
| **systematic review** | "Evidence synthesis method that aims to answer a specific question as precisely as possible in an unbiased way. The method collates, critically appraises, and synthesizes all available evidence relevant to the question. Reviewers use pre-defined methods to identify risks of bias in the evidence itself, and to minimise bias in the way evidence is identified and selected, and thus provide reliable findings that could inform decision making." | Collaboration for Environmental Evidence (2018) |

# APPENDIX A – RESOURCES FOR SYSTEMATIC REVIEWS

More information on systematic reviews can be found:

Collaboration for Environmental Evidence. 2018. Guidelines and Standards for Evidence synthesis in Environmental Management. Version 5.0 (AS Pullin, GK Frampton, B Livoreil & G Petrokofsky, Eds) www.environmentalevidence.org/information-for-authors. – Includes primers on how to conduct systematic reviews, different types of reviews and specialized terminology.

Journal of Environmental Evidence: Publishes systematic reviews that adhere to the guidelines set by the Collaboration for Environmental Evidence.

# APPENDIX B – CRITICAL APPRAISAL TOOL

*Table B1. Critical appraisal tool of the study validity assessment for inclusion in the systematic review. Authors of the systematic review provided a rating of high, medium, or low for each of the specific data quality features and comments for each study based on external validity (generalizability). Table 2 from Taylor et al. (2019)*

| Category | Bias and generic data quality features | Specific data quality features | Validity | Design of assessed study |
|---|---|---|---|---|
| 1 | Selection bias: study design | Design (i.e., controlled) | High | BACI |
| | | | Medium | BA or CI |
| | | Replication | High | Replication at level of intervention (n>5) |
| | | | Medium | Replication at level of intervention (true n=1 with pseudoreplication) or n=2-5) |
| | | | Low | Unreplicated (i.e. no variance, or variance across years only) |
| | | Control Matching* | High | Control and treatment samples well-matched or likely well-matched at baseline |
| | | | Medium | Control and treatment samples moderately matched |
| | | | Low | Control and treatment samples poorly matched |
| 2 | Assessment bias: measurement of outcome | Measured outcome | High | Quantitative |
| | | | Medium | Quantitative approximations or semi-quantitative |
| | | | Low | Qualitative |
| 3 | Performance bias: baseline comparison | Other confounding environment all factors** | High | Intervention and comparator sites homogenous |
| | | | Medium | Intervention and comparator sites moderately comparable with respect to confounding factors |
| | | | Low | Intervention and comparator sites hardly comparable with respect to confounding factors or lacking sufficient information to judge |
| | | | | N/A if BA design and before measurement taken immediately prior to restoration |

* How well matched the intervention and comparator sites were at site selection and/or study initiation (e.g., physical characteristics)

**Environmental or other factors that differ between intervention and comparator sites and/or times, that occur after site selection and/or study initiation (e.g., flood, drought, other (unplanned) human alteration)

# APPENDIX C – EVALUATION OF SPAWNING HABITAT MANIPULATION PROPOSALS

Additional guidance to evaluate proposals spawning habitat manipulation.

The table below was created to evaluate proposals for offset/restoration projects, using spawning habitat as an example. Spawning habitat was chosen because of the focus of the science advice and the high level of interest on spawning habitat creation. However, the criteria can be substituted for any habitat type for different life stages (e.g., nursery habitat).

The level of monitoring that is appropriate for projects that include and warrant post-restoration/offset monitoring can be determined by referring to science advisory reports on functional monitoring (SAR 2019/042) versus effectiveness monitoring (SAR 2012/060).

Questions **bolded** in the table are focused towards general fish habitat restoration/offset projects. Questions not bolded are more focused on spawning habitat restoration/offset projects, but can be substituted for any life stage (e.g., nursery habitat).

*Table B2. Guidance tool to evaluate proposals of spawning habitat manipulation project.*

| | |
|---|---|
| **RESTORATION/OFFSET PROJECT CONTEXT AND OBJECTIVES** | 1. **What are the physical and biological characteristics of the site in terms of fish and fish habitat and how will your project impact these?**<br>2. **How will the project conserve or enhance fish populations?**<br>• Does the project target a high priority species (i.e., native, rare, or at risk)?<br>• How does the proposal indicate that the creation of spawning habitat is necessary for population recovery/sustainability? Is spawning success a limiting factor?<br>3. **How will the project restore or replace an important feature (e.g. wetland), natural process or function (e.g., water quality)?**<br>• How is the project objective linked to fish spawning (productivity)?<br>4. **Will this project be detrimental to natural, currently functioning habitat, and if so, how will the impacts be mitigated/offset?**<br>5. **What are the threats or other limiting factors at the project site (e.g., land use, invasive species, climate change, other planned/likely pressures)?**<br>• What threats are on site that would affect the success of spawning habitat or the species spawning?<br>6. **What uncertainties/constraints exist (e.g., related to project management)?** |

| | |
|---|---|
| **RESTORATION/OFFSET PROJECT METHODOLOGY** | **7. Is the project's spatial and temporal scale appropriate for its objectives, methodology and expected results?**<br>• **Is the project's timeline well thought out/developed?**<br>• How will the project use a spatial scale appropriate for the spawning habitat requirements of the species (considering e.g., the home range, spawning site fidelity, fish/egg/nest capacity per spawning habitat area)?<br>• When should the restoration occur based on when spawning occurs? Other time windows of importance?<br>• How will the project be completed at a time scale that is appropriate for the species (considering e.g., the spawning time and frequency and other life history events)?<br>**8. Is the project located in an area where restoration will ultimately be successful?**<br>• Why will the fish return, arrive or stay in this area to spawn (are other interventions planned; egg baskets, moving spawners, etc.)?<br>• Do other species in the area use similar spawning habitat areas/substrate? Will this affect success?<br>**9. Does the project identify an appropriate monitoring design type and comparator?**<br>• Are there an appropriate number of replicates?<br>**10. How will the project use appropriate methodology for the objectives and restoration type?**<br>• How is the spawning habitat substrate type and quantity that is identified, appropriate?<br>• What is the likelihood of success?<br>• How well studied is spawning habitat manipulation for the species? |

| | |
|---|---|
| **POST RESTORATION/OFFSET MONITORING METHODS** | **11. What is the monitoring and data collection plan?**<br>• At what point will monitoring occur during the life cycle (e.g., active spawning, nesting, larval phase, juvenile recruitment) and for how long?<br>**12. Will the monitoring use appropriate methodology for the objectives and intervention type?**<br>• **Are there an appropriate number of replicates?**<br>**13. How meaningful and relevant are the evaluation criteria (biological endpoints) for assessing project success?**<br>• How are the indicators for spawning success appropriate?<br>• Have milestones been developed based on the life cycle/spawning behaviour of the target species?<br>**14. Will the project provide long-term, sustainable, self-maintaining ecological benefits?**<br>• **What is the likelihood of success?**<br>• How well studied is spawning habitat manipulation for the species?<br>• Is it likely that maintenance of the manipulation will be required?<br>**15. Will the deliverables be in a form that can readily be used by management and policy-makers?**<br>**16. Will the project address the impacts or respond to the threats of climate change?**<br>• How will the spawning habitat change with climate change? Is the species vulnerable to climate change (and if so, how)? |

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Fisheries and Oceans Canada
200 Kent Street, Ottawa, ON K1A 0E6

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

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