How effective are spawning-habitat creation or enhancement measures for substrate-spawning fish? A synthesis

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Canadian Technical Report of Fisheries and Aquatic Sciences

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How effective are spawning-habitat creation or enhancement measures for substrate-spawning fish? A synthesis

by

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ABSTRACT

Rytwinski, T., Elmer, L.K., Taylor, J.J., Donaldson, L.A., Bennett, J.R., Smokorowski, K.E., Winegardner, A.K., and Cooke, S.J. 2019. How effective are spawning-habitat creation or enhancement measures for substrate-spawning fish? A synthesis. Can. Tech. Rep. Fish. Aquat. Sci. 3333: viii + 183 p.

A systematic literature review was conducted by Taylor et al. (2019) to quantitatively assess the effectiveness of spawning habitat creation or enhancements (interventions) for substrate spawning temperate fishes, using rigorous criteria that resulted in the exclusion of many related reports. The objective of this report was to supplement Taylor et al. (2019) using a more inclusive evidence base, subjected to consideration for study validity. Each study was assigned an overall 'low' (high risk of bias), 'medium', or 'high' (low risk of bias) validity rating and the percent change in effectiveness was calculated for any evaluation that reported quantitative data for both the intervention and comparator group. Because not all studies included quantitative outcomes, for each study we also gave an effectiveness rating based on outcome data type, whether the reported outcome was considered a direct or indirect measure of successful intervention, and post-treatment monitoring duration. Based on weighted-mean percent changes, all spawning habitat creations and enhancements when applied alone appeared to increase fish abundance and to a lesser degree survival of substrate-spawning fishes. The relative magnitude of intervention effectiveness appears to be influenced, at least for rock material additions, by study validity, with higher mean increases in abundance for analyses based on studies with lower susceptibility to bias. Based on our effectiveness rating, when considering only those studies that were deemed low biased, only 17% (i.e., 14/83) of medium validity and 0% (i.e., 0/3) of high validity evaluations that showed an increase in fish abundance/survival were deemed 'effective' spawning habitat interventions. The balance of the low biased studies were classified as 'potentially effective'. Overall, the results from this report support the general findings from Taylor et al. (2019), yet it also demonstrates the importance of basing quantitative analyses on high validity studies. This report did however allow for the inclusion of a greater diversity of species and intervention types, and serves as an annotated source of (accessible) information.

RÉSUMÉ

Rytwinski, T., Elmer, L.K., Taylor, J.J., Donaldson, L.A., Bennett, J.R., Smokorowski, K.E., Winegardner, A.K., and Cooke, S.J. 2019. How effective are spawning-habitat creation or enhancement measures for substrate-spawning fish? A synthesis. Can. Tech. Rep. Fish. Aquat. Sci. 3333: viii + 183 p.

Taylor *et al.* (2019) ont effectué une analyse documentaire systématique pour évaluer quantitativement l'efficacité de la création ou de l'amélioration de l'habitat de frai (interventions) pour le poisson frayant dans le substrat des eaux tempérées, en utilisant des critères rigoureux qui ont entraîné l'exclusion de nombreux rapports connexes. Le présent rapport vise à compléter l'ouvrage de Taylor *et al.* (2019) à l'aide d'une base probante plus inclusive, soumise à l'examen de la validité de l'étude. Chaque étude a reçu une cote de validité globale « faible » (risque élevé de biais), « moyenne » ou « élevée » (risque faible de biais), et le pourcentage de changement dans l'efficacité a été calculé pour toute évaluation ayant fourni des données quantitatives pour l'intervention et le groupe témoin. Puisque certaines études ne comprenaient pas de résultats quantitatifs, nous avons également attribué une cote d'efficacité à chaque étude sur la base de trois critères : le type de mesure du succès de l'intervention (quantitative ou qualitative), si la mesure était considérée comme directe ou indirecte et la durée du suivi après le traitement. En se basant sur les changements dans le pourcentage moyen pondéré, toutes les créations et améliorations de l'habitat de frai, lorsqu'elles sont appliquées seules, semblent accroître l'abondance des poissons et, dans une moindre mesure, la survie des poissons qui fraient dans le substrat. L'ampleur relative de l'efficacité de l'intervention semble être influencée, du moins pour les ajouts de matériaux rocheux, par la validité de l'étude, l'augmentation moyenne de l'abondance étant plus élevée pour les analyses fondées sur des études moins susceptibles aux biais. En se fondant sur notre cote d'efficacité et en tenant compte uniquement des études jugées peu biaisées, seulement 17 % (c.-à-d. 14/83) des évaluations de validité moyenne et 0 % (c.-à-d. 0/3) des évaluations de validité élevée qui ont révélé une augmentation de l'abondance et de la survie du poisson ont été jugées « efficaces » dans les interventions en matière de fraie. Le reste des études peu biaisées ont été classées comme « potentiellement efficaces ». Dans l'ensemble, les résultats de ce rapport appuient les conclusions générales de Taylor *et al.* (2019), tout en démontrant l'importance de fonder les analyses quantitatives sur des études à validité élevée. Ce rapport a toutefois permis d'inclure une plus grande diversité d'espèces et de types d'intervention et sert de source annotée d'information (accessible).

INTRODUCTION

Productive fish populations rely on ample, good quality habitat. Several authors argue that the greatest threat to freshwater species and ecosystems is habitat degradation (Dudgeon et al*.* 2006; Lapointe et al*.* 2014), which can destroy critical environments needed by fishes for activities such as spawning, feeding, or migration. Habitat loss and degradation are also of great concern for coastal marine environments and the many nearshore fishes that depend on them (e.g., seagrasses: Short and Wyllie-Echeverria 1996; Allen et al. 2002).

Spawning habitat is defined as the environment in which a fish species will spawn. As the spawning process requires the release and fertilization of eggs, there are often very particular habitat requirements for each species, such as substrate type, water depth, wave exposure and water flow (Snickars et al*.* 2010). Survival and development of eggs and fry will also depend on environmental factors such as water flow, vegetation, temperature, and water quality (Cramer and Ackerman 2009). Many common fish taxa in Canada rely heavily on specific spawning habitat, for example, centrarchids (Brown et al*.* 2009), salmonids (Cramer and Ackerman 2009), and esocids (Casselman and Lewis 1996). Certain fish species have very specific spawning habitat requirements, such as Brook Trout (*Salvelinus fontinalis*) which in southwestern Ontario rely on sites with distinct groundwater discharge (Curry and Noakes 1995). These more specific environmental requirements further limit the habitat available for spawning. For these fish species, proposed developments that will affect spawning habitat may have dramatic effects on fish populations. Therefore, spawning habitat offsetting may be particularly important for protecting certain fish species such as habitat specialists.

In 2012, Canada's *Fisheries Act* was amended to put responsibility on proponents to avoid and mitigate any serious harm to fish that are part of a commercial, recreational or Aboriginal fishery, or to fish that support such a fishery, resulting from projects affecting aquatic habitat. Fisheries and Oceans Canada (DFO) updated the way they managed threats to fisheries from development projects such that if projects could not avoid or mitigate serious harm, proponents were required to develop a plan to counterbalance the residual harm using offsetting measures (DFO 2013; DFO 2014; Rice et al. 2016). Offsetting measures will differ on a case-by-case basis; however, all must support fisheries management objectives, balance project impacts, and generate long-term, self-sustaining benefits for the fishery (DFO 2013). In an era of increasing human development (Vitousek et al. 1997), it is important to assess the effectiveness of such habitat offsetting measures to ensure both maximal benefit to fish populations, and the most efficient, economical allocation of scarce resources. In this regard, DFO's Fisheries Protection Program (FPP) identified this topic as a priority, and was seeking advice on best practices in habitat restoration and information on the effectiveness of restoration practices in regions of varying productivity and community compositions.

To address this request, in part, Taylor et al. (2019) conducted a systematic review (including a quantitative synthesis using formal meta-analytical methods) to assess the effectiveness of techniques currently used to create or enhance spawning habitat for substrate-spawning (including vegetation-spawning) fish in temperate (freshwater and marine) regions, and to investigate the factors that influence the effectiveness of habitat creation or enhancement. The evidence-based nature of systematic reviews conducted under the guidance of the Collaboration for Environmental Evidence (CEE) (2018) makes them increasingly valuable tools for informing management decisions. Though this methodology allows one to identify the most relevant, and reliable (minimally biased) sources of information, following such rigorous guidelines set out by CEE can result in the exclusion of some studies that could still provide valuable information on a topic of interest. For instance, in the Taylor et al. (2019) systematic review, a number of studies were excluded because they did not meet all of the inclusion criteria [i.e., studies were deemed relevant but they did not include a comparator (e.g., studies were post-treatment or impact only designs), or they used an alternative comparator (e.g., the comparison of the intervention was not with non-intervention but an alternate level of the same intervention or a different intervention)], or they were relevant but were considered unsuitable for quantitative synthesis meta-analysis (e.g., studies lacked replication, or did not report measures of outcome variability and/or data on sample size, etc.). Additionally, studies focusing entirely on juvenile fish (age-1) were excluded from the Taylor et al. review (i.e., only fish from egg and larval to age-0 life stages, as well as spawning adults were included to ensure the focus was on spawning habitat); however, studies reporting on outcomes of age-1 fish may reflect important information on nursery habitat as well. Although these excluded studies were considered to be less reliable sources of information (i.e., highly susceptible to bias and/or had inadequate study designs) or were slightly beyond the scope to be included in the systematic review, these studies could further contribute useful information and provide a more comprehensive knowledge base on the subject, when accompanied with an appropriate consideration for study validity. As such, the objective of this DFO technical report was to supplement the Taylor et al. (2019) systematic review, with a full synthesis using the whole evidence base, including those studies excluded for reasons described above, to assess the effectiveness of spawning habitat creation or enhancements for substrate spawning temperate fish.

METHODS

SEARCH STRATEGY AND STUDY SELECTION

The detailed search strategy for both the Taylor et al. (2019) systematic review and this paper are outlined in a published *a priori* protocol (Taylor et al. 2017). Publication databases (Web of Science Core Collections, Scopus, DFO Waves, ProQuest Dissertations and Theses, and Science.gov) were searched in December 2016 with a search string that had been thoroughly scoped to ensure comprehensiveness. Additional searches were performed on Google Scholar and specialist websites identified by the Advisory Team (i.e., included academics, staff from the Canadian Wildlife Federation, and staff from DFO, specifically FPP and the Ecosystems and Ocean Science Sector) for the Taylor et al. review. Calls for evidence were distributed through social media, email list serves, and relevant networks to target sources of grey literature.

Search results from the databases were screened at two distinct stages (1) title and abstract and (2) full-text. At each stage, a consistency check was performed with a subset (10%) of the articles to ensure consistency between screeners. All results were screened for relevance based on the following inclusion criteria:

Population – Substrate-spawning fish in north and south temperate regions (in freshwater and marine environments) from egg and larval stage to age-0 (e.g., alevin, fry, young-of-the-year [YOY]) as well as spawning adults were included.

Intervention – Any creation or enhancement of spawning habitat including, but not limited to, the addition of rock or plant material, creation of bays or artificial streams, modifications to the riparian zone, or addition of human-made structures were included. Based on discussions with the Advisory Team for the Taylor et al. review, interventions that involved flooding or altering flows were excluded (but is the topic of an ongoing systematic review; see Rytwinski et al. 2017), unless if it was for the purpose of cleaning or altering the substrate by removing sediment (e.g., Ortlepp and Mürle 2003). Allowing fish access to pre-existing habitat (e.g., adding a culvert) was not considered a relevant intervention for the purpose of this review (but is the topic of an ongoing systematic review; see Rytwinski et al. 2018), as it does not involve creating or enhancing a habitat and was excluded.

Comparator - A non-intervention comparator was required in every included study. Study designs could take the form of Before-After (BA) (or Trend-by-time), Control-Impact (CI) [or Reference Condition Approach (RCA), Normal Range Approach], Before-After-Control-Impact (BACI), or Randomized Control Trial (RCT).

Outcome - Only direct outcomes in the form of a quantitative or qualitative measured effect of intervention were included. Relevant outcomes included, but were not limited to, abundance/density of nests, eggs, or age-0 fish, survival/success of nests or eggs, presence of spawning adults. Relative abundance estimates based on catch-per-unit-effort (CPUE) were also included, but indirect estimates using survival rate calculations or changes in physical habitat measures like spawning area were excluded.

Language – Only English-language literature was included.

As described above, this set of inclusion criteria excluded studies that were highly susceptible to bias, had poor study designs, or were outside of the scope of the systematic review (Taylor et al. 2019). In order to create a more comprehensive database for the purpose of this review, the population criteria were modified to include those studies that reported data on only juvenile fish, and the comparator inclusion criteria were modified to include those studies that reported only post-treatment (PT) or impact data (see Table 1 for a comparison of review numbers and methods). Recording exclusion reasons during full text screening allowed the articles originally excluded to be retrieved and re-screened with the new criteria. Furthermore, we performed additional non-systematic searches to ensure that marine spawning habitat restorations studies were not missed in the original searches.

STUDY VALIDITY ASSESSMENT

All studies in this review (i.e., all studies included in the Taylor et al. (2019) systematic review and those added for this review) were critically appraised for study validity using a framework that was developed based on Bilotta et al. (2014) and adapted to suit this subject matter. The criteria in the framework were designed to appraise the internal validity (methodological quality), whereas external validity (study generalizability) was more broadly assessed during the screening process or otherwise noted. The framework was adapted to ensure that it accurately reflected the characteristics of an ideal study, regardless of resources or experimental/field restrictions.

Each criterion was scored as ‘high’ (low risk of bias), ‘medium’ (medium risk of bias), or ‘low’ (high risk of bias) based on the predefined framework (see Taylor et al. 2019 for full details of the framework). A study was given an overall ‘low’ validity if it scored low for one or more of the criteria. If the study did not score low or all high for any of the criteria, it was assigned an overall ‘medium’ validity. Studies that scored only high for all of the criteria were assigned an overall ‘high’ validity. The internal validity criteria included: study design [PT (no comparator), BA, CI, or BACI)], replication (true or pseudoreplication), control matching (how well matched the intervention and comparator sites were at site selection and/or study initiation [e.g., physical characteristics]), measured outcome (quantitative, quantitative approximation, semi-quantitative, or qualitative), and confounding factors (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, unplanned human alteration]).

DATA EXTRACTION

All studies included after full-text assessment underwent meta-data and qualitative and/or quantitative data extraction using the extraction form designed for the Taylor et al. (2019) systematic review. This form was designed to capture study data including:

publication details, study location, study summary and timeline, population details, intervention and comparator details, and outcome variables. When provided, sample sizes, outcome means, and measures of variability (e.g., standard deviation) were also extracted for each study. Eligible interventions were categorized and defined as in Table 2.

If an article reported data separately for sites that we considered ecologically independent (i.e., different interventions were applied to a number of sites, each with their own controls), these studies were considered independent for the purpose of this review (refer to Table 3 for term definitions). If a study reported outcome data at multiple time points (before and/or after intervention), we extracted only the most recent time point before and after the intervention. This provides the most relevant data prior to the intervention and the most long-term data after the intervention, given that interventions were meant to be permanent. Averaging across multiple time points was also considered; however, there were relatively few studies that monitored interventions for ≥3 years post-treatment (31%), and not all of which used continuous yearly monitoring. As such, this would have resulted in the majority of quantitative evaluations based on outcome data from a single year and relatively few cases of averages across years; therefore, we used only the most recent time point before and after the intervention to make evaluations more comparable. A single independent study could also report separate relevant comparisons. For this review, we considered comparisons separately (i.e., a separate data set/row in the database) for: (1) different species, and/or (2) the same species but for (a) different responses (i.e., abundance, survival, body size), (b) different interventions (e.g., rock material, plant material, waterbody creation/extension, etc.), or (c) different life stages (e.g., the abundance of eggs for species A, and the abundance of age-0 for species A).

Lastly, replication within a study was considered at two levels (1) true replication and (2) pseudoreplication. We considered true replicates to be independent intervention areas (i.e., separate waterbodies or separate sections of a waterbody) and the number of areas was recorded as the level of true replication. Pseudoreplication was considered in cases when only one true replicate was subsampled (i.e., reported variances referred to variability within a true replicate) and the number of subsamples (e.g., plots or nests) was recorded as the level of replication. In these cases, mean outcomes for intervention and comparator groups were taken from all subsamples, but appropriate adjustments to the level of replication were made for study weighting during quantitative synthesis (see below).

For the purpose of this review, we extracted additional data that was not included in the Taylor et al. (2019) systematic review. To better capture the goals of the study, the pre-defined target outcome for the intervention (e.g., increase egg-to-fry survival by 10%) was extracted if reported by the author. We also extracted the author's conclusions and statements of caveats and/or confounding factors for use in the effectiveness rating (see below). These statements can indicate if the author thought the intervention was effective, but attributed the improvement to something other than the intervention, and if they were basing their conclusion on statistical significance or a pre-defined target, as opposed to an improvement in outcomes. Finally, the type of comparator (i.e., if the site was degraded or not prior to treatment, or whether for the waterbody creation intervention category, if the control site was a natural waterbody or a nearby reference section within the same waterbody) was extracted. For both BA study designs, and CI designs that compared control and impact sites from the same stream (i.e., impact sites were sites within the same stream where the intervention was applied but otherwise, control and impact sites were similar), based on the percent change in intervention effectiveness (see Eq 1 below), we would expect a positive estimate if the outcome (abundance, survival, or body size) was higher/larger in the created or enhanced spawning habitat areas (or the after intervention time period) than in areas with no intervention (or the before intervention time period). However, for CI designs that compared impact sites that were degraded and to which an intervention was applied, or newly created waterbodies with control sites that represented a more natural condition, based on percent change in intervention effectiveness, we would expect: (1) a positive percent change (i.e., > 0%) if the intervention resulted in a larger improvement than the control (natural condition), or (2) a neutral percent change (i.e., 0%) if the outcome at the impact sites was similar to the outcome at the control sites. The type of comparator directly affects the interpretation of the percent change and must therefore be taken into consideration when drawing conclusions about effectiveness.

DATA SYNTHESIS AND PRESENTATION

Descriptive statistics and a narrative synthesis

Following data extraction, meta-data from each study was used to generate descriptive statistics, a narrative synthesis of the evidence and an annotated bibliography (see Appendix A).

Effectiveness rating

Not all studies measured and/or reported quantitative outcomes to allow for a quantitative evaluation of intervention effectiveness. Therefore, we developed an effectiveness rating based on three main criteria related to study relevance and design: (1) outcome data type (i.e., quantitative or qualitative); (2) whether the reported outcome measure was consider a direct measure of successful restoration (e.g., egg-to-fry survival, abundance of larvae/age-0 fishes) versus an indirect measure (e.g., the presence or density of nests/eggs, juveniles, or spawning adults, presence of larvae/age-0 fishes, or body size metrics); and (3) post-treatment monitoring duration. Each study was given an effectiveness rating based on the criteria detailed in Table 4.

To be categorized as effective, we based evidence on the quantitative data only (i.e., >0% change in effectiveness for any outcome regardless of reported statistical significance or authors conclusions stated in studies; see Quantitative synthesis below). Authors conclusions regarding pre-defined targets or potentially confounding factors, along with information on study validity (critical appraisal CA) are discussed in the annotated bibliography (see Appendix A). Since monitoring duration was not incorporated into our critical appraisal tool, we included monitoring time in the effectiveness rating criteria to account for situations where, for example, the intervention was deemed quantitatively effective, yet the monitoring was only conducted over a short period of time post-treatment, limiting correct interpretation of effectiveness. We used a 3-year minimum post-treatment monitoring as our criteria to be considered effective, as recommended by Smokorowski et al. (2015). To summarize, to be deemed effective, studies needed to have a quantitative percent change in intervention effectiveness of >0 (from the last year of monitoring) and had monitored the intervention for at least 3 years post-treatment. Note, for cases where degraded impact sites were compared to non-degraded control sites, or where created artificial streams/spawning channels were compared to natural waterbodies, we deemed these cases effective when there was a ≥0 % proportional change (from the last year of monitoring) and monitoring of the intervention was conducted for at least 3 years post-treatment. Here, we assumed the goal was to restore degraded impact sites to natural conditions or to create artificial streams/spawning channels similar to natural conditions (control sites), therefore the intervention(s) were only considered effective if outcomes were equal to or greater than control site outcomes (<0% may still be an improvement in the degraded sites but not relative to control site).

To be categorized as *potentially effective*, studies had a quantitative percent change in intervention effectiveness of >0 (or ≥0 % proportional change for studies that use degraded impact sites/artificial streams) for (1) body size of hatched or juvenile fishes, (2) density of nests/eggs, juveniles or adults, or (3) any outcome (1-3) listed under the effective rating criteria (Table 4) that had <3 years post-treatment monitoring. For studies that reported qualitative or semi-qualitative outcomes, we deemed these to be potentially effective based on the author statement that a successful increase in the use of spawning habitat had occurred (i.e. in the case of qualitative: absence/presence; or in the case of degraded impact sites/artificial streams: presence/presence, or semi-qualitative: absence/numbers).

To be categorized as *potentially ineffective*, studies had either no change (0%) or a decrease (<0%; a <0% proportional change for studies that use degraded impact sites/artificial streams) in the quantitative percent change in intervention effectiveness for (1) body size of hatches or juvenile fishes, (2) density of nests/eggs, juveniles or adults, or (3) any outcome (1-3) listed under the effective rating criteria (Table 4) that had <3 years post-treatment monitoring. We base qualitative or semi-qualitative evidence on author statements that either no change or a decrease in the use of spawning habitat had occurred (i.e. in the case of qualitative: presence/absence, absence/absence, presence/presence, or in the case of degraded impact sites/artificial streams: absence/presence, or semi-qualitative: presence/numbers, numbers/absence).

To be categorized as *ineffective*, studies either had no change (0%), or a decrease (<0%; a <0% proportional change for studies that use degraded impact sites/artificial streams) in intervention effectiveness for (1) egg survival, (2) the abundance/density of larvae or age-0 fish(es) and had monitored the intervention for at least 3 years post-treatment.

Lastly, to be categorized as *unclear* regarding intervention effectiveness, studies had to either use: (1) a post-treatment only study design where there was a complete lack of information (i.e., data or author statements) regarding the comparator group (i.e., before or control site), making an effectiveness assessment impossible, or (2) semi-quantitative or qualitative outcome measures and the authors stated the effectiveness of the intervention was unclear.

<u>Quantitative synthesis</u>

To be inclusive as possible (i.e., allow inclusion of data sets that either lacked replication or that did not report variances or sample sizes for mean outcomes), we did not use formal meta-analytical methods. Instead, for any data set that we have quantitative data [either a mean (number of replicates >1) or total count (n=1) for both the intervention and comparator group], we calculated the percent change in intervention effectiveness:

$$= \frac{\bar{X}_{G2} - (\bar{X}_{G1} + q)}{\bar{X}_{G1} + q} * 100, \qquad (1)$$

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, we added a small constant *q*=0.01 to $\bar{X}_{G1}$ 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. Note, for cases where degraded impact sites were compared to non-degraded control sites, or where created artificial streams/spawning channels were compared to natural waterbodies, a percent change equal to 0 indicates the outcomes at the degraded impact sites or created streams were similar to control sites/ natural waterbodies (i.e., natural conditions). For these same designs, a percent change >0 indicates the degraded impact sites or the created artificial streams/spawning channels increased outcomes over and above the natural conditions. Therefore, to help with interpretation, 100% was added to these percent changes to more clearly indicate the magnitude of the proportional change (e.g., 15% increase in an outcome with a newly created stream over and above natural conditions based on equation (1) would be indicated instead by a percent change of 115%).

We calculated weighted-mean percent changes for each intervention category (i.e., rock material, plant material, waterbody creation, waterbody modification, human-made structures, and combinations of these interventions) and outcome metric (i.e., abundance, survival, and body size) separately. Where there were sufficient sample sizes, we also calculated weighted-mean percent changes for specific types of spawning habitat creation or enhancement interventions (e.g., addition of cobble, gravel washing within the rock material alone category). Individual percent changes were weighted in mean calculations by total sample size (i.e., the number of treatment and control sites). The weighted-mean percent change was considered to be significantly different from zero (i.e. there was a significant either positive or negative effect of intervention) when the 95% confidence intervals (CI) did not overlap zero. Note, for cases where degraded impact sites were compared to non-degraded control sites, or where created artificial streams/spawning channels were compared to natural waterbodies, a percent change equal to 0 would indicate that the outcomes at the degraded impact sites or created streams were restored to natural conditions. For these cases, having a summary effect size at or near 0 would be the desired outcome. However, it was not possible to statistically show that an effect is exactly 0. Therefore, for these cases, we include 95% CIs along with weighted-mean percent changes, as an indication of the accuracy of the mean effect size (i.e., width of the interval) but do not use these CIs to consider statistical significance.

For those data sets that did not provide a sample size or sample sizes were unclear, we inputted the smallest sample size (i.e., 2) to be conservative. Furthermore, to avoid giving pseudoreplicated data too much weight in calculations of mean percent change in intervention effectiveness, in cases where outcomes were based on partly pseudoreplicated data (i.e., outcome were not from independent replicates such as waterbodies or sections of a waterbody, but subsamples such as subplots or individual nests), we used a conservative total sample size. This conservative total sample size was based on the number of true sample sites instead of pseudoreplicated sites and for this review, in all cases, the conservative sample size was 2 (i.e., one intervention and one comparator waterbody where plot or nest subsamples were taken from). We only calculated weighted-mean percent changes where there were sufficient combinable data sets (i.e., > 2 data sets from ≥2 independent studies) for each subset. We treated each data set as independent in our analyses.

RESULTS

STUDY DESCRIPTIONS

The original search of 5 databases and Google Scholar in December 2016 returned 5,164 individual records, resulting in 4,611 articles after duplicate removal, and 244 articles after Title and Abstract screening (one of which we were unable to obtain at full-text). Full-text screening with the modified inclusion criteria as described above resulted in 78 articles from databases and Google Scholar, which includes 26 PT only, 1 additional marine, and 9 juvenile-only studies that were not included in Taylor et al. (2019). In addition, 17 articles from searching the bibliographies of relevant articles and 5 articles submitted from our grey literature solicitation were included in this review for a total of 100 articles with 134 studies and 359 data sets (Table 1).

Included articles were published from 1955-2016 with the number publications increasing over time. From 1951 to 1990, grey literature made up a larger proportion of the included articles per decade (100%, 67%, 60%, 71%) than in more recent decades (1991-2016; 17%, 30%, 26%). Critical appraisal indicated that study validity tended to improve over time, with medium validity studies making up 52%, 39%, and 26% of studies in each of the last three decades (1991-2016) compared to 10%, 9%, 0% and 0% in the previous four decades (1951-1990). Interestingly, low validity studies were consistently the majority across all decades, except for the last (i.e., in 2011-2016 low validity= 48% and medium validity=52% of studies). Most of the studies were performed in North America (77%) – 40% of which were in the United States of America and 34% in Canada –, with some carried out in Europe (22%), Asia (1%), and Oceania (1%).

Of the 134 studies included in this review, 29 implemented a BA design, most of which were either unreplicated or pseudoreplicated. A CI design was used in 52 studies (Figure 1) and BACI design was used in 18 of the studies (Figure 1), and included a minimum of 1 year of before and after data and 1 control and 1 impact site. A PT or impact only design was used in 42 studies, which often described a habitat creation or enhancement with monitoring data, but no data from before the intervention or at a control site.

Studies included in this review investigated the effectiveness of spawning habitat creation or enhancement on 44 species from 26 genera and 12 families. Salmonidae were included in 60% of studies making them the most commonly studied family (Figure 2). The majority of studies applied only 1 intervention type to create or enhance spawning habitat for substrate-spawning fish (62% of data sets, Table 5) with manipulation of rock material (see Table 2 for examples and definitions) being the most common single intervention used across studies (46% of data sets, Table 5). A combination of interventions (e.g., rock materials and waterbody modification) was applied in 38% of all data sets (Table 5).

Most studies reported a metric of abundance as an outcome (including abundance, density, CPUE, and biomass), whereas relative fewer studies reported a survival or body size metric (Figure 3). Across all outcomes, the studies focused mostly on early life-stage outcomes as opposed to spawning adults.

Of the 359 data sets included in this review, 228 had a calculable percent changes (64% of data sets) and could be used to calculate the weighted-mean percent increase for individual intervention categories (Table 1). However, 9 data sets (from 6 studies) were excluded from the weighted-mean percent change calculations because the control site included as a comparator was considered degraded and therefore not comparable to all other control sites (Table 5). Sample sizes were too small to include these data sets in separate analyses.

EVIDENCE OF EFFECTIVENESS

The below sections are organized first by broad intervention categories (e.g., rock material, plant material, waterbody creation; see Table 2 for definitions) for each outcome metric separately, followed by specific types of spawning habitat creation or enhancements (subsets) for each outcome metric separately (e.g., within rock material: sediment, gravel, cobble, sediment trap, gravel washing, rock combinations, for each of abundance, survival, and body size where applicable). For each individual section, we provide summaries and descriptive statistics on, for example, the overall number of data sets, effectiveness ratings, study validity and design, and an overall weighted-mean percent change in intervention effectiveness. As a reminder, all data sets were given an effectiveness rating based on the criteria detailed in Table 4, and here we present tallies of the number of data sets for each effectiveness rating. Where there were sufficient sample sizes within intervention categories and subsets, we also present weighted-mean percent changes calculated from all data sets that had quantitative data for both the intervention and comparator group. While these mean percent changes were weighted based on a proxy of study 'quality' (i.e., sample size), they do not explicitly incorporate a measure of study validity or relevance. As a result, it is possible to estimate a high positive weighted-mean percent change in intervention effectiveness from a subset of data sets whereby either none or very few data sets were of high study validity and/or determined to be effective interventions based on the criteria outlined in Table 4 (e.g., outcome metrics used to evaluate intervention effectiveness were indirect measures of successful restoration). Therefore, careful consideration of effectiveness ratings should be made when interpreting weighted-mean percent changes for a given intervention category or subset thereof.

Rock material alone

Abundance

We found 110/359 of all data sets used rock material alone to enhance or create spawning habitat for substrate spawning fish (see Appendix A). The majority of these data sets (92/110) measured abundance to assess effectiveness of the intervention (Table 5).

There were few data sets (n=3) where the addition/alteration of rock material alone were deemed to be effective (Table 6), but most were determined to be potentially effective (n=47) or potentially ineffective (n=31), with some ineffective (n=2) or unclear ratings (n=9; Table 6). Overall, study validity was low for the majority of these data sets (n=65), with the remaining data sets deemed to have medium (n=24) or high (n=3) study validity.

We were able to calculate the percent change in effectiveness for 82/92 abundance data sets; however, four of these used a degraded impact site and were therefore excluded from the weighted-mean percent change calculation. Quantitative synthesis of 78 data sets found that overall, the addition of rock material alone increased abundance in substrate spawning fish by approximately 18% (CI: 1.32, 35.12) compared to controls (Figure 4 and Table 7).

Survival

Of the data sets using rock material alone to enhance or create spawning habitat, 15/110 measured survival (e.g., egg-to-fry survival, nest success) as the outcome metric to assess effectiveness of the intervention (Table 5).

We found only 1 data set to be effective at increasing survival of fishes (Dumont et al. 2011c; Table 6 and Appendix A). Most evaluations of rock intervention effectiveness were determined to be potentially effective (n = 7 data sets), with some potentially ineffective (n = 6) or unclear ratings (n = 1) (Table 6). Overall, study validity was medium for most data sets (n = 10), with the remaining data sets deemed to have low validity (n = 5).

There were sufficient quantitative data to calculate the percent change in effectiveness for 14/15 data sets. Of these 14, none used a degraded impact site. Overall, the addition of rock material alone increased survival of fishes by approximately 10% (CI: -11.48, 10.17) compared with control (Figure 4 and Table 7).

Body Size

We found 3/110 data sets using rock material alone to enhance or create spawning habitat measured body size as the outcome metric (Table 5 and Appendix A).

Overall, we determined all data sets to either be effective (n = 1) or potentially effective (n = 2) (Table 6). We deemed these cases to have either low (n = 1) or medium (n = 2) validity ratings (Table 6).

We had sufficient quantitative data for all 3 data sets to calculate a percent change in effectiveness. Overall, rock material alone increases body size of fishes by 4% (CI: -3.45, 12.57) compared with controls (Figure 4 and Table 7).

Sediment

Abundance. **—** Only a single data set investigated the effectiveness of fine sediment addition alone (Table 5). Toft et al. (2013a) used a BACI study design to look at the effect of sediment addition on larvae abundance of various species in Puget Sound, Washington, USA (see Appendix A). This data set was assessed to have a medium overall study validity, and there was quantitative evidence with at least three years of post-treatment monitoring to conclude the intervention was effective in increasing larvae abundance.

Gravel

Abundance. — Of the 22 data sets for gravel additions, none were found to be effective at increasing fish abundance (Table 5). The majority of cases (n=15 data sets) were potentially effective in increasing fish abundance (i.e., either there was evidence to conclude that gravel additions/alterations could be effective but the biological endpoint reported only confirms the use of spawning habitat, or there was quantitative evidence to conclude that the addition/alteration of gravel was successful in increasing the abundance of larvae/alevins or age-0 fishes but there was <three years of post-treatment monitoring). Potentially effective data sets primarily focused on salmonid species (Chum Salmon, Rainbow Trout, Brown Trout, and others) and mainly targeted egg life stage (i.e., eggs, redds, larvae). Studies were conducted in either Germany (n=7 data sets) or the USA (n=8), using primarily CI designs (n=9), but also BA designs (n=6) (Table 6 and Appendix A). The majority of potentially effective data sets (11/15) were considered of low overall study validity due to a lack of replication at the level of intervention; however, there were a few medium validity data sets (i.e., Wilson 1976b&c; Zeug et al. 2014a&b; Table 6). Gravel additions/alterations were potentially ineffective in increasing fish abundance for 6/22 data sets. There were no clear differences between data sets that were potentially effective compared to those that were potentially ineffective in increasing fish abundance. Potentially ineffective data sets also primarily focused on egg life stages of salmonids and were conducted in similar geographical locales, and all were of low study validity due to a lack of replication (Table 6). Finally, 1 data set was given an

unclear effectiveness rating for gravel additions since only post-treatment monitoring of Lake Sturgeon egg abundance was reported (Johnson et al. 2006a; Table 6).

There was sufficient quantitative data to calculate percent change in effectiveness of gravel addition/alterations on fish abundance for 21/22 data sets; however, one of these was excluded due to the use of degraded impact sites (West 1965). Overall, the addition of gravel material alone increased abundance in substrate spawning fish by approximately 75% (CI: 54.15, 95.01) compared to controls (Figure 5A and Table 7).

Survival. — Of the 5 gravel addition data sets, none were found to be effective at increasing fish survival (Table 6). We found 3 data sets to be potentially effective in increasing fish survival (Merz et al. 2004a; Fjeldstad et al. 2012; Mueller et al. 2014g). These studies were conducted in the USA (CI design), Norway (BACI design), and Germany (CI design) (Table 6). These studies focused on salmonid species (Chinook and Atlantic Salmon, and Brown Trout, respectively), and targeted age-0 and egg life stages. A 3 data sets were given medium overall validity (Table 6). We also found one data set to be potentially ineffective at improving survival (Mueller et al. 2014h). Mueller et al. (2014h) focused on Brown Trout egg survival in Germany using a CI study design and was deemed to have medium overall validity (Table 6). Finally, 1 study (20% of data sets), was unclear as to its effectiveness as it was a low validity, post-treatment only study (Johnson et al. 2006b; Table 6). There were no clear differences between gravel addition data sets that were potentially effective, versus those that were potentially ineffective, at increasing survival of substrate-spawning fishes. However, the number of data sets presented here was low and thus hard to determine any major differences (see Table 6).

We had sufficient quantitative data for 4/5 data sets measuring the effect of gravel addition on survival of fishes to calculate percent effectiveness change. Overall, the addition of gravel material alone increased survival in fishes by approximately 16% (CI: -10.53, 42.15) compared with controls (Figure 5A and Table 7).

Body Size. — Only 1 data set, conducted in California, USA, measured the effectiveness of gravel addition on body size (Merz et al., 2004; Table 6 and Appendix A). This evaluation focused on Chinook Salmon larvae and used a CI study design with only 1 year of post-intervention monitoring. The data set was assessed to have a medium validity rating, and because there was quantitative evidence with only one year of post-intervention monitoring, we determined the data set to be potentially effective at increasing body size of Chinook larvae (Table 6).

Cobble

Abundance. — Of the 52 cobble addition data sets, there was only 1 deemed to be effective at increasing fish abundance, and was conducted in Lake Huron, Canada (Marsden et al. 2016a). This data set measured the abundance of Lake Trout fry in control and intervention sites for five years post-intervention and was determined to be of medium validity (Table 6 and Appendix A). The majority of cobble addition data sets were potentially effective at increasing fish abundance (n = 24/52), and mainly conducted in the USA (n = 17), but also in Canada (n = 6), and one in Finland. Many different species, and life stages, were targeted amongst these data sets (see Table 6). Most of the data sets used CI study designs (n = 13), however BA were used by some (n = 8), and 3 data sets used BACI study designs. Most data sets were deemed to have low overall validity, mainly because they were unreplicated. The number of true post-intervention monitoring years, in these data sets, ranged from one1 to 7. Cobble addition interventions were potentially ineffective at increasing fish abundance in 20/52 data sets (Table 6). Geographically, these data sets were mainly located in North America (Canada, n = 5 and the USA, n = 9); however, a smaller number were also located in European countries such as Germany (n = 3), Finland (n = 2), and Sweden (n = 1). Most used a BACI study design (n = 8), the remaining data sets using a BA (n = 6) or CI design (n = 6). The number of true post-intervention monitoring years ranged from 1 to 3, with the majority just monitoring for one year. There was a wide variety of study species and life-stages monitored, see Table 6 for an overview. Most data sets were given low overall validity, for the BACI studies this was mainly because of poor matching of control and intervention sites, or a lack of replication. Finally, the effectiveness of seven data sets were unclear as they were measured post-treatment only with no comparator (Table 6). Again, there were no clear differences in data sets that were effective or potentially effective, versus those that were ineffective or potentially ineffective (see Table 6).

We had sufficient quantitative data for 44/52 data sets measuring the effect of cobble addition on abundance of fishes to calculate percent effectiveness change. However, 1 of these used a degraded impact site and was excluded from the weighted-mean percent change calculation, meaning a total of 43 data sets were used to calculated percent effectiveness change. Overall, we found cobble addition increased fish abundance by 5% (CI: -19.41, 28.56) compared with control sites (Figure 5A and Table 7).

Survival. — Of the 4 data sets evaluating the effectiveness of cobble additions, 1 investigation was deemed effective (Dumont et al. 2011c) and another potentially effective at increasing fish survival (Marsden et al. 1995b). In addition, 2 were potentially ineffective at increasing survival of fishes (Palm et al. 2007b; Mueller et al. 2014l) (Table 6). The evaluations that were either effective or potentially effective were conducted in Canada and focused on age-0 Lake Trout and Lake Sturgeon eggs. The data sets used CI and BA study designs, for 1 and 3 years of post-intervention monitoring, respectively (Table 6). The Lake Trout data set was given medium validity, whereas the Lake Sturgeon data set was deemed low validity as it was unreplicated (Table 6). The 2 potentially ineffective data sets were conducted in Canada and Germany. The Canadian data set (Mueller et al. 2014l) measured Brown Trout egg survival in control and intervention sites for one-year post-intervention, and was given medium validity. The German data set (Palm et al. 2007b) also focused on brown trout, but at age-0 life stage (Table 6). This data set was given a low validity rating because of lack of evidence of matching of control and intervention sites.

There was sufficient quantitative data to calculate percent change in effectiveness of cobble addition/alterations on fish survival for 4/4 data sets (Table 5). Overall, we found that cobble addition increased survival of fishes by 10% (CI: -47.06, 66.85) compared with controls (Figure 5A and Table 7).

Body Size. — Only a single data set investigated the effect of cobble addition on body size of fish (Crossman and Hildebrand 2014b; Table 6). This investigation was conducted in the Columbia River BC, Canada, and focused on White Sturgeon larvae (Appendix A). This data set was a CI study, with only 1 year of post-intervention monitoring. We determined this data set to be potentially effective at increasing sturgeon larvae body size, and it was given a medium validity rating (Table 6).

Sediment Trap

Abundance. — We found three data sets from a single study that used sediment traps and tested their effect on the abundance of fishes (Avery 1996a-c) (Table 5).

We found that no data sets were effective or potentially effective. Sediment traps were potentially ineffective at increasing fish abundance in 1/3 data sets. Avery (1996a) was conducted in Hay Creek, Wisconsin, measuring the abundance of Brown Trout redds before and after addition of sediment traps to the creek. The investigation was performed for 5 years post-intervention and was found to be potentially ineffective because the biological endpoint reported (i.e., abundance of redds) only confirmed the use of spawning habitat and not necessarily success. We gave this data set a low validity rating because it was unreplicated (Table 6 and Appendix A). We found sediment traps to be ineffective at increasing fish abundance in 2/3 data sets (Avery 1996 b&c). These data sets used a BACI design and measured the abundance of age-0 Brook and Brown Trout for5 years post-intervention. We also deemed these 2 data sets to be of low validity because they were unreplicated (Table 6).

We did not calculate a mean percent effectiveness changes for this intervention category since all 3 data sets were from a single study.

Gravel Washing

Abundance. — Of the 9 data sets, 4 were potentially effective at increasing fish abundance (1 of these having a degraded impact site). All of these data sets focused on Brown Trout. The 3 data sets without a degraded impact site were conducted in the United Kingdom, and focused on Brown Trout larvae using a CI study design with one year of post-intervention monitoring (all given a medium validity rating; see Table 6). Four of the data sets were potentially ineffective at increasing fish abundance (1 of these having a degraded impact site). The 3 data sets without a degraded impact site were conducted in Germany and measured abundance of Common Minnow, Grayling and Brown Trout redds in CI study designs with 1 year of post-intervention monitoring. All these studies were deemed to have low validity rating because they were unreplicated. The effectiveness of 1 data set was unclear as it was only measured post-treatment with no comparator (Andrew 1981a; Table 6). When comparing the evaluations that were potentially effective versus potentially ineffective, all evaluations that were potentially ineffective measured abundance of redds (n = 3) or spawners (n = 1). These biological endpoints are indicative of the use of spawning grounds and not necessarily success. Conversely, the data sets that were determined to be potentially effective mainly focused on Brown Trout larvae (n = 3).

We had sufficient data for 8/9 data sets to measure the effect of gravel washing on fish abundance and calculate mean percent effectiveness change. However, 2 of these data sets used a degraded impact site and thus were excluded from the weighted mean percentage change calculation (Tables 5 and 6). Overall, we found that gravel washing decreased abundance of fishes by 12% (CI: -58.52, 34.34) compared to control sites (Figure 5A and Table 7).

Survival. — There were 5 data sets measuring the effectiveness of gravel washing on fish survival. We found 3 of these data sets to be potentially effective at increasing survival of fishes (Wilson 1976e; Andrew 1981b; Sternecker et al. 2013) (Table 6). These investigations were conducted in the USA, Canada, and Germany, measuring age-0 salmonid survival (Chinook Salmon, Sockeye Salmon, and Brown Trout, respectively). Only 1 year of post-intervention monitoring was performed in all data sets, and BA and CI study designs were used (Table 6). Data sets were given medium validity ratings, except from the USA data set which was given a low validity rating because there were some potentially influential differences in confounding factors between the control and intervention sites. We found 2 data sets to be potentially ineffective at increasing survival of fishes (Andrew 1981c; Mueller et al. 2014p). These data sets were conducted in Canada and Germany, and measured survival of age-0 Sockeye Salmon and Brown Trout eggs, respectively. Both data sets were conducted for 1-year post-intervention and were given medium validity ratings (Table 6).

We had sufficient data for 5/5 data sets measuring the effectiveness of gravel washing on fish survival to calculate mean percent effectiveness change (Table 5). Overall, we found gravel washing to increase survival of fishes by 10% (CI: -22.21, 42.09) compared to control sites (Figure 5A and Table 7).

Rock combinations

Abundance

Of the 5 data sets investigating the effectiveness of rock combinations (i.e., all gravel+cobble), we found 1 to be effective at increasing abundance of substrate spawning fishes (Weber and Imler 1974a). This data set was conducted in Colorado, USA, and measured abundance of YOY Walleye using a BA design with 3 years post-intervention monitoring. However, this data set was given low overall validity because it was unreplicated. The other 4 data sets were determined to be potentially effective at increasing abundance of fishes (LaHaye et al. 1992; Geiling et al.o 1996; Avery 2004b; Palm et al. 2007c). These data sets were conducted in Sweden, USA, and Canada, and focused on Walleye, Brown Trout, Lake Sturgeon, and Lake Trout. LaHaye et al. (1992) and Avery (2004b) were given a low validity rating because they were unreplicated, the other 2 data sets were deemed of medium study validity (Table 6). No data sets using rock intervention combinations for abundance were found to be ineffective or potentially ineffective.

We had sufficient data for 5/5 data sets measuring the effect of rock intervention combinations on abundance of fishes to calculate percent effectiveness change (none of these data sets used a degraded impact site. Overall, we found rock combinations to increase abundance of substrate spawning fishes by 81% (CI: 59.50, 102.94) compared to control sites (Figure 5A and Table 7).

Survival

Only a single data set measured the effect of rock combinations (i.e., gravel+cobble) on survival of substrate spawning fish (Palm et al. 2007d). This investigation was conducted in Sweden and focused on age-0 Brown Trout in control and intervention sites. There were 2 years of post-intervention monitoring that was performed and we found the data set to be potentially ineffective at increasing survival of brown trout. However, the data set was given low overall validity as it was deemed to have poor matching of control and intervention sites (see Table 6).

Body Size

Only a single data set measured the effect of rock combinations (i.e., gravel+cobble) on altering body size of substrate spawning fish (Weber and Imler 1974b; Appendix A). This investigation was conducted in Colorado, USA, and measured the body size of YOY Walleye before and after the intervention was applied. Three years of post-intervention monitoring was performed and the data set was deemed to be effective at increasing body size; however, it was given a low overall validity rating because it was unreplicated (see Table 6).

Plant material alone

Abundance

We found 70/359 of all data sets used plant material alone to enhance or create spawning habitat for substrate spawning fish. The majority of these data sets (57/70) measured abundance as the outcome metric to assess effectiveness of the intervention (Table 5).

Overall, only 1 data set was determined to be effective at increasing fish abundance (Johnson et al. 2005a) and 16 was determined to be potentially effective (Table 8). The majority of data sets (n = 31) were given an unclear rating as they were assessed post-treatment only with no comparator, and a lesser number of data sets were deemed ineffective (n = 1) or potentially ineffective (n = 8; Table 8). Most data sets (n = 37) were given low study validity, with the remainder (n = 20) deemed as medium validity (Table 8).

We had sufficient quantitative data for 29/57 data sets measuring the effect of plant material alone on the abundance of substrate spawning fish species to calculate percentage change in effectiveness. However, 3 of the 29 used a degraded impact site and were excluded from the weighted-mean percent change calculation (Tables 5 and 8). Quantitative synthesis of 26 data sets found that overall, the addition of plant material alone increased abundance in substrate spawning fish by approximately 45% (CI: 30.41, 60.34) compared with control sites (Figure 4 and Table 7).

Survival

Of the 70 data sets that used plant material alone as the intervention, 6 of these measured survival as the outcome metric (Table 5).

We found that most data sets were potentially effective at increasing survival of substrate spawning fish (n = 5), and a single data set was potentially ineffective (Table 8). All of the data sets were given medium study validity ratings (Table 8).

We had sufficient quantitative data for 6/6 data sets measuring the effect of plant material alone on the survival of fish species to calculate a percent change in effectiveness.

Overall, plant material alone increased survival of fishes by about 70% (CI: 41.66, 98.76) compared with control sites (Figure 4 and Table 7).

Body Size

In total, 7/70 data sets assessing the effectiveness of plant material alone measured body size as the outcome metric (Table 5).

Overall, we found only 1 data set was potentially effective at increasing body size of fishes (Giannico and Hinch 2003m), 3 were potentially ineffective (Giannico and Hinch 2003n-p), and 3 were unclear as to their effectiveness (Roni 2003d-f; Table 8). All data sets here were given medium overall study validities (Table 8).

We had sufficient quantitative data for 7/7 data sets measuring the effect of plant material alone on the body size of substrate spawning fish species to calculate the percent change in effectiveness (Table 5). Overall, quantitative synthesis found that plant material alone decreased body size of substrate spawning fishes by 0.5% (CI: -5.11, 4.16) compared with control sites (Figure 4 and Table 7).

Log

Abundance. — We found one of the 26 data sets to be effective at increasing the abundance of substrate spawning fish (Johnson et al. 2005a; Table 8). This investigation, based in Oregon, USA, used a BACI design measuring the abundance of age-0 Coho Salmon for four years post-intervention. This data set was given a medium validity rating. We found the majority of data sets with sufficient quantitative data to be potentially effective at increasing fish abundance (n = 8; Table 8). Of these, 5 were BACI studies, and 3 were CI studies. All of the data sets were located in the USA, and mainly focused on salmonid species (and also Largemouth Bass). Most of these data sets were deemed of medium validity; however, 2 were unreplicated and thus given a low validity rating (Table 8). One data set, based in Arkansas, USA, was potentially ineffective (Hunt and Annett 2002d). This study focused on age-0 Largemouth Bass and used a CI study design. The data set was unreplicated, and thus given a low overall validity rating. One data set, based in Oregon, USA, was ineffective at increasing age-0 Steelhead abundance in a BACI study (Johnson et al. 2005e). The data set was thus given a medium overall validity rating. All other data sets focused on log addition intervention (n = 15) were unclear with respect to effectiveness at increasing fish abundance as they were assessed post-treatment only with no comparator (see Table 8). There were no clear differences between data sets that were potentially effective/effective compared to those that were potentially ineffective/ineffective in increasing fish abundance; however, it is worth noting that the number of data sets that were potentially effective/effective (n = 9) out-weighed the number of data sets that were potentially ineffective/ineffective (n = 2; Table 8).

There was sufficient quantitative data for 14/26 data sets to calculate mean percent change in effectiveness (none of these data sets had degraded impact sites; Table 5). Overall, addition of log increased abundance of substrate spawning fish by 50% (CI: 35.74, 64.97) compared with control sites (Figure 5B and Table 7).

Survival. — There were only 2 data sets that measured the effectiveness of log placement on survival of fishes, we therefore did not calculate weight-mean percent change in effectiveness for this sub-category (Table 5).

One data set was potentially effective at increasing survival of juvenile Coho Salmon in a CI design study in British Columbia, Canada (Giannico and Hinch 2007). Juvenile abundance was monitored for 2 years post-intervention, and we deemed this data set to be of medium validity (Table 8). The second data set was in Oregon, USA, and measured survival of juvenile steelhead in a BACI design study (Johnson et al. 2005f). We deemed this data set to be of medium overall validity.

Body Size. — In total there were only 3 data sets from a single study that measured the effectiveness of log placement in increasing body size of substrate spawning fish (Roni 2003d-f; Table 5 & 8); therefore, a weighted-mean percent change in effectiveness was not calculated.

All data sets, based in the USA, were unclear with respect to their effectiveness at increasing body size as they were only monitored post-intervention with no comparator (Table 8).

Brush

Abundance. — We found 5/23 data sets were potentially effective at increasing fish abundance (two of these had degraded impact sites) (see Table 8). Geographically, these data sets were from studies located in New Zealand (n = 2) and the USA (n = 3). All data sets used CI study designs and monitored for 1-year post-intervention and thus were determined to be only potentially effective, and not effective. Study species included Common Galaxias (n = 2; New Zealand) and Largemouth (n = 1), Smallmouth (n = 1), and Spotted Bass (n = 1; USA) at egg and nest life stages, respectively. All data sets were given low validity ratings because they were unreplicated (USA) or had potentially influential differences in confounding factors (New Zealand; see Table 8). Two data sets were potentially ineffective at increasing abundance of fishes (Table 8). Hickford and Schiel (2013c), based in New Zealand, measured the abundance of Common Galaxias eggs in a CI study where the impact site was originally degraded. Only 1 year of post-intervention monitoring was performed and the data set was given a low validity rating due to potentially influential differences in confounding factors between the control and intervention sites. The second potentially ineffective data set was performed in San Diego Bay, California, and measured the abundance on adult Barred Sand Bass spawners in a CI-design study (Pondella et al. 2006b). The data set was given a medium overall validity rating. All other data sets (n = 16) were unclear with respect to their effectiveness at increasing fish abundance because they were monitored post-treatment only (see Table 8).

We had sufficient data for 7/23 data sets to calculate mean percent change in effectiveness. However, 3 of these data sets had degraded impact sites and thus were excluded from the weighted-mean percent change in effectiveness calculation (Table 5). Four data sets from two studies were included in the weighted-mean calculation (Vogele and Rainwater 1975a-c; Pondella et al. 2006b). Overall, we calculated that addition of brush increased abundance of substrate spawning fishes by 33% (CI: -50.15, 115.09) compared with control sites (Figure 5B and Table 7).

Plant combinations

Abundance

There were 8 data sets that evaluated the effectiveness of plant combination interventions on the abundance of substrate spawning fish; however, these were from a single article, therefore we did not calculate a weighted-mean percent change in effectiveness for this sub-category (Table 5).

All 8 data sets were from the same article (Giannico and Hinch 2003a-h); all performed in British Columbia, Canada, used a CI study design with 1 year of post-intervention monitoring, and were deemed of medium study validity (Table 8). Three of the data sets were potentially effective at increasing abundance of juvenile Coho Salmon (Giannico and Hinch 2003a-c; Table 8). All other data sets (n = 5) were potentially ineffective (Giannico and Hinch 2003d-h; Table 8). A combination of log and brush was added to 2 different streams (Upper Paradise Creek and Upper Mamquam Creek) for 2 years. In Upper Paradise Creek, the addition of logs and brush was potentially ineffective at increasing juvenile Coho and smolt abundance in both years. However, in Upper Mamquam Creek, the intervention was potentially effective at increasing juvenile Coho abundance in both years, yet for smolts, the intervention was potentially effective in the first year, but potentially ineffective in the second year; suggesting that the effectiveness of the intervention may be creek/river-specific.

Survival

There were 4 data sets from a single article; therefore, we did not calculate a mean percent effectiveness change (Table 5). All 4 data sets were also from the same article as the abundance data sets (Giannico and Hinch, 2003i-l), and were all potentially effective at increasing survival of juvenile Coho Salmon (Table 8).

Body Size

Here again, we had sufficient data for 4/4 data sets to calculate mean percent effectiveness change (Table 5); however, they were all from a single article and we did not calculate an average percent change in effectiveness.

All 4 data sets (again all from the same article described in the above two sections; Giannico and Hinch 2003m-p) were based in British Columbia, Canada, and measured body size of juvenile Coho in CI designed studies. One data set was potentially effective (Giannico and Hinch 2003m), whereas the other 3 were potentially ineffective (Giannico and Hinch, 2003n-p).

Waterbody Creation

Abundance

In total, 57/359 of all data sets in this review used waterbody creation to improve spawning conditions for substrate spawning fish. Of these 57 data sets, 49 measured abundance as the outcome metric to assess effectiveness of the intervention (Table 5).

In total, 10 of the 49 data sets that measured abundance as the outcome metric created bays as the intervention, and 39 data sets created/extended streams. Of these data sets, we determined 10/49 to be effective, 10/49 to be potentially effective, 7/49 potentially ineffective, 2/49 ineffective, and 20/49 were unclear with respect to effectiveness. We determined 31/49 of the data sets to be of low validity, 18/49 were of medium validity, and none were determined high validity (Table 9).

We had sufficient data for 26/49 data sets that measured the effect of waterbody creation on abundance of substrate spawning fish to calculate a percent change in effectiveness (Table 5). To ensure correct interpretation of percent change in effectiveness for this intervention category, we separated data sets by the type of comparator used: (A) where the control site was a natural waterbody (n=4), or (B) a nearby reference section within the same waterbody (n=22). Overall, we found that that waterbody creation when compared to a natural waterbody (A), increased the abundance of substrate spawning fish by 144% (CI: -130.45, 218.06) (Figure 4 and Table 7). When waterbody creation was compared to a nearby reference section within the same waterbody (B), there was an overall increase in fish abundance by 46% (CI: 16.35, 75.45) (Figure 4 and Table 7).

Survival

All data sets that measured survival as the outcome metric created/extended streams i.e., there were no bay creation interventions that assess survival of fishes. Of the data sets, 1/7 was effective (Fraser et al. 1983a), 1/7 was potentially ineffective (Wissmar 2008b), 1/7 was ineffective (Fraser et al. 1983b), and 4/7 were unclear with respect to their effectiveness (Bonnell 1991g-j); Table 9). All 7 data sets were deemed to have low validity rating, all used a natural waterbody for a comparator (Table 9).

We have sufficient data for 3/7 data sets to measure the effect of waterbody creation on fish survival and calculate mean percent effectiveness change. Overall, waterbody creation increased survival of fishes by 102% (CI: -177.95, 181.27) relative to the natural condition controls (Figure 4 and Table 7: Waterbody creation A).

Body Size

Only a single data set measured the effect of waterbody creation on body size (Driedger et al. 2011) and thus we could not calculate weighted-mean percent change in effectiveness. This investigation created an artificial stream and compared it with two reference streams, and was found to be potentially ineffective at increasing body size of substrate spawning fish (Table 9). This data set was of medium validity and found that stream creation decreased body size of Arctic Grayling in the Northwest Territories by 119% compared with control streams (see Appendix A).

Bay Creation

Abundance. — We found 1 of the10 data sets to be effective at increasing fish abundance (Toft et al. 2013b) (Table 9). This data set was conducted in Puget Sound, USA, and measured the abundance of larvae from various species using a BACI study design with 3 years of post-intervention monitoring (Toft et al. 2013b). Here, Toft et al. (2003b) compared a ~100 m long pocket beach that was excavated from a stretch of riprap armoring and surfaced with pebbles and cobbles to adjacent un-restored sites. We determined this data set to be of medium study validity. The remaining 9/10 bay creation data sets were all from a single medium validity study conducted in the United Kingdom using a CI study design that reported age-0 abundance data for 9 non-salmonid species (Langler 2001a-i). We found 4 data sets to be potentially effective at increasing abundance (Langler 2001a, b, g, h; Table 9). Five data sets were potentially ineffective at increasing abundance of fishes (Langler 2001c-f, i; Table 9).

There was sufficient quantitative data to calculate the percent change in effectiveness of artificial bay creation for 10/10 data sets; all data sets used a nearby reference section within the same waterbody as comparators (Table 5). Overall, we found that bay creation increased abundance of substrate spawning fishes by 26% (CI: -20.99, 73.37) compared to controls (Figure 5C and Table 7).

Stream Creation

Abundance. — Of the 39 data sets, we found 9 to be effective at increasing the abundance of fishes (see Table 9). Geographically, these data sets were located in Denmark (n = 6), Canada (n = 2), and the USA (n = 1). The data sets focused on YOY/fry salmonids (Brown Trout, n = 7; and Sockeye Salmon, n = 2) and were mainly CI study designs (n = 8), with 1 BA-design study (Table 9). The number of years of post-intervention monitoring ranged from 3 to 17 years, and the majority of data sets were given a medium validity rating (3 data sets with a low validity rating; Table 9). Six evaluations were potentially effective at increasing abundance of fishes. These data sets were located in Denmark (n = 3), Sweden (n = 1), and the USA (n = 2). Various species were studied (see Table 9), and most evaluations used a CI study design (n = 5), with 1 data set being a BA design. Post-intervention monitoring ranged from 2 to 12 years, and data sets were either of low or medium validity rating. Two data sets from a single article in Sweden (Nilsson et al. 2014b, c) were potentially ineffective at increasing abundance of fishes at 2 separate streams. These studies measured the abundance of juvenile Northern Pike before and after stream extensions. Both data sets were of low study validity (Table 9). Two data sets were ineffective at increasing abundance of fishes (Table 9). One of these data sets was conducted in the USA (Moerke and Lamberti 2003c), and the other in Canada (Jones et al. 2003), studying age-0 Rainbow Trout and Arctic Grayling, using a BA and CI study design, respectively, with 3 years of post-intervention monitoring. Moerke and Lamberti (2003c) was unreplicated, and thus given a low validity rating, and Jones et al. (2003) was given a medium validity rating (Table 9). There were no clear differences between data sets that were effective/potentially effective compared to those that were ineffective/potentially ineffective. A fairly well-distributed range of life stages and species were studied in similar locales making it difficult to see any obvious differences. All other data sets (n = 20) were unclear with respect to effectiveness at increasing fish abundance as they were monitored post-treatment only with no comparator (Table 9).

We had sufficient quantitative data for 16/39 data sets to measure the effect of stream creation on abundance of substrate spawning fish and calculate mean percent effectiveness change (no studies had degraded impact sites; Table 5). Of the 16 data sets that measured the effect of artificial stream/spawning channel creation on abundance, 4 used a natural waterbody comparator. Overall, stream creation increased the abundance of substrate spawning fishes relative to natural waterbodies by 144% (CI: -130.45, 218.06) (Figure 5C and Table 7: Stream A). The remaining 12 data sets used a nearby reference section within the same waterbody as a comparator and resulted in an estimated average increase in abundance of 75% (CI: 46.02, 103.40) relative to control sites (Figure 5C and Table 7: Stream B).

Survival. — We found 1 of 7 data sets to be effective at increasing survival of age-0 Chum Salmon in an artificial spawning channel compared to a natural river (Fraser et al. 1983a). This data set was conducted in British Columbia, Canada and monitoring was conducted for 7 years post-intervention (Table 9). The data set was unreplicated, and thus deemed to have low study validity. Interestingly, another artificially created spawning channel from Fraser et al. (2003b) was deemed ineffective in increasing the survival of age-0 Chum Salmon. One data set found stream creation to be potentially ineffective at increasing survival of age-0 Sockeye Salmon in Washington USA (Wissmar 2008b). This data set used a CI study design and was given low study validity rating because it was unreplicated. The remainder of the data sets (n = 4) were unclear with respect to effectiveness at improving survival through stream creation/extension because they were monitored post-treatment only with no comparator (Table 9).

We had sufficient quantitative data for 3/7 data sets to calculate mean percent effectiveness change for improving survival of fishes following stream creation (Table 5). All data sets used a natural waterbody for a comparator. Overall, we found that stream creation increased survival by 102% (CI: -177.95, 181.27) relative to natural controls (Figure 5C and Table 7: Stream A).

Body Size. — Only a single data set measured the effect of stream creation on body size of substrate spawning fish. This data set was conducted in the Northwest Territories, Canada, and found that stream creation was potentially ineffective at increasing body size of juvenile Arctic Grayling and in this study body size was 119% smaller in the artificial stream compared with the control (Driedger et al. 2011). The study used a CI study design and monitored for 1-year post-intervention. The study was deemed to have medium study validity (Table 9).

Waterbody Modification

Abundance

A total of 3/359 data sets used waterbody modifications to improve habitat conditions for substrate spawning fish, all measuring abundance as the outcome metric (Table 5).

We found 2/3 data sets using waterbody modifications to be effective at increasing abundance of fishes (Hunt 1988; Linlokken 1997), and 1/3 data sets were potentially effective (Iversen 1993). Of the data sets, 2/3 were deemed to have low study validity, and 1/3 was of medium validity (Table 10).

We had sufficient data for all 3 data sets to calculate a mean percent change in effectiveness. Overall, waterbody modifications alone increased abundance in substrate spawning fish by 100% (CI: 100.00, 100.00) compared to controls (Figure 4 and Table 7).

Excavation

Abundance. — In total, 2/3 data sets used excavation to improve habitat conditions and measured abundance of substrate spawning fish (Table 5). There were too few data sets to calculate a mean percent change in effectiveness.

One data set was conducted in Norway and measured the abundance of age-0 Brown Trout using a CI designed study (Linlokken et al. 1997). The data set monitored abundance for 7 years post-intervention and found the intervention (i.e., constructed rapids) to be effective at increasing abundance. The data set was given a medium validity rating (Table 10). The second data set was conducted in Denmark and measured the abundance of various fry species in a BA designed study (Iversen 1993). The number of years of post-intervention monitoring was not reported, and thus the intervention (i.e., created pools by construction of weirs) was determined to be potentially effective and of low overall validity (Table 10).

Riparian Modification

Abundance. — Only a single data set assessed the effect of riparian modifications (i.e., modified with fencing, riprap, bank covers and current deflectors) on the abundance of age-0 Brown Trout. This data set was conducted in Wisconsin, USA, and used a BA study design (Hunt 1988). Three years of post-intervention monitoring was performed, and the intervention was deemed effective at increasing abundance. The study was unreplicated, and thus was given a low overall study validity (Table 10).

Human-made structures

Abundance

A total of 7/359 data sets used human-made structures to improve habitat conditions for substrate spawning fish. All of these data sets measured abundance as the outcome metric.

No data sets evaluating human-made structures were found to be effective at increasing fish abundance (Table 11). The majority of data sets were potentially effective at increasing abundance of fishes (n = 4). These data sets were mainly based in the USA (n = 3), but 1 data set was based in Canada. These data sets measured the abundance of various species at various life stages (see Table 11). The number of years of post-intervention monitoring ranged from 1 to 2 years and data sets were mainly of low validity (n = 5), but 2 were of medium validity. One data set was potentially ineffective at increasing Smallmouth Bass nest abundance in Wisconsin, USA (Hoff 1991). Hoff (1991) used a BACI study design with 3 years of post-intervention monitoring, and was given a low overall validity rating because there were potentially influential differences in confounding factors between the control and intervention sites. The remaining data sets (n = 2) were unclear with respect to their effectiveness at increasing fish abundance because they were only monitored post-treatment with no comparator (Knaepkens et al. 2004a&b; Table 11).

We had sufficient quantitative data for 5/7 data sets to calculate mean percent effectiveness change (Table 5). Quantitative synthesis found that overall, human-made structures alone increased abundance in substrate spawning fish by approximately 28% (CI: -31.44, 86.64) compared to controls (Figure 4 and Table 7).

Combinations of different habitat creation or enhancement measures

Abundance

A total of 112/359 data sets used various combinations of the different habitat creation or enhancement measures described above. Of these 112 data sets, 99 measured abundance as the outcome metric to assess effectiveness of the intervention (Table 5).

Overall, we found most data sets were unclear with respect to their effectiveness at increasing abundance of substrate spawning fish (n = 55/99; Table 12). We found 7 evaluations to be effective at increasing fish abundance. Most data sets that were effective, used a combination of rock and plant material additions (4/7; Avery 1996d&e; Naito 2016a&b; Table 12). Other effective modifications included rock material + human-made structure (n = 1; Scuton et al. 2005; degraded impact site), rock + waterbody modification (n = 1; Luhta et al. 2012; degraded impact site), and plant material + waterbody modifications (n = 1; Lorenz et al 2013). We found 27 combination data sets were potentially effective, 6 potentially ineffective, and four to be ineffective at increasing fish abundance (Table 12). For study validity ratings across this intervention subgroup, the majority of data sets were of low validity rating (n = 73), 22 were medium validity, and 4 were high validity (see Table 12).

We had sufficient quantitative data for 44/99 data sets to calculate mean percent change in effectiveness. However, 2 of the 44 used a degraded impact site and were excluded from the weighted-mean percent change calculation (Table 5). Overall, our weighted-mean percent change in effectiveness of combinations of habitat creation or enhancement measures (n=42) suggested an overall increase of 61% (CI: 41.03, 80.01) in abundance of substrate spawning fishes compared with controls (Figure 4 and Table 7).

In total there were 15 different combinations of habitat creation and enhancement measures (see Table 12 for all combinations). The combinations for which we had a sufficient number to perform weighted-mean percent change in effectiveness calculation for included: rock material + human-made structured (n = 8; all 8 had sufficient data, 1 degraded and thus excluded), rock material + plant material (n = 23; 20 of which had sufficient data), rock + plant + waterbody modification (n = 5; 4 of which had sufficient data), and plant + waterbody modification (n = 8; 8 of which had sufficient data (Table 5).

<u>Survival</u>

We only had sufficient quantitative data for 2/10 data sets that measured survival as the outcome metric, and thus we did not calculate the weighted-mean percent effectiveness change (Table 5). These two data sets were deemed potentially effective (Klassen and Northcote 1988b; Wills 2004b; Table 11). Wills (2004b) evaluated nest survival of Smallmouth Bass in Au Sable River, Michigan, USA in response to the addition of plant material (i.e., logs) and human-made structures. This data set was deemed to have medium overall validity, but only 1 year of post-intervention monitoring was performed, and thus was determined the intervention to be potentially effective (Table 12 and Appendix A). Klassen and Northcote (1988b) evaluated the effectiveness of a combination of rock material (i.e., gravel) and human-made structures between control and impact sites in Sachs Creek, British Columbia for egg survival of Pink Salmon. This data set was given a medium overall validity rating, but only 1 year of post-intervention monitoring was performed and thus the intervention was determined to be potentially effective (Table 12 and Appendix A).

The other 8 data sets were unclear with respect to their effectiveness as they were monitored post-treatment only with no comparator (Table 12).

<u>Body Size</u>

We had sufficient quantitative data for 3/3 data sets that measured body size in response to a combination of intervention-types (Table 5). All 3 data sets were from a single study (Naito 2016 e-g); therefore, no weighted-mean calculation was performed.

In the Whatshan River, British Columbia, Naito (2016 e-g) measured the effectiveness of a combination of rock (cobble) and plant material (logs) on fry body size of Slimy Sculpin, Steelhead Trout, and Brook Trout compared to control sites. For Slimy Sculpin and Steelhead fry, the intervention was effective at increasing body size; however, for Brook Trout, the same intervention was ineffective at increasing body size (Table 12). All 3 data sets were deemed to have medium study validity.

Rock material + Human-made structures

Abundance. — Only 1 of the 8 data sets was determined to be effective at increasing abundance of Brook Trout in response to rock material (i.e., gravel) and human-made structure addition (i.e., low head barriers); however, this data set had a degraded impact site (Scruton et al. 2005). Scruton et al. (2005) used a CI study in the Rose-Blanche River, Newfoundland, and was given medium validity (Table 12). We found 5 data sets, from a single article House and Boehne (1985d-h), to be potentially effective at increasing abundance of fishes. These 5 data sets were BACI designs that looked at the effect of rock addition (i.e., cobble) in combination with human-made structures (i.e., V-shaped gabions) on the abundance of age-0 salmonids and Coho Salmon fry in East Fork Lobster Creek, Oregon (Table 12). Finally, we found 2 data sets using rock (gravel or cobble) + human-made structures (V-shaped gabions) to be potentially ineffective at increasing abundance of substrate spawning fishes. These data sets focused on trout (House and Boehne 1985i) and Pink Salmon (Klassen & Northcote 1988a) in the USA and Canada, respectively. There were no obvious differences between data sets that were effective/potentially effective compared to those that were potentially ineffective.

We had sufficient quantitative data for 8/8 data sets that used rock + human-made structures as an intervention to calculate mean percent change in effectiveness. However, one of these had a degraded impact site and thus was excluded from the weighted mean percent change calculation (Table 5). Overall, we found that a combination of rock addition and human-made structures increased abundance of substrate spawning fishes by 59% (CI: 7.21, 111.38) compared to controls (Figure 5D and Table 7).

Rock material + Plant material

Abundance. — Most combination data sets that measured abundance as the outcome metric used a combination of rock + plant material (n = 23).

We found that 4/23 data sets that used a combination of rock and plant material were effective at increasing the abundance of substrate spawning fish (Table 12). Naito (2016a&b) monitored the effect of plant and rock material additions (i.e., cobble + logs) on the abundance of Brook Trout and Steelhead fry in the Whatshan River, British Columbia, using BACI study designs. The abundance of these species was monitored for 5 years post-intervention and the intervention was determined to be effective for species (Table 12). Overall these data sets were given medium validity ratings (Table 12). Avery (1996d&e) monitored the effect of plant and rock addition (i.e., sediment trap + gravel + logs) on the abundance of age-0 Brook Trout and Brown Trout in Waupee and Chaffee Creek, USA, using a BACI design. These data sets were both given low validity ratings because they were unreplicated; however, they were both determined to be effective at increasing the abundance of the species

(Table 12). We found that 11 data sets that used a combination of rock and plant material were potentially effective at increasing fish abundance. Geographically, these data sets were mainly located in Canada (n = 6) and the USA (n = 4), but also in Finland (n = 1). Four used a BACI design, another 4 were BA designs, and 3 were CI studies, with most data sets given low validity ratings because they were unreplicated (n = 9). There were 2 data sets however given high validity ratings (House 1996; Vehanen et al. 2010d). We found 2 data sets to be potentially ineffective at increasing abundance. These 2 data sets (Vehanen et al. 2010e-f) were both deemed to be of high validity and monitored the effect of plant and rock material addition (i.e., logs + cobble) on abundance of age-0 and juvenile Brown Trout in a BACI-designed study in Finland. We found 3 data sets to be ineffective at increasing abundance of substrate-spawning fishes (Avery 1996h; Naito 2016c&d). All used BACI designs with 3 to 5 years of post-intervention monitoring and were located in either Canada (n = 2) or the USA (n = 1). Finally, three data sets were unclear with respect to their intervention effectiveness as they were monitored post-treatment only with no comparator (Triton Environmental. Consultants Ltd 2000; Halyk 2008b &c; Table 12). There were no clear differences between data sets that were effective/potentially effective compared to those that were ineffective/potentially ineffective in increasing fish abundance. Potentially ineffective evaluations also focused on various life stages of salmonids and were conducted in similar geographical locales.

We had sufficient data for 20/23 data sets to calculate a mean percent change in effectiveness (Table 5). Overall, we found that a combination of rock and plant material increased abundance of substrate spawning fish by 54% (CI: 19.49, 87.92) compared to controls (Figure 5D and Table 7).

Rock material + Plant material + Waterbody modifications

Abundance. — Two of the 5 data sets were found to be potentially effective at increasing fish abundance using this combination of interventions (Kelly and Bracken 1998a; Ward et al. 2003a). The first data set investigated juvenile Atlantic Salmon (Kelly and Bracken 1998a; channel excavation and modification to create meanders, pool-riffles, vegetation removal, addition of gravel), while the second found increased abundances of Coho Salmon fry after the implementation of these interventions (Ward et al. 2003a; cobble, logs, nutrient addition). Kelly and Bracken (1998a) conducted their study in River Liffey, Ireland, using a BACI study design, and was determined to have medium validity (Table 12). Ward et al. (2003a) conducted a CI-designed study in the Keogh and Waukwass Rivers in British Columbia, and was deemed to have medium study validity. Interestingly, these same two studies had data sets that were deemed potentially ineffective when reporting responses for different study species (Kelly and Bracken 1998b: Brown Trout; Ward et al. 2003b:

Rainbow Trout; Table 12). Finally, another data set was unclear with respect to its effectiveness as it was monitored post-treatment only with no comparator (Island Stream and Salmon Enhancement Program 2002; Table 12).

We had sufficient data for 4/5 data sets that used rock material + plant material + waterbody modifications to calculate mean percent change in effectiveness (Table 5). Overall, we found that this intervention combination decreased abundance of substrate spawning fish by 3% (CI: -76.95, 71.55) compared to controls (Figure 5D and Table 7).

Plant material + Waterbody modification

Abundance. — Of the 8 data sets that used a combination of plant material and waterbody modification, we found 1 to be effective at increasing the abundance of various species at age-0 with 1 to 19 years post-intervention (Lorenz et al. 2013; removing bank and bed fixations, installing large woody debris). This data set took place in various locations in Germany, using a CI study design, and was given medium overall study validity (Table 12). The remaining 7 data sets were all determined to be potentially effective. One of these data sets measured the abundance of age-0 Brook Trout for 1-year post-intervention in Price Creek, Wisconsin (Avery 2004c; deburshed streambank and added brush and logs). This data set was a BA study of low validity as it was unreplicated. The remaining 6 potentially effective data sets were all reported in a single study by Langler (2001j-o) conducted in the Huntspill River, United Kingdom. This study measured the abundance of age-0 fish of 6 different species (Common Bream, Gudgeon, Eurasian Ruffe, Sunbleak, European Perch, and Common Roach) in control and impact sites (modified bank gradient with the addition of macrophytes) with a 1-year post-intervention monitoring period (Table 12). There were no potentially ineffective or ineffective data set found.

We had sufficient quantitative data for 8/8 data sets to calculate mean percent change in effectiveness (Table 5). Overall, we found that a combination of plant material and waterbody modification increased abundance of substrate spawning fish by 79% (CI: 67.68, 89.29) compared to controls (Figure 5D and Table 7).

DISCUSSION

This review was intended to act as a supplement to the Taylor et al. (2019) systematic review by providing a more comprehensive knowledge base to assess the effectiveness of spawning habitat creation or enhancements for substrate spawning temperate fish. Here, we identified 134 studies from 100 relevant articles which generated

359 data sets, of which 228 were eligible for quantitative synthesis. This included 36 additional articles (59 studies), and 176 additional data sets that were either excluded because they were considered to be unreliable sources of information (i.e., highly susceptible to bias and/or had inadequate study designs) or were slightly beyond the scope to be included in the Taylor et al. (2019) systematic review (see Table 1 and 7 for a comparison of reviews). As discussed below, it is imperative that readers are aware of the potential risks of using data arising from studies that are susceptible to bias or have inadequate study design to guide decision making. Nonetheless, such information is still part of the evidence base and may provide some guidance to practitioners given that habitat offsetting is so common and will continue to occur with or without high quality evidence.

EFFECTIVENESS OF INTERVENTIONS

All broad categories of spawning habitat creation or enhancements when applied alone increased the abundance and survival of substrate-spawning fish on average compared to controls i.e., there were no intervention categories that resulted in an overall decrease in fish abundance or survival (Figure 4 and Table 7).

There were relatively few studies that evaluated the effectiveness of interventions at increasing fish body size (Table 5). Based on the available evidence, overall, interventions resulted in minimal increases (i.e., Rock material alone: cobble and/or gravel) or even decreases (i.e., Plant material alone: logs with or without brush bundles) in body size relative to controls (Figure 4 and Table 7). Although “growth” is directly related to fisheries productivity, growth is a complex phenomenon affected by factors such as food quality and quantity and density of competitors (including conspecifics). While the intended focus of this review was on creation of spawning habitats rather than on rearing/growth habitats, the inclusion of juvenile fishes likely confounds the effects of spawning habitat enhancements with those of nursery or rearing habitat quality. Moreover, a certain level of ambiguity exists around cases where authors report on age-0 fishes for evaluations of spawning habitat creation or enhancements. While there are instances when age-0 fish responses are likely the most relevant, practical, and/or appropriate age for a particular species/study (i.e., where it known that this age class remains on the spawning substrate for a time period prior to relocation to nursery habitat, or sampling dispersing fish immediately on or downstream of spawning habitat creation/enhancements), there could also be cases where this age metric is more indicative of nursery habitat use in that fish could have hatched elsewhere. The inclusion of body size as an outcome of interest for this review originally stemmed from discussions with the Advisory Team for the Taylor et al. review around the topic of survival of age-0 fishes. For instance, while the abundance/density of age-0 fish could be used as a metric of successful restoration/enhancements, it could be reasoned that first overwinter survival is a key parameter determining successful recruitment into northern fish populations, albeit an indirect measure. In turn, body size of age-0 fish heading into winter could be a key metric influencing overwinter survival (albeit, even more indirect). We emphasize that we only ever considered body size as an indirect outcome metric in our effectiveness rating criteria (Table 4) given the aforementioned limitations.

The addition or alteration of rock material was the most commonly used intervention and achieved mean increases in the abundance and to a lesser degree survival of substrate-spawning fish compared to controls (18% and 10% increase, respectively; Figure 4 and Table 7). Only four evaluations were found to be effective (i.e., showed a quantitative increase in the abundance of larvae/age-0 fishes (n=3) or survival of eggs/nests (n=1) with at least 3 years of post-treatment monitoring) (Table 6). A much larger treatment effect on fish abundance was achieved in Taylor et al. (2019) (i.e., 90% increase; Table 7). A possible reason for the lower magnitude in intervention effectiveness estimated in this review could be due to the fact that the evidence base was dominated by studies with high susceptibility to bias [i.e., 52/78 data sets; the majority of which due to a lack of replication (27/52)] compared to the systematic review (n=6 data sets, all medium study validity). Furthermore, in Taylor et al. (2019), there was a strong taxonomic bias towards salmonids for this intervention category, i.e., 5/6 data sets for abundance were salmonids, and studies only focused on egg or larvae life stages (i.e., no studies focused on adult fish). Here, however, 36% of the data sets were evaluations of non-salmonid species/groups, and focused on a variety of life stages (Table 6). Interestingly, when separating salmonids and non-salmonids, the weighted-mean percent changes in effectiveness of rock material alone in increasing fish abundance were similar [i.e., 20% (CI: -1.26, 41.31; n=50) vs. 25% (CI: 3.74, 45.63; n=28), respectively], suggesting the effectiveness of rock material alone in this review was influenced by study validity and/or life stage. For example, when comparing the relative strength of the intervention effectiveness between medium/high and low validity salmonid only studies, we saw a larger average increase in fish abundance compared to controls for the former [i.e., 31% (CI: 0.26, 62.04; n=21) vs. 13% (CI: -15.42, 41.95; n=29), respectively]. Indeed, this pattern was observed for non-salmonid species as well [medium/high validity studies: 62% (CI: 20.98, 103.83; n=5) vs. low validity studies: 18% (CI: -5.74, 41.37; n=23)]. Therefore, in both reviews, the synthesis of available evidence suggests that the addition or alteration of rock material (e.g., addition of gravel, substrate washing) was an effective means of enhancing spawning habitat; however, the relative magnitude of this intervention effectiveness was influenced by study validity, with higher mean increases in abundance for analyses based on studies with lower susceptibility to bias (Table 7). Furthermore, the results from this review suggest that the effectiveness of rock material applies to other species beyond just salmonids.

The more comprehensive data base of evidence in this review allowed for a quantitative investigation of the relative effectiveness of different forms of rock material which was not possible in Taylor et al. (2019) (Table 7). Of the rock interventions, the addition of gravel with or without the addition of cobble (i.e., rock combinations) were the most effective spawning habitat creation or enhancements for increasing fish abundance relative to controls (81% and 75% increase, respectively; Figure 5A and Table 7). For gravel alone additions, there was a strong taxonomic bias towards salmonids, and studies primarily focused on egg or larvae life stages (Table 6). There was only a single data set found to be effective using gravel, in this case, along with the addition of cobble for Walleye (Weber 1974a); however, the data set was considered to have low validity (Table 6). In fact, the majority of data sets evaluating gravel, with or without cobble, were of low study validity (19/25 data sets). There was relatively little evidence in comparison that other rock additions or alterations (i.e., cobble and/or gravel washing), increased fish abundance overall relative to controls (Figure 5A and Table 7). However, upon further investigation into the addition of cobble, we found that the weighted-mean percent change in effectiveness in increasing fish abundance was higher and less variable for non-salmonids than salmonids [i.e., 22% (CI: -6.69, 51.48; n=20) vs. -1.34% (CI: -35.54, 32.86; n=23), respectively], but confidence intervals overlapped 0% for both groups. This observation suggests the type of rock addition or alteration is likely species or species group specific.

Relatively similar overall increases in fish survival were observed across the different forms of rock material additions or alterations (i.e., gravel, cobble and gravel washing; Figure 5A). Survival evaluations were conducted almost exclusively on salmonids (Table 6). The single study that focused on a non-salmonid (Lake Sturgeon) was also the only survival evaluation of rock effectiveness (i.e., addition of cobble) that was deemed to be effective, albeit of low study validity (Dumont et al. 2011c; Table 6).

The addition of plant material (i.e., large woody debris, brush piles) was also effective in increasing substrate-spawning fish abundance and survival on average compared to controls (45% and 70% increase, respectively; Figure 4 and Table 7). Only one plant material data set (i.e., addition of logs) had sufficient evidence to be considered an effective spawning habitat creation or enhancement measure (Johnson et al. 2005a). Interestingly, however, the majority of data sets were considered to be of medium study validity (20/26 abundance and 6/6 survival data sets, respectively; Table 8). Similar treatment effects of plant material additions on fish abundance were observed here as in the Taylor et al. (2019) systematic review (45% and 49% increase, respectively; Table 7), likely owing to the dominance of higher validity studies included in both data bases for this intervention category. At a finer scale, the addition of logs was more effective overall than brush piles for increasing fish abundance relative to controls (50% and 33% increase, respectively; Figure 5B and Table 7). Evaluations of logs targeted a mixture of salmonids and non-salmonids and life stages, and were primarily of medium study validity (Table 8). Whereas, data sets implementing brush piles targeted centrarchid nests and serranid adult spawners to evaluate changes in abundance, and all but one were of low study validity (primarily due to a lack of replication at the level of the intervention) (Table 8).

The paucity of plant material evaluations considered to be effective, despite many having low susceptibility to bias, suggests the evidence base is largely made up of data sets based on indirect outcome metrics and/or short-term post-treatment monitoring periods. With the inclusion criteria broadened in this review to cover juvenile fish life stages, a number of data sets on salmonid responses to the addition of logs and brush were captured

(Table 8). In fact, all data sets investigating the effectiveness of log and brush additions on fish survival were from juvenile salmonid species (i.e., Coho and Steelhead Salmon) (Table 8). Furthermore, of the data sets that evaluated the effectiveness of adding plant material on non-salmonid fish abundance, most targeted egg life stages of centrarchids (Table 8). Outcome metrics such as the presence/abundance of eggs, nests, juveniles, and/or adults only confirms the use of spawning habitat and not spawning success directly, whereas embryonic survival can often be taken as direct evidence of successful restoration (Fitzsimons 2014; Smokorowski et al. 2015). Additionally, many evaluations monitored the intervention for less than 3 years post-treatment (~70%). This trend was also observed in a recent meta-analysis on the effect of instream structures on salmonids that found fewer than 5 projects were monitored beyond 10 years (White et al. 2010). Long-term studies are important to identify changes in the effectiveness and longevity of the interventions.

The creation of a new waterbody or the extension of an existing waterbody also achieved mean increases in the abundance of substrate-spawning fish (Figure 4 and Table 7). For investigations that compared newly created artificial streams or spawning channels with natural waterbodies, changes in abundance were variable but an average increase in abundance of 144% compared to natural conditions were estimated (i.e., if artificial streams were similar to natural conditions, we would expect a % change in intervention effectiveness equal to 0; therefore an >0 indicates the intervention exceeded natural conditions) (Figure 4 and Table 7: Waterbody creation A). There were relatively few evaluations but 2 of the 4 data sets had sufficient evidence to be considered an effective spawning habitat creation or enhancement measure (West and Mason 1987a&b), both of which were for Sockeye Salmon; however, both data sets were considered to have high susceptibility to bias (Table 9). There were no such cases using a natural waterbody as a comparator included in Taylor et al. (2019) (Table 7).

For investigations that compared extensions of an existing waterbody (e.g., re-meandered sections, creation of bays) with nearby reference sections within the same waterbody, mean increases in abundance were also achieved (46% increase; Figure 4 and Table 7: Waterbody creation B) (note here, if extensions of an existing waterbody improved fish abundance relative to reference sections, we would expect a % change in intervention effectiveness > 0). In comparison to all other intervention categories, the number of effective data sets was relatively high (i.e., 8/22 data sets), most of which were considered of medium study validity and targeted Brown Trout (7/8) (Table 9). Similar treatment effects on fish abundance for cases using reference sections within the same waterbody as a comparator were observed here, as in the Taylor et al. (2019) systematic review (46% and 39% increase, respectively; Table 7), again, likely owing to the dominance of higher validity studies included in both data bases for this intervention category. At a finer scale, extensions of an existing stream (i.e., impacts sites were re-meandered and compared to unrestored straight reaches within the same waterbody) were more effective overall than the creation of bays (i.e., created bays or pocket beaches) for increasing fish abundance relative to controls (75% and 26% increase, respectively; Figure 5C and Table 7). Data sets of extensions of an existing stream primarily targeted Brown and Rainbow Trout, whereas, data sets creating bays primarily targeted age-0 non-salmonids (i.e., cyprinids) (Table 9).

There were relatively fewer data sets that evaluated the effectiveness of waterbody modifications (e.g., excavations, riparian modifications, grading banks, etc.) and the addition of human-made structures (e.g., mesh tubes, PVC, masonry blocks, ceramic tiles) in increasing substrate-spawning fish abundance (Figure 4; Tables 10&11). Based on these relatively low samples, quantitative synthesis suggested both intervention categories were effective in increasing abundance on average compared to controls (100% and 28% increase, respectively; Figure 4 and Table 7). Three individual papers reported increases in age-0 trout species abundance from waterbody modifications relative to controls, 2 of which were deemed effective (Table 10). Changes in fish abundance with the addition of human-made structures were more variable, and targeted salmonids and non-salmonid species of various life stages.

Combinations of interventions showed some of the largest increases in abundance relative to controls (Figures 5 & 6D and Table 7). The most effective combination was plant material (i.e., woody debris or planting of macrophytes) + waterbody modifications (i.e., riparian modifications or excavation), followed by rock material + human-made structures, and rock + plant material (79%, 59%, and 54% increases, respectively; Figure 5D). Similar treatment effects of plant material + waterbody modifications on fish abundance were observed here as in the Taylor et al. (2019) systematic review (79% and 78% increase, respectively; Table 7). This was not surprising as only 1 additional data set was included to this review i.e., it was excluded from Taylor et al. (2019) quantitative synthesis due to low study validity. All data sets targeted age-0 fishes and mostly non-salmonid species (Table 12). The combination of rock material + human-made structures was not included in the Taylor et al. (2019) meta-analysis as the evaluations were considered unsuitable for quantitative synthesis meta-analysis (i.e., they did not report measures of outcome variability); therefore, the relative magnitude in intervention effectiveness cannot be compared to results presented here. All evaluations targeted age-0 salmonids, and no evaluations were considered to be effective (Table 12). A much larger treatment effect of rock (i.e., gravel with or without sediment traps, or cobble) + plant material (i.e., logs or brush piles) on fish abundance was achieved in this review compared to Taylor et al. (2019) (i.e., 54% vs. 6% increase, respectively). However, in the Taylor et al. (2019) meta-analysis, to increase sample size, we 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). As a result, the relative treatment effect observed in the systematic review is not comparable to the treatment effect observed here for the rock + plant material combination. Four of 20 data sets had sufficient evidence to be considered an effective combination of spawning habitat creation or enhancement measures. Most data sets targeted salmonid species (18/20), of a variety of life stages and there was no obvious pattern between intervention effectiveness and study validity (Table 12).

LIMITATIONS OF THE QUANTITATIVE SYNTHESIS

The weighted-mean percent changes in intervention effectiveness presented here, and in the Taylor et al. (2019) systematic review, can be used to inform regulatory decisions regarding ratios and benchmark indicators; however, they should not be used towards advocating an ***explicit*** offsetting value, ratio, or benchmark indicator. For example, this metric cannot explicitly provide an offsetting value to say for example, 100 m^2 of rock are needed to achieve an increase in age-0 fish density. Furthermore, a comparison between an estimated 45% increase in abundance with the addition of woody debris relative to areas with no intervention and a 18% increase in abundance with the addition of rock material relative to control sites, should not be used to infer that fewer logs than rocks are required to achieve equivalency. Also, the weighted-mean percent change in intervention effectiveness should not be used as an explicit benchmark indicator for effectiveness consideration (e.g., a 45% increase in abundance must be achieved for logs to be considered effective and anything less would require additional offsetting). These recommendations stem from a few considerations. First, while percent changes from individual comparisons were weighted in summary effect estimates based on a proxy of study 'quality' (i.e., sample size), this metric/weighting does not explicitly incorporate a measure of study validity. The results of this report highlight this issue as we found that different weighted-mean percent changes were estimated depending on the quality of the studies included in the analyses (based on evaluations of methodological quality during critical appraisal), with higher mean increases in abundance for analyses based on studies with lower susceptibility to bias. Second, this metric does not capture issues related to study relevance or generalizability, for example, whether the reported outcome measure was considered a direct measure of successful restoration (e.g., egg-to-fry survival, abundance of larvae/age-0 fishes) versus an indirect measure (e.g., the presence or density of nests/eggs, juveniles, or spawning adults, presence of larvae/age-0 fishes, or body size metrics). As a result, it was possible to estimate a high positive weighted-mean percent change in intervention effectiveness from a subset of data sets whereby either none or very few data sets were determined to be effective interventions based on our effectiveness rating criteria outlined in Table 4. Therefore, using weighted-mean percent changes at face-value could be misleading without careful consideration of certain study quality and relevance related variables. Third, sample sizes within intervention categories and subsets thereof were often small and/or combined data sets that varied across species, life stages and ecosystems which increases uncertainty in the estimated effectiveness of interventions. Also, data within intervention categories and subsets thereof were often negatively skewed and these distributions were not improved by applying a transformation. Uncertainty estimation using bootstrapping was not appropriate given the small sample sizes, which has the potential to increase uncertainty in estimated weighted-mean percent changes and confidence intervals. All we can infer from the weighted-mean percent change metric is the direction (an increase, decrease, or no change) and the *relative* strength of the treatment effect. Furthermore, analyses used here were unsophisticated in comparison to the systematic review meta-analysis. For instance, we did not control for the lack of independence between data sets (i.e., data sets were treated independent), which has the potential to increase uncertainty in results presented in this review.

COMPARISON OF FINDINGS ARISING FROM THE DFO TECHNICAL REPORT AND THE SYSTEMATIC REVIEW

The systematic review conducted by Taylor et al. (2019) used rigorous procedures to identify papers for inclusion in their quantitative analysis. As such, there were studies that were excluded because they did not meet all of the inclusion criteria, or they were relevant but were considered unsuitable for quantitative synthesis meta-analysis. Additionally, studies focusing entirely on juvenile fish (age-1) were excluded from Taylor et al. (2019) to ensure focus on spawning habitat effectiveness yet such habitats may be used as nurseries. Following CEE standards, excluded studies were considered to be unreliable sources of information (i.e., highly susceptible to bias and/or had inadequate study designs) or were slightly beyond the scope to be included in the systematic review. Yet, these studies could further contribute useful information and provide a more comprehensive knowledge base on the subject, when accompanied with appropriate consideration and caveats for study validity. Indeed, that is the basis for this report. This begs the question – what, if anything was learned from this additional evidence synthesis (i.e., the technical report) that extends beyond the initial systematic review (i.e., Taylor et al. 2019).

One of the most notable observations is that by adding the lower validity studies to this report, there was evidence of increased uncertainty in the estimated effectiveness relative to the systematic review. For example, in the report all enhancements/creations appeared to increase fish abundance and to a lesser degree survival. The relative magnitude of treatment effects in the report varied greatly across interventions (see Figure 4; ranges from 18-144% for abundance; 2-70% for survival). Moreover, the relative magnitudes differ for some interventions (i.e., rock material) between the report and the systematic review. In contrast, there were relatively fewer intervention categories and outcomes that could be evaluated in the systematic review due to small sample sizes; however, the relative magnitude of treatment effects for those that could be evaluated ranged from 39-90% for abundance. It appears that at least for rock, the addition of lower validity studies is reducing the treatment effect on average related to the systematic review when only high validity studies were included. It is difficult to know if the increased variability in papers summarized in the report is a function of the way in which the science was conducted (i.e., lower quality and thus inherently more variable due to errors or bias) or if it is simply a matter of it encompassing a greater diversity of studies (endpoints, species).

One of the primary benefits of the report is that it enabled us to include a greater diversity of species. For example, in the systematic review the rock analyses were dominated by salmonids (5/6) yet in the report there were several examples that demonstrated that rock could also be effective for non-salmonids such as walleye and sturgeon. Given the diversity of species that fish habitat managers and restoration practitioners consider when dealing with off-setting, relying solely on data emanating from studies on salmonids is problematic. Nonetheless, the treatment effect is influenced by study validity given that low quality studies were included in the report. Hence, we encourage practitioners to consider both the systematic review and report but ensure that they fully understand the reliability of findings emanating from each document (approach) and the relatively small samples in both.

Overall, the results from the report support the general findings from the systematic review. Yet, it also demonstrates the importance of basing quantitative analyses on high validity studies. The report analyses were comparatively simpler than the those in the systematic review meta-analysis. As mentioned above, for example, in the report we did not control for the lack of independence between data sets. One of the greatest benefits of the report is that it serves as an annotated (in a standardized manner) source of information that can be easily accessed by practitioners. The annotations provide an independent and candid critical appraisal that can guide practitioners in the extent to which they can rely on their findings (Appendix A). This is particularly relevant for the non-salmonid examples. Consider an example where a practitioner is tasked with identifying an off-setting strategy for walleye spawning. Although the systematic review can provide some insight, it would be foolhardy not to also search the report database for walleye (or other percid) examples. At the end of the day offsetting decisions need to be made irrespective of whether the current evidence base is lacking. As such, anything that provides more evidence to guide decision makers while also identifying bias and uncertainty will be useful. Perhaps there will be a time in the future where the evidence base for fish spawning habitat creation and enhancement is populated with many diverse studies that are highly reliable but in the interim, such activities will continue and the data presented in the systematic review and report serve as complementary and transparent sources of evidence synthesis.

CONCLUSIONS

This review uncovered several key insights worthy of consideration for fish habitat managers and restoration practitioners:

1. All spawning habitat creations and enhancements when applied alone appeared to increase fish abundance and to a lesser degree survival of substrate-spawning fish on average compared to controls.

2. The addition or alteration of rock material was an effective means of enhancing spawning habitat; however, the type of rock addition or alteration is likely species or

species group (e.g., spawning guild – see Balon 1975) specific. For example, gravel additions, with or without cobble were the most effective rock material interventions for increasing fish abundance relative to controls, but results may only be applicable for salmonids. The effectiveness of cobble additions in increasing fish abundance was higher and less variable for non-salmonids than salmonids.

3. The addition of plant material (e.g., large woody debris) with or without physical alterations to the waterbody (e.g., excavation) was also effective in increasing substrate-spawning fish abundance and survival (plant material only) on average compared to controls.

4. The creation of a new waterbody or the extension of an existing waterbody also achieved mean increases in the abundance of substrate-spawning fish. Results for increases in abundance from newly created artificial streams or spawning channels, and extensions of existing streams, may only be applicable to salmonid species; whereas, increases in abundance from creating bays may only be applicable for non-salmonids (i.e., cyprinids, percids).

5. The relative magnitude of intervention effectiveness appears to be influenced, at least for rock material additions, by study validity, with higher mean increases in abundance for analyses based on studies with lower susceptibility to bias.

6. Based on our effectiveness rating that considers study quality and relevance related variables, only 4% of evaluations were deemed effective spawning habitat creations or enhancements (i.e., showed a quantitative increase in a direct measure of successful restoration with at least 3 years of post-treatment monitoring) when considering only studies with low susceptibility to bias.

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Note, full citation information of all included studies can be found in Appendix A.

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Table 1. Comparison of numbers and methods between the Taylor et al. (2019) systematic review and this DFO technical report. H: high study validity (low bias); M: medium study validity (moderately bias); L: low study validity (high bias); SMD: standardized mean difference effect size measure used in formal meta-analysis (i.e., Hedges' *g*).

Review aspect	**Systematic review**	**DFO tehnical report**
No. of articles (studies)	64 (75)	100 (134)
No. of data sets in narrative (quantitative synthesis)	183 (53)	359 (228)
Quantitative synthesis		
Methods		
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

Table 2. Intervention types assessed in this review along with definitions. Intervention Types were assigned based on intervention details provided by authors. Intervention categories were assigned to combinations of one or more similar intervention types (i.e., Intervention Type). Both Intervention Types and Categories were used in the Narrative and Quantitative Syntheses.

Intervention Type	Definition	Intervention Category	Definition
Sediment	Fine sediment addition	**Rock material**	Aggregate/rock (additions/alterations)
Gravel	Gravel Addition		
Cobble	Addition of cobble, boulders, small rocks, artificial reefs made of rocks		
Sediment trap	Removal of sediment using a sediment trap		
Gravel washing	Gravel washing using pressure washers, or mixing substrate and allowing fine sediment to wash downstream, includes substratum raking, flooding to clean sediment		
Excavate	Excavation	**Waterbody Modification**	Waterbody modifications (physical alterations)
Riparian	Riparian modifications, grading of banks		
Nutrient	Addition of a nutrient		
Bay	Creation of bays	**Waterbody Creation**	Creation of a new waterbody or extension of an existing waterbody
Stream	Artificial stream, creek, spawning channels		
Structure	Human-made structure (e.g., mesh tubes, PVC, masonry blocks, ceramic tiles)	**Human-made Structures**	Human-made structures (additions)
Log	Addition of logs, large woody debris	**Plant material**	Plant material
Brush	Addition of brush bundles/straw bails		
Vegetation	Planting of vegetation including macrophytes		

Table 3. Terms related to study design and their definitions used throughout the report.

Term	Definitions
Article	An independent publication (i.e., the primary source of relevant information).
Study	An experiment or observation that was undertaken over a specific time period at a particular site (i.e., ecologically independent sites from the same or different article).
Data set	(1) A single independent study from a single article; or (2) when a single independent study reported separate comparisons for different: (a) species, and/or (b) the same species but responses for different outcome categories (i.e., abundance, survival, body size), different intervention categories (i.e., rock material, plant material, waterbody creation/extension, etc.), or different life stages (e.g., the abundance of eggs for species A, and the abundance of age-0 for species A).

Table 4. Criteria for rating intervention(s) effectiveness.

Effectiveness rating	Criteria
Effective	Quantitative evidence* exists to conclude that the intervention(s) was successful in increasing: (1) nest/egg survival/success (e.g., egg-to-fry survival); or (2) the abundance/density of larvae/alevins; or (3) the abundance/density of age-0 fish(es) (i.e., fry, parr, young-of-the-year (YOY)); and (4) quantitative data for minimum of 3 years post-treatment
Potentially effective	Evidence exists to conclude that the intervention(s) could be effective but the biological endpoint reported only confirms the use of spawning habitat and not necessarily success. These endpoints include an increase in: (1) the presence or density of nests/eggs; or (2) the presence of larvae and/or age-0 fish compared to absence (before or at control site); or (3) the presence or density** of juveniles; or (4) the presence or density of spawning adults; or Other circumstances deemed potentially effective include: (5) an increase in the body size for any hatched fishes (i.e., larvae and/or age 0) and/or juveniles. (6) Quantitative evidence* exists to conclude that the intervention(s) was successful in increasing any endpoint (1-3) listed under the effective rating criteria but there was only ≤2 years post-treatment monitoring.
Potentially ineffective	Evidence exists to conclude that the intervention(s) could be ineffective but the biological endpoint reported only confirms the lack of use of spawning habitat and not necessarily that the intervention was unsuccessful. These endpoints include an decrease or no change in: (1) the presence or density of nests/eggs; or (2) the presence of larvae and/or age-0 fish compared to absence (before or at control site); or (3) the presence or density of juveniles; or (4) the presence or density of spawning adults; or Other circumstances deemed potentially ineffective include: (5) an decrease or no change in the body size for any hatched fishes (i.e., larvae and/or age-0) and/or juveniles. (6) Quantitative evidence* exists to conclude that the intervention(s) was not successful in increasing any endpoint (1-3) listed under the ineffective rating criteria but there was only ≤2 years post-treatment monitoring.

Effectiveness rating	Criteria
Ineffective	Quantitative evidence* exists to conclude that the intervention(s) was not successful in increasing an endpoint i.e., there was no change or a decrease in: (1) nest/egg survival/success (e.g., egg-to-fry survival); or (2) the abundance/density of larvae/alevins; or (3) the abundance/density of age-0 fish(es) (i.e., fry, parr, young-of-the-year (YOY)); and (4) quantitative data for minimum of 3 years post-treatment
Unclear	Applies to post-treatment studies where there is a complete lack of information (data or author statements) regarding the comparator group (i.e., before or control site). Presence/absence or quantitative data are only reported for intervention group, making an effectiveness assessment impossible. Also, semi-quantitative (e.g., presence/numbers) or qualitative (e.g., presence/presence) studies where authors conclusions on the effectiveness of the intervention(s) is stated as unclear.

*see equation (1) from Quantitative synthesis

Table 5. Number of data sets for the three different outcome metrics and study validity ratings by interventions. Numbers in brackets indicate the number of data sets with a calculable percent change in effectiveness used for Quantitative synthesis. Asterisks indicate subsets which contain data sets that used a CI design comparing degraded impact sites to natural condition control sites (sample sizes were too small to include these data sets in separate analyses and were therefore excluded from weighted-mean calculations).

		Outcome			Study Validity		
	Totals	**Abundance**	**Survival**	**Body size**	**Low**	**Medium**	**High**
Alone							
Rock material	**110**	**92**	**15**	**3**	**71**	**36**	**3**
Sediment	*1*	1 (1)	0	0	0	1	0
Gravel	*28*	22 (21)*	5 (4)	1 (1)	19	9	0
Cobble	*57*	52 (44)*	4 (4)	1 (1)	37	17	3
Sediment trap	*3*	3 (3)	0	0	3	0	0
Gravel washing	*14*	9 (8)*	5 (5)	0	7	7	0
Rock combinations	*7*	5 (5)	1 (1)	1 (1)	5	2	0
Plant material	**70**	**57**	**6**	**7**	**37**	**33**	**0**
Log	*31*	26 (14)	2 (2)	3 (3)	15	16	0
Brush	*23*	23 (7)*	0	0	22	1	0
Vegetation	*0*	0	0	0	0	0	0
Plant combinations	*16*	8 (8)	4 (4)	4 (4)	0	16	0
Waterbody creation	***57***	**49**	**7**	**1**	**38**	**19**	**0**
Bay	*10*	10 (10)	0	0	0	10	0
Stream	*47*	39 (16)	7 (3)	1 (1)	38	9	0
Waterbody modification	**3**	**3**	**0**	**0**	**2**	**1**	**0**
Excavate	*2*	2 (2)	0	0	1	1	0
Riparian	*1*	1 (1)	0	0	1	0	0
Human-made Structures	**7**	**7**	**0**	**0**	**5**	**2**	**0**
Structure	*7*	7 (5)	0	0	5	2	0

		Outcome			Study Validity		
	Totals	**Abundance**	**Survival**	**Body size**	**Low**	**Medium**	**High**
<u>Combinations</u>	**112**	**99**	**10**	**3**	**81**	**27**	**4**
Rock material + Human-made structures	*9*	8 (8)*	1 (1)	0	4	5	0
Rock material + Waterbody creation	*28*	27	1	0	28	0	0
Rock material + Waterbody modifications	*11*	9 (1)*	2	0	10	1	0
Rock material + Waterbody modifications + Waterbody creation	*3*	2	1	0	3	0	0
Rock material + Waterbody modifications + Human-made structures	*6*	4	2	0	6	0	0
Rock material + Plant material	*26*	23 (20)	0	3 (3)	15	7	4
Rock material + Plant material + Human-made structures	*2*	2 (2)	0	0	1	1	0
Rock material + Plant material + Waterbody creation	*1*	1	0	0	1	0	0
Rock material + Plant material + Waterbody modifications	*5*	5 (4)	0	0	1	4	0
Rock material + Plant material + Waterbody modifications + Waterbody creation	*1*	1	0	0	1	0	0
Plant material + Human-made structures	*2*	1 (1)	1 (1)	0	0	2	0
Plant material + Waterbody modifications	*8*	8 (8)	0	0	1	7	0
Plant material + Waterbody modifications + Waterbody creation	*2*	2	0	0	2	0	0
Waterbody modifications + Waterbody creation	*2*	2	0	0	2	0	0
Waterbody modifications + Human-made structures	*6*	4	2	0	6	0	0
Totals	**359**	**307**	**39**	**13**	**234**	**118**	**7**

Table 6. Summary characteristics and results of studies using rock material alone to enhance or create spawning habitat for substrate spawning fish. Study designs: BA: before-after; CI: control-impact; BACI: before-after-control-impact; PT: post-treatment only. See Appendix A for full citation information of included studies.

Study citation	Location	Effectiveness rating	Critical appraisal	Species	No. of true post-treatment years	Study design	Outcome	Life stage	Replication	Outcome category
Sediment										
Toft et al. 2013a	Puget Sound, Washington, USA	Effective	Medium	*Various*	3	BACI	Abundance	larvae	pseudoreplicated	Quantitative
Gravel										
Merz and Setka 2004	Mokelumne River, California, USA	Potentially Effective	Low	*Oncorhynchus tshawytscha*	3	BA	Abundance	redd	unreplicated	Quantitative
Mueller et al. 2014a	Danube, Rhine and Elbe Rivers, Germany	Potentially Effective	Low	*Phoxinus phoxinus* (16-32mm grain size)	1	CI	Abundance	redd	unreplicated	Quantitative
Mueller et al. 2014b	Danube, Rhine and Elbe Rivers, Germany	Potentially Effective	Low	*Thymallus thymallus* (16-32mm grain size)	1	CI	Abundance	redd	unreplicated	Quantitative
Mueller et al. 2014c	Danube, Rhine and Elbe Rivers, Germany	Potentially Effective	Low	*Salmo trutta* (16-32mm grain size)	1	CI	Abundance	redd	unreplicated	Quantitative
Mueller et al. 2014d	Danube, Rhine and Elbe Rivers, Germany	Potentially Effective	Low	*Thymallus thymallus* (8-16mm grain size)	1	CI	Abundance	redd	unreplicated	Quantitative
Mueller et al. 2014e	Danube, Rhine and Elbe Rivers, Germany	Potentially Effective	Low	*Salmo trutta* (8-16mm grain size)	1	CI	Abundance	redd	unreplicated	Quantitative
Wilson 1976a	Perkins Creek, Washington, USA	Potentially Effective	Low	*Onchohynchus keta*	2	BA	Abundance	spawner	unreplicated	Quantitative
Wilson 1976b	Perkins Creek, Washington, USA	Potentially Effective	Medium	*Onchohynchus keta*	2	BA	Abundance	fry	pseudoreplicated	Quantitative
Wilson 1976c	Perkins Creek, Washington, USA	Potentially Effective	Medium	*Onchohynchus keta*	2	CI	Abundance	fry	pseudoreplicated	Quantitative
Wilson 1976d	Exeter Springs, Washington, USA	Potentially Effective	Low	*Onchohynchus keta*	1	BA	Abundance	fry	pseudoreplicated	Quantitative

Study citation	Location	Effectiveness rating	Critical appraisal	Species	No. of true post-treatment years	Study design	Outcome	Life stage	Replication	Outcome category
Gravel cont.										
Zeug et al. 2014a	Lower American River, California, USA	Potentially Effective	Medium	*Oncorhynchus tshawaytsch*	Varies between sites	BA	Abundance	redd	replicated	Quantitative
Zeug et al. 2014b	Lower American River, California, USA	Potentially Effective	Medium	*Oncorhynchus mykiss*	Varies between sites	BA	Abundance	redd	replicated	Quantitative
Zeh and Donni 1994a	Rhine River, Eastern Germany	Potentially Effective	Low	*Thymallus thymallus*	2	CI	Abundance	egg	unreplicated	Quantitative
Zeh and Donni 1994b	Rhine River, Eastern Germany	Potentially Effective	Low	*Thymallus thymallus*	2	CI	Abundance	larvae	unreplicated	Quantitative
West 1965†	Tex Creek, Oregon, USA	Potentially Effective	Low	*Oncorhynchus tshawytscha*	4	CI	Abundance	redd	unreplicated	Quantitative
Hunt et al. 2002	NESA Ponds, Kansas, USA	Potentially Ineffective	Low	*Micropterus salmoides*	1	CI	Abundance	nest	unreplicated	Quantitative
Mueller et al. 2014f	Danube, Rhine and Elbe Rivers, Germany	Potentially Ineffective	Low	*Phoxinus phoxinus* (8-16mm grain size)	1	CI	Abundance	redd	unreplicated	Quantitative
Zeh and Donni 1994c	Rhine River, Eastern Germany	Potentially Ineffective	Low	*Salmo trutta fario*	2	CI	Abundance	egg	unreplicated	Quantitative
Zeh and Donni 1994d	Rhine River, Eastern Germany	Potentially Ineffective	Low	*Oncorhynchus mykiss*	2	CI	Abundance	egg	unreplicated	Quantitative
Zeh and Donni 1994e	Rhine River, Eastern Germany	Potentially Ineffective	Low	*Salmo trutta fario*	2	CI	Abundance	larvae	unreplicated	Quantitative
Zeh and Donni 1994f	Rhine River, Eastern Germany	Potentially Ineffective	Low	*Oncorhynchus mykiss*	2	CI	Abundance	larvae	unreplicated	Quantitative
Johnson et al. 2006a	Lake St. Lawrence, New York, USA	Unclear	Low	*Acipenser fulvescens*	4	PT	Abundance	egg	unreplicated	Quantitative
Merz et al. 2004a	Mokelumne River, California, USA	Potentially Effective	Medium	*Oncorhynchus tshawytscha*	1	CI	Survival	age 0	replicated	Quantitative
Mueller et al. 2014g	Danube, Rhine and Elbe Rivers, Germany	Potentially Effective	Medium	*Salmo trutta* (16-32mm grain size)	1	CI	Survival	egg	replicated	Quantitative

Study citation	Location	Effectiveness rating	Critical appraisal	Species	No. of true post-treatment years	Study design	Outcome	Life stage	Replication	Outcome category
Gravel cont.										
Fjeldstad et al. 2012	Nidelva River, Norway	Potentially Ineffective	Low	*Salmo salar*	2	BACI	Survival	age 0	pseudoreplicated	Quantitative
Mueller et al. 2014h	Danube, Rhine and Elbe Rivers, Germany	Potentially Ineffective	Medium	*Salmo trutta* (8-16mm grain size)	1	CI	Survival	egg	replicated	Quantitative
Johnson et al. 2006b	Lake St. Lawrence, New York, USA	Unclear	Low	*Acipenser fulvescens*	2	PT	Survival	fry	replicated	Quantitative
Merz et al. 2004b	Mokelumne River, California, USA	Potentially Effective	Medium	*Oncorhynchus tshawytscha*	1	CI	Body Size	larvae	replicated	Quantitative
Cobble										
Marsden et al. 2016a	Lake Huron, Ontario, Canada	Effective	Medium	*Salvelinus namaycush*	5	CI	Abundance	fry	replicated	Quantitative
Avery 2004a	Lodi (Spring) Creek, Wisconsin, USA	Potentially Effective	Low	*Salmo trutta*	2	BACI	Abundance	age 0	unreplicated	Quantitative
Benoit & Legault 2002†	Aux Sables, Québec, Canada	Potentially Effective	Medium	*Salvelinus namaycush*	1	CI	Abundance	egg	replicated	Quantitative
Bouckaert et al. 2014a	St Clair River and Detroit River, Ontario/ Michigan, Canada/ USA	Potentially Effective	Low	*Acipenser fulvescens*	1	BA	Abundance	egg	replicated	Quantitative
Bouckaert et al. 2014b	St Clair River and Detroit River, Ontario/ Michigan, Canada/ USA	Potentially Effective	Low	*Acipenser fulvescens*	1	BA	Abundance	larvae	unreplicated	Quantitative
Dustin & Jacobson 2003d	Ada Brook, Minnesota, USA	Potentially Effective	Low	*Stizostedion vitreum*	2	BACI	Abundance	fry	pseudoreplicated	Quantitative approximation
Kevern 1985	Lake Michigan, Michigan, USA	Potentially Effective	Low	*Perca flavescens*	1	CI	Abundance	egg	qualitative	Qualitative
Manny 2006	Detroit River, Michigan, USA	Potentially Effective	Low	*Various (Walleye, Suckers, Lake Whitefish, Others)*	2	BA	Abundance	egg	unreplicated	Quantitative approximation

Study citation	Location	Effectiveness rating	Critical appraisal	Species	No. of true post-treatment years	Study design	Outcome	Life stage	Replication	Outcome category
Cobble cont.										
Marsden et al. 2016b	Lake Huron, Ontario, Canada	Potentially Effective	Medium	*Salvelinus namaycush*	5	CI	Abundance	spawner	replicated	Quantitative
Marsden & Chotkowski 2001b	Lake Michigan, Michigan, USA	Potentially Effective	Low	*Salvelinus namaycush*	1	CI	Abundance	fry	pseudoreplicated	Quantitative approximation
Marsden et al. 1995a	Lake Ontario, Ontario, Canada	Potentially Effective	Medium	*Salvelinus namaycush*	1	CI	Abundance	egg	pseudoreplicated	Quantitative
Moreau 1984	Hurdygurdy Creek, California, USA	Potentially Effective	Low	*Salmo gairdneri*	2	CI	Abundance	redd	unreplicated	Quantitative
Pondella et al. 2006a	San Diego Bay, California, USA	Potentially Effective	Medium	*Paralabrax nebulifer*	5	CI	Abundance	spawner	replicated	Quantitative
Roni et al. 2008a	West Fork Smith River, Oregon, USA	Potentially Effective	Medium	*Oncorhynchus kisutch*	1	CI	Abundance	redd	replicated	Quantitative
Roni et al. 2008b	West Fork Smith River, Oregon, USA	Potentially Effective	Medium	*Oncorhynchus kisutch*	1	CI	Abundance	spawner	replicated	Quantitative
Roni et al. 2008c	West Fork Smith River, Oregon, USA	Potentially Effective	Medium	*Oncorhynchus kisutch*	5	CI	Abundance	spawner	replicated	Quantitative
Roni et al. 2008d	West Fork Smith River, Oregon, USA	Potentially Effective	Medium	*Oncorhynchus kisutch*	5	CI	Abundance	redd	replicated	Quantitative
Roni et al. 2008e	West Fork Smith River, Oregon, USA	Potentially Effective	Medium	*Oncorhynchus mykiss*	5	CI	Abundance	redd	replicated	Quantitative
Roseman et al. 2011a	Detroit River, Ontario, Canada	Potentially Effective	Low	*Acipenser fulvescens*	2	BA	Abundance	egg	unreplicated	Quantitative
Roseman et al. 2011b	Detroit River, Ontario, Canada	Potentially Effective	Low	*Sander vitreus*	2	BA	Abundance	egg	unreplicated	Quantitative
Roseman et al. 2011c	Detroit River, Ontario, Canada	Potentially Effective	Low	*Catostomus commersonii*	2	BA	Abundance	egg	unreplicated	Quantitative
Vehanen et al, 2010a	Oulujoki watercourse, Finland	Potentially Effective	High	*Salmo trutta*	3	BACI	Abundance	juvenile	replicated	Quantitative

Study citation	Location	Effectiveness rating	Critical appraisal	Species	No. of true post-treatment years	Study design	Outcome	Life stage	Replication	Outcome category
Cobble cont.										
Wagner 1990a	Six Mile Lake, Michigan, USA	Potentially Effective	Low	*Stizostedion vitreum*	7	BA	Abundance	egg	pseudoreplicated	Semi-Quantitative
Wagner 1990b	Six Mile Lake, Michigan, USA	Potentially Effective	Low	*Stizostedion vitreum*	3	BA	Abundance	fry	pseudoreplicated	Semi-Quantitative
Wagner 1990c	Six Mile Lake, Michigan, USA	Potentially Effective	Low	*Stizostedion vitreum*	7	CI	Abundance	egg	unreplicated	Quantitative approximation
Crossman & Hildebrand 2014a	Columbia River, British Columbia, Canada	Potentially Ineffective	Low	*Acipenser transmontanus*	1	CI	Abundance	larvae	unreplicated	Quantitative
Dumont et al. 2011a	Des Prairies River, Québec, Canada	Potentially Ineffective	Low	*Acipenser fulvescens*	3	BA	Abundance	spawner	unreplicated	Quantitative approximation
Dumont et al. 2011b	Des Prairies River, Québec, Canada	Potentially Ineffective	Low	*Acipenser fulvescens*	3	BA	Abundance	egg	unreplicated	Quantitative approximation
Dustin & Jacobson 2003a	Pelican River, Minnesota, USA	Potentially Ineffective	Low	*Stizostedion vitreum*	2	BACI	Abundance	fry	pseudoreplicated	Quantitative approximation
Dustin & Jacobson 2003b	Pelican River, Minnesota, USA	Potentially Ineffective	Low	*Stizostedion vitreum*	2	BACI	Abundance	egg	pseudoreplicated	Quantitative approximation
Dustin & Jacobson 2003c	Ada Brook, Minnesota, USA	Potentially Ineffective	Low	*Stizostedion vitreum*	2	BACI	Abundance	egg	pseudoreplicated	Quantitative approximation
House and Boehne 1985a	East Fork Lobster Creek, Oregon, USA	Potentially Ineffective	Low	*Salmonids**	2	BACI	Abundance	age 0	pseudoreplicated	Quantitative
House and Boehne 1985b	East Fork Lobster Creek, Oregon, USA	Potentially Ineffective	Low	*Oncorhynchus kisutch*	2	BACI	Abundance	fry	pseudoreplicated	Quantitative
House and Boehne 1985c	East Fork Lobster Creek, Oregon, USA	Potentially Ineffective	Low	*Trout**	2	BACI	Abundance	fry	pseudoreplicated	Quantitative
Katt 2009a	Sherman Reservoir, New England, USA	Potentially Ineffective	Medium	*Stizostedion vitreum*	2	BA	Abundance	spawner	pseudoreplicated	Quantitative approximation
Katt 2009b	Sherman Reservoir, New England, USA	Potentially Ineffective	Medium	*Stizostedion vitreum*	2	BA	Abundance	egg	pseudoreplicated	Quantitative
Marsden et al. 2016c	Lake Huron, Ontario, Canada	Potentially Ineffective	Medium	*Salvelinus namaycush*	5	CI	Abundance	egg	replicated	Quantitative

Study citation	Location	Effectiveness rating	Critical appraisal	Species	No. of true post-treatment years	Study design	Outcome	Life stage	Replication	Outcome category
Cobble cont.										
Marsden & Chotkowski 2001a	Lake Michigan, Michigan, USA	Potentially Ineffective	Low	*Salvelinus namaycush*	1	CI	Abundance	egg	replicated	Quantitative approximation
Palm et al. 2007a	Hartijokki Stream, Sweden	Potentially Ineffective	Medium	*Salmo trutta*	1	BA	Abundance	age 0	pseudoreplicated	Quantitative
Roseman et al. 2011d	Detroit River, Ontario, Canada	Potentially Ineffective	Low	*Coregonus clupeaformis*	2	BA	Abundance	egg	unreplicated	Quantitative
Vehanen et al. 2010b	Oulujoki watercourse, Finland	Potentially Ineffective	High	*Salmo trutta*	2	BACI	Abundance	age 0	replicated	Quantitative
Vehanen et al. 2010c	Oulujoki watercourse, Finland	Potentially Ineffective	High	*Salmo trutta*	3	BACI	Abundance	juvenile	replicated	Quantitative
Mueller et al. 2014i	Danube, Rhine, and Elbe Rivers, Germany	Potentially Ineffective	Low	*Phoxinus phoxinus*	1	CI	Abundance	redd	unreplicated	Quantitative
Mueller et al. 2014j	Danube, Rhine, and Elbe Rivers, Germany	Potentially Ineffective	Low	*Thymallus thymallus*	1	CI	Abundance	redd	unreplicated	Quantitative
Mueller et al. 2014k	Danube, Rhine, and Elbe Rivers, Germany	Potentially Ineffective	Low	*Salmo trutta*	1	CI	Abundance	redd	unreplicated	Quantitative
Bouckaert et al. 2014c	St Clair River and Detroit River, Ontario/Michigan, Canada/USA	Unclear	Low	*Acipenser fulvescens*	2	PT	Abundance	egg	replicated	Quantitative
Bouckaert et al. 2014d	St Clair River and Detroit River, Ontario/Michigan, Canada/USA	Unclear	Low	*Acipenser fulvescens*	2	PT	Abundance	larvae	replicated	Quantitative
Bouckaert et al. 2014e	St Clair River and Detroit River, Ontario/Michigan, Canada/USA	Unclear	Low	*Acipenser fulvescens*	3	PT	Abundance	egg	replicated	Quantitative

Study citation	Location	Effectiveness rating	Critical appraisal	Species	No. of true post-treatment years	Study design	Outcome	Life stage	Replication	Outcome category
Cobble cont.										
Bouckaert et al. 2014f	St Clair River and Detroit River, Ontario/Michigan, Canada/USA	Unclear	Low	*Acipenser fulvescens*	3	PT	Abundance	larvae	unreplicated	Quantitative
Martin 1955	Lake Shirley, Ontario, Canada	Unclear	Low	*Salvelinus namaycush*	1	PT	Abundance	egg	pseudoreplicated	Quantitative
Chiotti 2012	St Clair River, Michigan, USA	Unclear	Low	*Acipenser fulvescens*	1	PT	Abundance	spawner	unreplicated	Qualitative
Kerr 1980	Wawa Lake, Ontario, Canada	Unclear	Low	*Salvelinus namaycusch*	1	PT	Abundance	spawner	unreplicated	Quantitative
Dumont et al. 2011c	Des Prairies River, Quebec, Canada	Effective	Low	*Acipenser fulvescens*	3	BA	Survival	egg	unreplicated	Quantitative approximation
Marsden et al. 1995b	Lake Ontario, Ontario, Canada	Potentially Effective	Medium	*Salvelinus namaycush*	1	CI	Survival	age 0	pseudoreplicated	Quantitative
Mueller et al. 2014l	Danube, Rhine, and Elbe Rivers, Germany	Potentially Ineffective	Medium	*Salmo trutta*	1	CI	Survival	egg	replicated	Quantitative
Palm et al. 2007b	Hartijokki Stream, Sweden	Potentially Ineffective	Low	*Salmo trutta*	2	CI	Survival	age 0	pseudoreplicated	Quantitative
Crossman & Hildebrand 2014b	Columbia River, British Columbia, Canada	Potentially Effective	Medium	*Acipenser transmontanus*	1	CI	Body Size	larvae	pseudoreplicated	Quantitative
Sediment Trap										
Avery 1996a	Hay Creek, Wisconsin, USA	Potentially Ineffective	Low	*Salmo trutta*	5	BA	Abundance	redd	unreplicated	Quantitative
Avery 1996b	Hay Creek, Wisconsin, USA	Ineffective	Low	*Salvelinus fontinalis*	5	BACI	Abundance	age 0	unreplicated	Quantitative
Avery 1996c	Hay Creek, Wisconsin, USA	Ineffective	Low	*Salmo trutta*	5	BACI	Abundance	age 0	unreplicated	Quantitative
Gravel Washing										
Ortlepp & Murle 2003a†	River Spol, Switzerland	Potentially Effective	Low	*Salmo trutta fario*	1	BA	Abundance	redd	unreplicated	Quantitative

Study citation	Location	Effectiveness rating	Critical appraisal	Species	No. of true post-treatment years	Study design	Outcome	Life stage	Replication	Outcome category
Gravel Washing cont.										
Shackle et al. 1999a	Kennet, Coln, Windrush, and Leach Rivers, England	Potentially Effective	Medium	*Salmo trutta* (Tractor rotovating)	1	CI	Abundance	larvae	replicated	Quantitative
Shackle et al. 1999b	Kennet, Coln, Windrush, and Leach Rivers, England	Potentially Effective	Medium	*Salmo trutta* (High-pressure jet washing)	1	CI	Abundance	larvae	replicated	Quantitative
Shackle et al. 1999c	Kennet, Coln, Windrush, and Leach Rivers, England	Potentially Effective	Medium	*Salmo trutta* (Pump washing)	1	CI	Abundance	larvae	replicated	Quantitative
Ortlepp & Murle 2003b†	River Spol, Switzerland	Potentially Ineffective	Low	*Salmo trutta fario*	1	BA	Abundance	spawner	unreplicated	Quantitative
Andrew 1981a	Fraser River, British Columbia, Canada	Unclear	Low	*Oncorhynchus nerka*	1	CI	Abundance	spawner	qualitative	Qualitative
Mueller et al. 2014m	Danube, Rhine, Elbe River, Germany	Potentially Ineffective	Low	*Phoxinus phoxinus*	1	CI	Abundance	redd	unreplicated	Quantitative
Mueller et al. 2014n	Danube, Rhine, Elbe River, Germany	Potentially Ineffective	Low	*Thymallus thymallus*	1	CI	Abundance	redd	unreplicated	Quantitative
Mueller et al. 2014o	Danube, Rhine, Elbe River, Germany	Potentially Ineffective	Low	*Salmo trutta*	1	CI	Abundance	redd	unreplicated	Quantitative
Andrew 1981b	Fraser River, British Columbia, Canada	Potentially Effective	Medium	*Oncorhynchus nerka*	1	CI	Survival	age 0	pseudoreplicated	Quantitative
Sternecker et al. 2013	River Moosach, Germany	Potentially Effective	Medium	*Salmo trutta*	1	BA	Survival	age 0	pseudoreplicated	Quantitative
Wilson 1976e	Entiat River, Washington, USA	Potentially Effective	Low	*Oncorhynchus tshawytscha*	1	CI	Survival	age 0	pseudoreplicated	Quantitative
Andrew 1981c	Fraser River, British Columbia, Canada	Potentially Ineffective	Medium	*Oncorhynchus nerka*	1	CI	Survival	age 0	pseudoreplicated	Quantitative

Study citation	Location	Effectiveness rating	Critical appraisal	Species	No. of true post-treatment years	Study design	Outcome	Life stage	Replication	Outcome category
Gravel Washing cont.										
Mueller et al. 2014p	Danube, Rhine, Elbe River, Germany	Potentially Ineffective	Medium	*Salmo trutta*	1	CI	Survival	egg	replicated	Quantitative
Rock Combinations (all Gravel+Cobble)										
Weber & Imler 1974a	Lonetree Reservoir, Colorado, USA	Effective	Low	*Stizostedion vitreum*	3	BA	Abundance	YOY	unreplicated	Quantitative
Geiling et al. 1996	Current River, Ontario, Canada	Potentially Effective	Medium	*Stizostedion vitreum vitreum*	2	BA	Abundance	spawner	pseudoreplicated	Quantitative approximation
LaHaye et al. 1992	Des Prairies and L'Assomption Rivers, Québec, Canada	Potentially Effective	Low	*Acipenser fulvescens*	1	CI	Abundance	egg	unreplicated	Quantitative approximation
Palm et al. 2007c	Hatijokki Stream, Sweden	Potentially Effective	Medium	*Salmo trutta*	1	BA	Abundance	age 0	pseudoreplicated	Quantitative
Avery 2004b	Big (Cataract) Creek, Wisconsin, USA	Potentially Effective	Low	*Salvelinus fontinalis*	2	CI	Abundance	age 0	unreplicated	Quantitative
Palm et al. 2007d	Hatijokki Stream, Sweden	Potentially Ineffective	Low	*Salmo trutta*	2	CI	Survival	age 0	pseudoreplicated	Quantitative
Weber & Imler 1974b	Lonetree Reservoir, Colorado, USA	Effective	Low	*Stizostedion vitreum*	3	BA	Body Size	YOY	pseudoreplicated	Quantitative

†Data sets that use a degraded impact site.

*Data sets that use a combination of species/ species groups.

Table 7. Comparison of results between the Taylor et al. (2019) systematic review and this DFO technical report. H: high study validity (low bias); M: medium study validity (moderately bias); L: low study validity (high bias); Hedges' *g*: standardized mean difference effect size measure used in formal meta-analysis; CI: 95% confidence intervals. Results are for abundance outcome metrics only (i.e., survival and body size outcomes are not compared here).

Review aspect	**Systematic review**	**DFO tehnical report**
Results		
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, 35.12; 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, 28.56; 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		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
Waterbody creation	B: Hedges' *g*: 0.61 (CI: -0.05, 1.27); 39% (CI: 0.48, 76.97) (n=14)	A: 144% (CI: -130.45, 218.06; n=4) primarily low validity studies; B: 46% (CI: 16.35, 75.45; n=22) primarily M validity studies

Review aspect	Systematic review	DFO tehnical report
Stream A		144% (CI: -130.45, 218.06; 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		100% (CI: 100.00, 100.00; n=3)
Human-made structure		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)

** In the Taylor et al. (2019) systematic review, to increase sample size, we 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 this DFO technical report.

Table 8. Summary characteristics and results of studies using plant material alone to enhance or create spawning habitat for substrate spawning fish. Study designs: BA: before-after; CI: control-impact; BACI: before-after-control-impact; PT: post-treatment only. See Appendix A for full citation information of included studies.

Study citation	Location	Effectiveness rating	Critical appraisal	Species	No. of true post-treatment years	Study design	Outcome	Life stage	Replication	Outcome category
Log										
Johnson et al. 2005a	Tenmile and Cummins Creek, Oregon, USA	Effective	Medium	*Oncorhynchus kisutch*	4	BACI	Abundance	age 0	pseudoreplicated	Quantitative
Cederholm et al. 1997a	Chehalis River, Washington, USA	Potentially Effective	Medium	*Oncorhynchus kisutch* Imported trees	4	BACI	Abundance	juvenile	pseudoreplicated	Quantitative
Cederholm et al. 1997b	Chehalis River, Washington, USA	Potentially Effective	Medium	*Oncorhynchus kisutch* Felled trees from streambank	4	BACI	Abundance	juvenile	pseudoreplicated	Quantitative
Hunt & Annett 2002a	Lake Wedington, Arkansas, USA	Potentially Effective	Medium	*Micropterus salmoides*	1	CI	Abundance	nest	replicated	Quantitative
Hunt & Annett 2002b	Lake Wedington, Arkansas, USA	Potentially Effective	Low	*Micropterus salmoides*	1	CI	Abundance	egg	unreplicated	Quantitative
Hunt & Annett 2002c	Lake Wedington, Arkansas, USA	Potentially Effective	Low	*Micropterus salmoides*	1	CI	Abundance	age 0	unreplicated	Quantitative
Johnson et al. 2005b	Tenmile and Cummins Creek, Oregon, USA	Potentially Effective	Medium	*Oncorhynchus mykiss*	4	BACI	Abundance	juvenile	pseudoreplicated	Quantitative
Johnson et al. 2005c	Tenmile and Cummins Creek, Oregon, USA	Potentially Effective	Medium	*Oncorhynchus clarkii*	4	BACI	Abundance	juvenile	pseudoreplicated	Quantitative
Johnson et al. 2005d	Tenmile and Cummins Creek, Oregon, USA	Potentially Effective	Medium	*Oncorhynchus kisutch*	4	BACI	Abundance	juvenile	pseudoreplicated	Quantitative
Hunt & Annett 2002d	Lake Wedington, Arkansas, USA	Potentially Ineffective	Low	*Micropterus salmoides*	1	CI	Abundance	age 0	unreplicated	Quantitative
Johnson et al. 2005e	Tenmile and Cummins Creek, Oregon, USA	Ineffective	Medium	*Oncorhynchus mykiss*	4	BACI	Abundance	age 0	pseudoreplicated	Quantitative

Study citation	Location	Effectiveness rating	Critical appraisal	Species	No. of true post-treatment years	Study design	Outcome	Life stage	Replication	Outcome category
Log cont.										
Roni 2003a	Multiple Rivers, Washington/Oregon, USA	Unclear	Medium	*Entosphenus tridentatus and Lampetra spp.*	varies between sites	CI	Abundance	larvae	replicated	Quantitative
Roni 2003b	Multiple Rivers, Washington/Oregon, USA	Unclear	Medium	*Cottus perplexus*	varies between sites	CI	Abundance	age 0	replicated	Quantitative
Roni 2003c	Multiple Rivers, Washington/Oregon, USA	Unclear	Medium	*Cottus rhotheus*	varies between sites	CI	Abundance	age 0	replicated	Quantitative
Mangan 2005a	Little Brush and Dry Wetlands, South Dakota, USA	Unclear	Low	*Perca flavescens* Inshore tree reef	1	PT	Abundance	egg	replicated	Quantitative
Mangan 2005b	Little Brush and Dry Wetlands, South Dakota, USA	Unclear	Low	*Perca flavescens* Offshore tree reef	1	PT	Abundance	egg	replicated	Quantitative
Mangan 2005c	Little Brush and Dry Wetlands, South Dakota, USA	Unclear	Low	*Perca flavescens* Inshore new tree reef	1	PT	Abundance	egg	replicated	Quantitative
Mangan 2005d	Little Brush and Dry Wetlands, South Dakota, USA	Unclear	Low	*Perca flavescens* Inshore 1 yr. old tree reef	1	PT	Abundance	egg	replicated	Quantitative
Mangan 2005e	Little Brush and Dry Wetlands, South Dakota, USA	Unclear	Low	*Perca flavescens* Offshore new tree reef	1	PT	Abundance	egg	replicated	Quantitative
Mangan 2005f	Little Brush and Dry Wetlands, South Dakota, USA	Unclear	Low	*Perca flavescens* Offshore 1 yr. old tree reef	1	PT	Abundance	egg	replicated	Quantitative
Mangan 2005g	Little Brush and Dry Wetlands, South Dakota, USA	Unclear	Low	*Perca flavescens* Spruce/fir tree reef	1	PT	Abundance	egg	replicated	Quantitative
Mangan 2005h	Little Brush and Dry Wetlands, South Dakota, USA	Unclear	Low	*Perca flavescens* Pine tree reef	1	PT	Abundance	egg	replicated	Quantitative

Study citation	Location	Effectiveness rating	Critical appraisal	Species	No. of true post-treatment years	Study design	Outcome	Life stage	Replication	Outcome category
Log cont.										
Day 1983a	Ferguson River, Ohio, USA	Unclear	Low	*Perca flavescens*	3	PT	Abundance	age 0	pseudoreplicated	Quantitative Approximation
Day 1983b	Ferguson River, Ohio, USA	Unclear	Low	*Perca flavescens*	3	PT	Abundance	YOY	pseudoreplicated	Quantitative Approximation
Day 1983c	Ferguson River, Ohio, USA	Unclear	Low	*Perca flavescens*	2	PT	Abundance	spawner	unreplicated	Quantitative approximation
Day 1983d	Ferguson River, Ohio, USA	Unclear	Low	*Perca flavescens*	3	PT	Abundance	egg	unreplicated	Quantitative
Giannico and Hinch 2007	Mamquam River, British Columbia, Canada	Potentially Effective	Medium	*Oncorhynchus kisutch*	2	CI	Survival	juvenile	replicated	Quantitative
Johnson et al. 2005f	Tenmile and Cummins Creek, Oregon, USA	Potentially Ineffective	Medium	*Oncorhynchus mykiss*	4	BACI	Survival	juvenile	pseudoreplicated	Quantitative
Roni 2003d	Multiple Rivers, Washington/Oregon, USA	Unclear	Medium	*Entosphenus tridentatus and Lampetra spp.*	varies between sites	CI	Body Size	larvae	replicated	Quantitative
Roni 2003e	Multiple Rivers, Washington/Oregon, USA	Unclear	Medium	*Cottus perplexus*	varies between sites	CI	Body Size	age 0	replicated	Quantitative
Roni 2003f	Multiple Rivers, Washington/Oregon, USA	Unclear	Medium	*Cottus rhotheus*	varies between sites	CI	Body Size	age 0	replicated	Quantitative
Brush										
Hickford & Schiel 2013a†	Banks Peninsula, South Island, New Zealand	Potentially Effective	Low	*Galaxias maculatus* Straw bales	1	CI	Abundance	egg	replicated	Quantitative
Hickford & Schiel 2013b†	Banks Peninsula, South Island, New Zealand	Potentially Effective	Low	*Galaxias maculatus* Mesh tubes of straw	1	CI	Abundance	egg	replicated	Quantitative
Vogele & Rainwater 1975a	Bull Shoals Lake, Arkansas, USA	Potentially Effective	Low	*Micropterus salmoides*	1	CI	Abundance	nest	unreplicated	Quantitative

Study citation	Location	Effectiveness rating	Critical appraisal	Species	No. of true post-treatment years	Study design	Outcome	Life stage	Replication	Outcome category
Brush cont.										
Vogele & Rainwater 1975b	Bull Shoals Lake, Arkansas, USA	Potentially Effective	Low	*Micropterus dolomieui*	1	CI	Abundance	nest	unreplicated	Quantitative
Vogele & Rainwater 1975c	Bull Shoals Lake, Arkansas, USA	Potentially Effective	Low	*Micropterus punctulatus*	1	CI	Abundance	nest	unreplicated	Quantitative
Hickford & Schiel 2013c†	Banks Peninsula, South Island, New Zealand	Potentially Ineffective	Low	*Galaxias maculatus Mesh tubes of straw*	1	CI	Abundance	egg	replicated	Quantitative
Pondella et al. 2006b	San Diego Bay, California, USA	Potentially Ineffective	Medium	*Paralabrax nebulifer*	5	CI	Abundance	spawner	pseudoreplicated	Quantitative
Nash and Hendry 1999a	Salford Quay, Manchester, England	Unclear	Low	*Perca fluviatilis* Lime brush	1	PT	Abundance	egg	replicated	Quantitative
Nash and Hendry 1999b	Salford Quay, Manchester, England	Unclear	Low	*Perca fluviatilis* Pear willow brush	1	PT	Abundance	egg	replicated	Quantitative
Nash and Hendry 1999c	Salford Quay, Manchester, England	Unclear	Low	*Perca fluviatilis* Thin willow brush	1	PT	Abundance	egg	replicated	Quantitative
Nash and Hendry 1999d	Salford Quay, Manchester, England	Unclear	Low	*Perca fluviatilis* Sycamore brush	1	PT	Abundance	egg	replicated	Quantitative
Nash and Hendry 1999e	Salford Quay, Manchester, England	Unclear	Low	*Perca fluviatilis* Conifer sprue brush	1	PT	Abundance	egg	replicated	Quantitative
Nash and Hendry 1999f	Salford Quay, Manchester, England	Unclear	Low	*Perca fluviatilis* Laurel brush	1	PT	Abundance	egg	replicated	Quantitative
Nash and Hendry 1999g	Salford Quay, Manchester, England	Unclear	Low	*Perca fluviatilis* 10, 0.2m strands plastic netting	1	PT	Abundance	egg	replicated	Quantitative
Nash and Hendry 1999h	Salford Quay, Manchester, England	Unclear	Low	*Perca fluviatilis* 10m length plastic netting	1	PT	Abundance	egg	replicated	Quantitative

Study citation	Location	Effectiveness rating	Critical appraisal	Species	No. of true post-treatment years	Study design	Outcome	Life stage	Replication	Outcome category
Brush cont.										
Nash and Hendry 1999i	Salford Quay, Manchester, England	Unclear	Low	*Perca fluviatilis* Lime brush	1	PT	Abundance	egg	replicated	Quantitative
Nash and Hendry 1999j	Salford Quay, Manchester, England	Unclear	Low	*Perca fluviatilis* Pear willow brush	1	PT	Abundance	egg	replicated	Quantitative
Nash and Hendry 1999k	Salford Quay, Manchester, England	Unclear	Low	*Perca fluviatilis* Thin willow brush	1	PT	Abundance	egg	replicated	Quantitative
Nash and Hendry 1999l	Salford Quay, Manchester, England	Unclear	Low	*Perca fluviatilis* Sycamore brush	1	PT	Abundance	egg	replicated	Quantitative
Nash and Hendry 1999m	Salford Quay, Manchester, England	Unclear	Low	*Perca fluviatilis* Conifer sprue brush	1	PT	Abundance	egg	replicated	Quantitative
Nash and Hendry 1999n	Salford Quay, Manchester, England	Unclear	Low	*Perca fluviatilis* Laurel brush	1	PT	Abundance	egg	replicated	Quantitative
Nash and Hendry 1999o	Salford Quay, Manchester, England	Unclear	Low	*Perca fluviatilis* 10, 0.2m strands plastic netting	1	PT	Abundance	egg	replicated	Quantitative
Nash and Hendry 1999p	Salford Quay, Manchester, England	Unclear	Low	*Perca fluviatilis* 10m length plastic netting	1	PT	Abundance	egg	replicated	Quantitative
Plant Combinations										
Giannico and Hinch 2003a	Upper Mamquam Creek, British Columbia, Canada	Potentially Effective	Medium	*Oncorhynchus kisutch*	1	CI	Abundance	juvenile	pseudoreplicated	Quantitative
Giannico and Hinch 2003b	Upper Mamquam Creek, British Columbia, Canada	Potentially Effective	Medium	*Oncorhynchus kisutch*	1	CI	Abundance	juvenile	pseudoreplicated	Quantitative
Giannico and Hinch 2003c	Upper Mamquam Creek, British Columbia, Canada	Potentially Effective	Medium	*Oncorhynchus kisutch*	1	CI	Abundance	juvenile	pseudoreplicated	Quantitative

Study citation	Location	Effectiveness rating	Critical appraisal	Species	No. of true post-treatment years	Study design	Outcome	Life stage	Replication	Outcome category
Plant Combinations cont.										
Giannico and Hinch 2003d	Upper Paradise Creek, British Columbia, Canada	Potentially Ineffective	Medium	*Oncorhynchus kisutch*	1	CI	Abundance	juvenile	pseudoreplicated	Quantitative
Giannico and Hinch 2003e	Upper Paradise Creek, British Columbia, Canada	Potentially Ineffective	Medium	*Oncorhynchus kisutch*	1	CI	Abundance	juvenile	pseudoreplicated	Quantitative
Giannico and Hinch 2003f	Upper Paradise Creek, British Columbia, Canada	Potentially Ineffective	Medium	*Oncorhynchus kisutch*	1	CI	Abundance	juvenile	pseudoreplicated	Quantitative
Giannico and Hinch 2003g	Upper Paradise Creek, British Columbia, Canada	Potentially Ineffective	Medium	*Oncorhynchus kisutch*	1	CI	Abundance	juvenile	pseudoreplicated	Quantitative
Giannico and Hinch 2003h	Upper Mamquam Creek, British Columbia, Canada	Potentially Ineffective	Medium	*Oncorhynchus kisutch*	1	CI	Abundance	juvenile	pseudoreplicated	Quantitative
Giannico and Hinch 2003i	Upper Paradise Creek, British Columbia, Canada	Potentially Effective	Medium	*Oncorhynchus kisutch*	1	CI	Survival	juvenile	pseudoreplicated	Quantitative
Giannico and Hinch 2003j	Upper Paradise Creek, British Columbia, Canada	Potentially Effective	Medium	*Oncorhynchus kisutch*	1	CI	Survival	juvenile	pseudoreplicated	Quantitative
Giannico and Hinch 2003k	Upper Mamquam Creek, British Columbia, Canada	Potentially Effective	Medium	*Oncorhynchus kisutch*	1	CI	Survival	juvenile	pseudoreplicated	Quantitative
Giannico and Hinch 2003l	Upper Mamquam Creek, British Columbia, Canada	Potentially Effective	Medium	*Oncorhynchus kisutch*	1	CI	Survival	juvenile	pseudoreplicated	Quantitative
Giannico and Hinch 2003m	Upper Paradise Creek, British Columbia, Canada	Potentially Effective	Medium	*Oncorhynchus kisutch*	1	CI	Body Size	juvenile	pseudoreplicated	Quantitative
Giannico and Hinch 2003n	Upper Paradise Creek, British Columbia, Canada	Potentially Ineffective	Medium	*Oncorhynchus kisutch*	1	CI	Body Size	juvenile	pseudoreplicated	Quantitative

Study citation	Location	Effectiveness rating	Critical appraisal	Species	No. of true post-treatment years	Study design	Outcome	Life stage	Replication	Outcome category
Plant Combinations cont.										
Giannico and Hinch 2003o	Upper Mamquam Creek, British Columbia, Canada	Potentially Ineffective	Medium	*Oncorhynchus kisutch*	1	CI	Body Size	juvenile	pseudoreplicated	Quantitative
Giannico and Hinch 2003p	Upper Mamquam Creek, British Columbia, Canada	Potentially Ineffective	Medium	*Oncorhynchus kisutch*	1	CI	Body Size	juvenile	pseudoreplicated	Quantitative

† Data sets that use a degraded impact site.

Table 9. Summary characteristics and results of studies using waterbody creation alone to enhance or create spawning habitat for substrate spawning fish. Study designs: BA: before-after; CI: control-impact; BACI: before-after-control-impact; PT: post-treatment only. See Appendix A for full citation information of included studies.

Study citation	Location	Effectiveness rating	Critical appraisal	Species	No. of true post-treatment years	Study design	Outcome	Life stage	Replication	Outcome category
Bay Creation										
Toft et al. 2013b	Puget Sound, Washington, USA	Effective	Medium	*various*	3	BACI	Abundance	larvae	pseudoreplicated	Quantitative
Langler 2001a	Huntspill River, Somerset, England	Potentially Effective	Medium	*Abramis brama*	1	CI	Abundance	age 0	replicated	Quantitative approximation
Langler 2001b	Huntspill River, Somerset, England	Potentially Effective	Medium	*Cyprinus carpio*	1	CI	Abundance	age 0	replicated	Quantitative approximation
Langler 2001g	Huntspill River, Somerset, England	Potentially Effective	Medium	*Leucaspius delineatus*	1	CI	Abundance	age 0	replicated	Quantitative approximation
Langler 2001h	Huntspill River, Somerset, England	Potentially Effective	Medium	*Perca fluviatilis*	1	CI	Abundance	age 0	replicated	Quantitative approximation
Langler 2001c	Huntspill River, Somerset, England	Potentially Ineffective	Medium	*Esox lucius*	1	CI	Abundance	age 0	replicated	Quantitative approximation
Langler 2001d	Huntspill River, Somerset, England	Potentially Ineffective	Medium	*Gasterosteus aculeatus*	1	CI	Abundance	age 0	replicated	Quantitative approximation
Langler 2001e	Huntspill River, Somerset, England	Potentially Ineffective	Medium	*Gobio gobio*	1	CI	Abundance	age 0	replicated	Quantitative approximation
Langler 2001f	Huntspill River, Somerset, England	Potentially Ineffective	Medium	*Gymnocephalus cernuus*	1	CI	Abundance	age 0	replicated	Quantitative approximation
Langler 2001i	Huntspill River, Somerset, England	Potentially Ineffective	Medium	*Rutilus rutilus*	1	CI	Abundance	age 0	replicated	Quantitative approximation

Study citation	Location	Effectiveness rating	Critical appraisal	Species	No. of true post-treatment years	Study design	Outcome	Life stage	Replication	Outcome category
Stream Creation										
Moerke and Lamberti 2003a	Juday Creek, Indiana, USA	Effective	Low	*Salmo trutta*	3	BA	Abundance	age 0	unreplicated	Quantitative
Pedersen et al. 2009a	GlesA River, Denmark	Effective	Medium	*Salmo trutta*	11	CI	Abundance	fry	pseudoreplicated	Quantitative
Pedersen et al. 2009b	GlesA River, Denmark	Effective	Medium	*Salmo trutta*	11	CI	Abundance	YOY	pseudoreplicated	Quantitative
Pedersen et al. 2009c	Stensbaek River, Denmark	Effective	Medium	*Salmo trutta*	13	CI	Abundance	fry	pseudoreplicated	Quantitative
Pedersen et al. 2009d	Stensbaek River, Denmark	Effective	Medium	*Salmo trutta*	13	CI	Abundance	YOY	pseudoreplicated	Quantitative
Pedersen et al. 2009e	RydsA River, Denmark	Effective	Medium	*Salmo trutta*	12	CI	Abundance	fry	pseudoreplicated	Quantitative
Pedersen et al. 2009f	RydsA River, Denmark	Effective	Medium	*Salmo trutta*	12	CI	Abundance	YOY	pseudoreplicated	Quantitative
West and Mason 1987a	Fulton Channel, Babine Lake, British Columbia, Canada	Effective	Low	*Oncorhyncus nerka*	14	CI‡	Abundance	fry	replicated	Quantitative
West and Mason 1987b	Pinkut Channel, Babine Lake, British Columbia, Canada	Effective	Low	*Oncorhyncus nerka*	17	CI‡	Abundance	fry	unreplicated	Quantitative
Moerke and Lamberti 2003b	Juday Creek, Indiana, USA	Potentially Effective	Medium	*Various*	3	CI	Abundance	redd	replicated	Quantitative
Nilsson et al. 2014a	Kronoback River, Sweden	Potentially Effective	Low	*Esox lucius*	2	BA	Abundance	juvenile	unreplicated	Quantitative approximation
Pedersen et al. 2009g	GlesA River, Denmark	Potentially Effective	Low	*Salmo trutta*	10	CI	Abundance	redd	unreplicated	Quantitative
Pedersen et al. 2009h	Stensbaek River, Denmark	Potentially Effective	Low	*Salmo trutta*	12	CI	Abundance	redd	unreplicated	Quantitative
Pedersen et al. 2009i	RydsA River, Denmark	Potentially Effective	Low	*Salmo trutta*	11	CI	Abundance	redd	unreplicated	Quantitative
Wissmar 2008a	Cedar River, Washington, USA	Potentially Effective	Low	*Oncorhynchus nerka*	Unclear	CI‡	Abundance	spawner	replicated	Quantitative

Study citation	Location	Effectiveness rating	Critical appraisal	Species	No. of true post-treatment years	Study design	Outcome	Life stage	Replication	Outcome category
Stream Creation cont.										
Nilsson et al. 2014b	Tornebybacken River, Sweden	Potentially Ineffective	Low	*Esox lucius*	2	BA	Abundance	juvenile	unreplicated	Quantitative approximation
Nilsson et al. 2014c	Lervik River, Sweden	Potentially Ineffective	Low	*Esox lucius*	1	BA	Abundance	juvenile	unreplicated	Quantitative approximation
Jones et al. 2003	Several streams, Northwest Territories, Canada	Ineffective	Medium	*Thymallus arcticus*	3	CI‡	Abundance	age 0	pseudoreplicated	Quantitative
Moerke and Lamberti 2003c	Juday Creek, Indiana, USA	Ineffective	Low	*Salmo gairdneri*	3	BA	Abundance	age 0	unreplicated	Quantitative
Nilsson et al. 2014d	Kronoback River, Sweden	Unclear	Low	*Esox lucius* Flooded terrestrial vegetation	1	PT	Abundance	larvae	replicated	Quantitative
Nilsson et al. 2014e	Kronoback River, Sweden	Unclear	Low	*Esox lucius* Flooded phragmite belts	1	PT	Abundance	larvae	replicated	Quantitative
Nilsson et al. 2014f	Kronoback River, Sweden	Unclear	Low	*Esox lucius* Flooded submerged macrophytes	1	PT	Abundance	larvae	replicated	Quantitative
Nilsson et al. 2014g	Kronoback River, Sweden	Unclear	Low	*Esox lucius* Flooded non-vegetated area	1	PT	Abundance	larvae	replicated	Quantitative
Yauck 2009	Lake Michigan, Michigan, USA	Unclear	Low	*Perca flavescens*	unknown	PT	Abundance	egg	unreplicated	Qualitative
Sheng 1990a	Upper Paradise Creek, British Columbia, Canada	Unclear	Low	*Oncorhynchus kisutch*	6	PT	Abundance	spawner	unreplicated	Quantitative approximation
Sheng 1990b	Mamquam Creek, British Columbia, Canada	Unclear	Low	*Oncorhynchus kisutch*	5	PT	Abundance	spawner	unreplicated	Quantitative approximation

Study citation	Location	Effectiveness rating	Critical appraisal	Species	No. of true post-treatment years	Study design	Outcome	Life stage	Replication	Outcome category
Stream Creation cont.										
Sheng 1990c	Judd Slough, British Columbia, Canada	Unclear	Low	*Oncorhynchus kisutch*	4	PT	Abundance	spawner	unreplicated	Quantitative approximation
Sheng 1990d	B.C. Rail Creek, British Columbia, Canada	Unclear	Low	*Oncorhynchus kisutch*	3	PT	Abundance	spawner	unreplicated	Quantitative approximation
Sheng 1990e	Worth Creek, British Columbia, Canada	Unclear	Low	*Oncorhynchus kisutch*	10	PT	Abundance	spawner	unreplicated	Quantitative approximation
Sheng 1990f	Deadman Creek, British Columbia, Canada	Unclear	Low	*Oncorhynchus kisutch*	3	PT	Abundance	spawner	unreplicated	Quantitative approximation
Sheng 1990g	Worth Creek, British Columbia, Canada	Unclear	Low	*Oncorhynchus kisutch*	8	PT	Abundance	age 0	pseudoreplicated	Quantitative
Sheng 1990h	Upper Paradise Creek, British Columbia, Canada	Unclear	Low	*Oncorhynchus kisutch*	6	PT	Abundance	age 0	pseudoreplicated	Quantitative
Sheng 1990i	Mamquam Creek, British Columbia, Canada	Unclear	Low	*Oncorhynchus kisutch*	5	PT	Abundance	age 0	pseudoreplicated	Quantitative
Bonnell 1991a	Multiple Rivers, British Columbia, Canada	Unclear	Low	*Oncorhynchus keta* Existing gravel substrate	10	PT	Abundance	spawner	pseudoreplicated	Quantitative
Bonnell 1991b	Multiple Rivers, British Columbia, Canada	Unclear	Low	*Oncorhynchus keta* Existing gravel substrate	10	PT	Abundance	egg	pseudoreplicated	Quantitative
Bonnell 1991c	Multiple Rivers, British Columbia, Canada	Unclear	Low	*Oncorhynchus keta* Existing gravel substrate	10	PT	Abundance	fry	pseudoreplicated	Quantitative

Study citation	Location	Effectiveness rating	Critical appraisal	Species	No. of true post-treatment years	Study design	Outcome	Life stage	Replication	Outcome category
Stream Creation cont.										
Bonnell 1991d	Multiple Rivers, British Columbia, Canada	Unclear	Low	*Oncorhynchus keta* Graded gravel substrate	10	PT	Abundance	spawner	pseudoreplicated	Quantitative
Bonnell 1991e	Multiple Rivers, British Columbia, Canada	Unclear	Low	*Oncorhynchus keta* Graded gravel substrate	10	PT	Abundance	egg	pseudoreplicated	Quantitative
Bonnell 1991f	Multiple Rivers, British Columbia, Canada	Unclear	Low	*Oncorhynchus keta* Graded gravel substrate	10	PT	Abundance	fry	pseudoreplicated	Quantitative
Fraser et al. 1983a	Big Qualicum River, British Columbia, Canada	Effective	Low	*Onchohynchus keta*	7	CI‡	Survival	age 0	unreplicated	Quantitative approximation
Wissmar 2008b	Cedar River, Washington, USA	Potentially Ineffective	Low	*Oncorhynchus nerka*	Unclear	CI‡	Survival	age 0	replicated	Quantitative
Fraser et al. 1983b	Big Qualicum River, British Columbia, Canada	Ineffective	Low	*Onchohynchus keta*	7	CI‡	Survival	age 0	unreplicated	Quantitative approximation
Bonnell 1991g	Multiple Rivers, British Columbia, Canada	Unclear	Low	*Oncorhynchus keta* Existing gravel substrate	10	PT	Survival	egg	pseudoreplicated	Quantitative
Bonnell 1991h	Multiple Rivers, British Columbia, Canada	Unclear	Low	*Oncorhynchus keta* Existing gravel substrate	10	PT	Survival	fry	pseudoreplicated	Quantitative
Bonnell 1991i	Multiple Rivers, British Columbia, Canada	Unclear	Low	*Oncorhynchus keta* Graded gravel substrate	10	PT	Survival	egg	pseudoreplicated	Quantitative
Bonnell 1991j	Multiple Rivers, British Columbia, Canada	Unclear	Low	*Oncorhynchus keta* Graded gravel substrate	10	PT	Survival	fry	pseudoreplicated	Quantitative

Study citation	Location	Effectiveness rating	Critical appraisal	Species	No. of true post-treatment years	Study design	Outcome	Life stage	Replication	Outcome category
Stream Creation cont.										
Driedger et al. 2011	Panda Division Channel, Polar-Vulture Stream, and Pidgeon Stream, Northwest Territories, Canada	Potentially Ineffective	Medium	*Thymallus arcticus*	1	CI‡	Body Size	juvenile	pseudoreplicated	Quantitative

‡ Data sets that compare newly created artificial streams or spawning channels with natural waterbodies (all others compare extensions of an existing waterbody with nearby reference sections within the same waterbody).

Table 10. Summary characteristics and results of studies using waterbody modification alone to enhance or create spawning habitat for substrate spawning fish. Study designs: BA: before-after; CI: control-impact; BACI: before-after-control-impact; PT: post-treatment only. See Appendix A for full citation information of included studies.

Study citation	Location	Effectiveness rating	Critical appraisal	Species	No. of true post-treatment years	Study design	Outcome	Life stage	Replication	Outcome category
Excavation										
Linlokken 1997	Letjern River, Norway	Effective	Medium	*Salmo trutta*	7	CI	Abundance	age 0	pseudoreplicated	Quantitative
Iversen 1993	River Hjortvad, Denmark	Potentially Effective	Low	*Various trout*	NR	BA	Abundance	fry	pseudoreplicated	Quantitative
Riparian Modification										
Hunt 1988	Coon Creek, Wisconsin, USA	Effective	Low	*Salmo trutta*	3	BA	Abundance	age 0	unreplicated	Quantitative

Table 11. Summary characteristics and results of studies using human-made structures alone to enhance or create spawning habitat for substrate spawning fish. Study designs: BA: before-after; CI: control-impact; BACI: before-after-control-impact; PT: post-treatment only. See Appendix A for full citation information of included studies.

Study citation	**Location**	**Effectiveness rating**	**Critical appraisal**	**Species**	**No. of true post-treatment years**	**Study design**	**Outcome**	**Life stage**	**Replication**	**Outcome category**
Anderson et al. 1984	Tioga Creek, Burnt Creek, and West Fork Smith River, Oregon, USA	Potentially Effective	Low	*Oncorhynchus tshawytscha*	1	BA	Abundance	redd	unreplicated	Quantitative
Piller & Burr 1999	Bayou du Chien River, Kentucky, USA	Potentially Effective	Medium	*Etheostoma chienense*	0	CI	Abundance	egg	pseudoreplicated	Quantitative
Saunders 1962	Hayes Brook, Prince Edward Island, USA	Potentially Effective	Low	*Salvelinus fontinalis*	1	BA	Abundance	age 0	unreplicated	Quantitative
Wilson 1976f	Jorsted Creek, Washington, USA	Potentially Effective	Medium	*Onchohynchus keta*	2	CI	Abundance	fry	pseudoreplicated	Quantitative
Hoff 1991	Edith Lake, Diamond Lake, Yawkey Lake, Dorothy Lake, and Nebish Lake, Wisconsin, USA	Potentially Ineffective	Low	*Micropterus dolomieui*	3	BACI	Abundance	nest	replicated	Quantitative
Knaepkens et al. 2004a	Zwaneneek River, Belgium	Unclear	Low	*Cottus gobio*	1	PT	Abundance	egg	replicated	Quantitative
Knaepkens et al. 2004b	Laarse Beek River, Belgium	Unclear	Low	*Cottus gobio*	1	PT	Abundance	egg	replicated	Quantitative

Table 12. Summary characteristics and results of studies using combinations of the different habitat creation or enhancement measures to enhance or create spawning habitat for substrate spawning fish. Study designs: BA: before-after; CI: control-impact; BACI: before-after-control-impact; PT: post-treatment only. See Appendix A for full citation information of included studies.

Study citation	Location	Effectiveness rating	Critical appraisal	Species	No. of true post-treatment years	Study design	Outcome	Life stage	Replication	Outcome category
Rock material + Human-made structures										
Scruton et al. 2005†	Rose Blanche River, Newfoundland, Canada	Effective	Medium	*Salvelinus fontinalis*	3	CI	Abundance	age 0	pseudoreplicated	Quantitative
House and Boehne 1985d	East Fork Lobster Creek, Oregon, USA	Potentially Effective	Medium	*Salmonids** 2 Gabions	2	BACI	Abundance	age 0	replicated	Quantitative
House and Boehne 1985e	East Fork Lobster Creek, Oregon, USA	Potentially Effective	Medium	*Oncorhynchus kisutch* 2 Gabions	2	BACI	Abundance	fry	replicated	Quantitative
House and Boehne 1985f	East Fork Lobster Creek, Oregon, USA	Potentially Effective	Low	*Salmonids** 1 Gabion	2	BACI	Abundance	age 0	pseudoreplicated	Quantitative
House and Boehne 1985g	East Fork Lobster Creek, Oregon, USA	Potentially Effective	Low	*Oncorhynchus kisutch* 1 Gabion	2	BACI	Abundance	fry	pseudoreplicated	Quantitative
House and Boehne 1985h	East Fork Lobster Creek, Oregon, USA	Potentially Effective	Medium	*Trout** 2 Gabions	2	BACI	Abundance	fry	replicated	Quantitative
Klassen & Northcote 1988a	Sachs Creek, British Columbia, Canada	Potentially Ineffective	Low	*Oncorhynchus gorbushca*	1	CI	Abundance	egg	replicated	Quantitative
House and Boehne 1985i	East Fork Lobster Creek, Oregon, USA	Potentially Ineffective	Low	*Trout** 1 Gabion	2	BACI	Abundance	fry	pseudoreplicated	Quantitative
Klassen & Northcote 1988b	Sachs Creek, British Columbia, Canada	Potentially Effective	Medium	*Oncorhynchus gorbushca*	1	CI	Survival	egg	pseudoreplicated	Quantitative

Study citation	Location	Effectiveness rating	Critical appraisal	Species	No. of true post-treatment years	Study design	Outcome	Life stage	Replication	Outcome category
Rock material + Waterbody creation										
Barlaup et al. 2008a	River Nidelva at weir Rygenefossen, Norway	Unclear	Low	*Unknown*	4	PT	Abundance	nest	unreplicated	Quantitative
Barlaup et al. 2008b	River Nidelva at weir Rygenefossen, Norway	Unclear	Low	*Salmo salar*	4	PT	Abundance	nest	unreplicated	Quantitative
Barlaup et al. 2008c	River Nidelva at weir Rygenefossen, Norway	Unclear	Low	*Salmo trutta trutta*	4	PT	Abundance	nest	unreplicated	Quantitative
Barlaup et al. 2008d	River Nidelva at weir Strubru, Norway	Unclear	Low	*Unknown*	4	PT	Abundance	nest	unreplicated	Quantitative
Barlaup et al. 2008e	River Nidelva at weir Strubru, Norway	Unclear	Low	*Salmo salar*	4	PT	Abundance	nest	unreplicated	Quantitative
Barlaup et al. 2008f	River Nidelva at weir Kalvehagefossen, Norway	Unclear	Low	*Unknown*	4	PT	Abundance	nest	unreplicated	Quantitative
Barlaup et al. 2008g	River Nidelva at weir Kalvehagefossen, Norway	Unclear	Low	*Salmo salar*	4	PT	Abundance	nest	unreplicated	Quantitative
Barlaup et al. 2008h	River Nidelva at weir Kalvehagefossen, Norway	Unclear	Low	*Salmo trutta trutta*	4	PT	Abundance	nest	unreplicated	Quantitative
Barlaup et al. 2008i	River Modalselva at weir Almeli, Norway	Unclear	Low	*Unknown*	5	PT	Abundance	nest	unreplicated	Quantitative
Barlaup et al. 2008j	River Modalselva at weir Almeli, Norway	Unclear	Low	*Salmo trutta trutta*	5	PT	Abundance	nest	unreplicated	Quantitative

Study citation	Location	Effectiveness rating	Critical appraisal	Species	No. of true post-treatment years	Study design	Outcome	Life stage	Replication	Outcome category
Rock material + Waterbody creation cont.										
Barlaup et al. 2008k	River Matreelva at outlet of lake Matrevatn, Norway	Unclear	Low	*Unknown*	5	PT	Abundance	nest	unreplicated	Quantitative
Barlaup et al. 2008l	River Matreelva at outlet of lake Matrevatn, Norway	Unclear	Low	*Salmo trutta trutta*	5	PT	Abundance	nest	unreplicated	Quantitative
Barlaup et al. 2008m	River Daleelva at weir, Norway	Unclear	Low	*Unknown*	3	PT	Abundance	nest	unreplicated	Quantitative
Barlaup et al. 2008n	River Daleelva at weir, Norway	Unclear	Low	*Salmo trutta trutta*	3	PT	Abundance	nest	unreplicated	Quantitative
Barlaup et al. 2008o	Lake Bjornesfjorden, Norway	Unclear	Low	*Salmo trutta*	4	PT	Abundance	nest	unreplicated	Quantitative
NYSDEC 2015a	St. Lawrence River, New York, USA	Unclear	Low	*Acipenser fulvescens,* Created upstream of Iroquouis Dam	7	PT	Abundance	spawner	pseudoreplicated	Quantitative
NYSDEC 2015b	St. Lawrence River, New York, USA	Unclear	Low	*Acipenser fulvescens,* Created downstream of Iroquouis Dam	7	PT	Abundance	spawner	pseudoreplicated	Quantitative
NYSDEC 2015c	St. Lawrence River, New York, USA	Unclear	Low	*Acipenser fulvescens,* Created upstream of Moses-Sanders Dam	3	PT	Abundance	spawner	pseudoreplicated	Quantitative
NYSDEC 2015d	St. Lawrence River, New York, USA	Unclear	Low	*Acipenser fulvescens,* Created downstream of Moses-Sanders Dam	3	PT	Abundance	spawner	pseudoreplicated	Quantitative
Environment Illimité Inc. 2009a	Lake St. Lawrence, Upstream of dam, New York, USA	Unclear	Low	*Acipenser fulvescens*	1	PT	Abundance	egg	unreplicated	Quantitative

Study citation	Location	Effectiveness rating	Critical appraisal	Species	No. of true post-treatment years	Study design	Outcome	Life stage	Replication	Outcome category
Rock material + Waterbody creation cont.										
Environment Illimité Inc. 2009b	Lake St. Lawrence, Downstream of dam, New York, USA	Unclear	Low	*Acipenser fulvescens*	1	PT	Abundance	egg	unreplicated	Quantitative
Environment Illimité Inc. 2009c	Lake St. Lawrence, Upstream of dam, New York, USA	Unclear	Low	*Acipenser fulvescens*	1	PT	Abundance	larvae	unreplicated	Quantitative
Environment Illimité Inc. 2009d	Lake St. Lawrence, Downstream of dam, New York, USA	Unclear	Low	*Acipenser fulvescens*	1	PT	Abundance	larvae	unreplicated	Quantitative
Peck 1986a	Lake Superior, Michigan, USA	Unclear	Low	*Salvelinus namaycush*	3	PT	Abundance	spawner	unreplicated	Quantitative
Peck 1986b	Lake Superior, Michigan, USA	Unclear	Low	*Salvelinus namaycush*	4	PT	Abundance	egg	pseudoreplicated	Quantitative
Peck 1986c	Lake Superior, Michigan, USA	Unclear	Low	*Salvelinus namaycush*	4	PT	Abundance	fry	pseudoreplicated	Quantitative
Bassett 1998a	Brevoort Lake, Michigan, USA	Unclear	Low	*Sander vitreus*	4	PT	Abundance	egg	pseudoreplicated	Quantitative
Bassett 1998b	Brevoort Lake, Michigan, USA	Unclear	Low	*Sander vitreus*	4	PT	Survival	egg	pseudoreplicated	Quantitative
Rock material + Waterbody modifications										
Luhta et al. 2012†	River Iijoki, Finland	Effective	Medium	*Salmo trutta*	5-9	CI	Abundance	age 0	replicated	Quantitative
Lister 1980a	Vedder River, British Columbia, Canada	Unclear	Low	*Oncorhynchus keta*	1	PT	Abundance	spawner	unreplicated	Quantitative approximation
Lister 1980b	Harrison River, British Columbia, Canada	Unclear	Low	*Oncorhynchus keta*	1	PT	Abundance	spawner	unreplicated	Quantitative approximation
Lister 1980c	Vedder River, British Columbia, Canada	Unclear	Low	*Oncorhynchus keta*	1	PT	Abundance	fry	unreplicated	Quantitative approximation

Study citation	Location	Effectiveness rating	Critical appraisal	Species	No. of true post-treatment years	Study design	Outcome	Life stage	Replication	Outcome category
Rock material + Waterbody modifications cont.										
Lister 1980d	Harrison River, British Columbia, Canada	Unclear	Low	*Oncorhynchus keta*	1	PT	Abundance	fry	unreplicated	Quantitative approximation
Hubert & Joyce 2005a	Christensen Creek (riffle), Wyoming, USA	Unclear	Low	*Oncorhynchus clarkii*	1	PT	Abundance	age 0	replicated	Quantitative
Hubert & Joyce 2005b	Christensen Creek (riffle margin), Wyoming, USA	Unclear	Low	*Oncorhynchus clarkii*	1	PT	Abundance	age 0	replicated	Quantitative
Hubert & Joyce 2005c	Christensen Creek (pool margin), Wyoming, USA	Unclear	Low	*Oncorhynchus clarkii*	1	PT	Abundance	age 0	replicated	Quantitative
Hubert & Joyce 2005d	Christensen Creek (backwaters), Wyoming, USA	Unclear	Low	*Oncorhynchus clarkii*	1	PT	Abundance	age 0	replicated	Quantitative
Lister 1980e	Vedder River, British Columbia, Canada	Unclear	Low	*Oncorhynchus keta*	1	PT	Survival	fry	unreplicated	Quantitative
Lister 1980f	Harrison River, British Columbia, Canada	Unclear	Low	*Oncorhynchus keta*	1	PT	Survival	fry	unreplicated	Quantitative
Rock material + Waterbody modifications + Waterbody creation										
Lister 1980g	Judd Slough, British Columbia, Canada	Unclear	Low	*Oncorhynchus keta*	1	PT	Abundance	spawner	unreplicated	Quantitative approximation
Lister 1980h	Judd Slough, British Columbia, Canada	Unclear	Low	*Oncorhynchus keta*	1	PT	Abundance	fry	unreplicated	Quantitative approximation
Lister 1980i	Judd Slough, British Columbia, Canada	Unclear	Low	*Oncorhynchus keta*	1	PT	Survival	fry	unreplicated	Quantitative
Rock material + Waterbody modifications + Human-made structures										
Lister 1980j	Railroad Creek, British Columbia, Canada	Unclear	Low	*Oncorhynchus keta*	1	PT	Abundance	spawner	unreplicated	Quantitative approximation

Study citation	Location	Effectiveness rating	Critical appraisal	Species	No. of true post-treatment years	Study design	Outcome	Life stage	Replication	Outcome category
Rock material + Waterbody modifications + Human-made structures cont.										
Lister 1980k	Railroad Creek, British Columbia, Canada	Unclear	Low	*Oncorhynchus keta*	1	PT	Abundance	fry	unreplicated	Quantitative approximation
Lister 1980l	Worth Creek, British Columbia, Canada	Unclear	Low	*Oncorhynchus keta*	1	PT	Abundance	spawner	unreplicated	Quantitative approximation
Lister 1980m	Worth Creek, British Columbia, Canada	Unclear	Low	*Oncorhynchus keta*	1	PT	Abundance	fry	unreplicated	Quantitative approximation
Lister 1980n	Railroad Creek, British Columbia, Canada	Unclear	Low	*Oncorhynchus keta*	1	PT	Survival	fry	unreplicated	Quantitative
Lister 1980o	Worth Creek, British Columbia, Canada	Unclear	Low	*Oncorhynchus keta*	1	PT	Survival	fry	unreplicated	Quantitative
Rock material + Plant material										
Naito 2016a	Whatshan River, British Columbia, Canada	Effective	Medium	*Salvelinus fontinalis*	5	BACI	Abundance	fry	pseudoreplicated	Quantitative approximation
Naito 2016b	Whatshan River, British Columbia, Canada	Effective	Medium	*Oncorhynchus mykis*	5	BACI	Abundance	fry	pseudoreplicated	Quantitative approximation
Avery 1996d	Chaffee Creek, Wisconsin, USA	Effective	Low	*Salmo trutta*	4	BACI	Abundance	age 0	unreplicated	Quantitative
Avery 1996e	Waupee Creek, Wisconsin, USA	Effective	Low	*Salvelinus fontinalis*	3	BACI	Abundance	age 0	unreplicated	Quantitative
Crispin et al. 1993	Elk Creek, Oregon, USA	Potentially Effective	Low	*Oncorhynchus kisutch*	5	BA	Abundance	redd	unreplicated	Quantitative
MacInnis et al. 2008	Brierly Brook, James River, Nova Scotia, Canada	Potentially Effective	Low	*Salmo salar*	6	CI	Abundance	redd	unreplicated	Quantitative
House 1996	Lobster Creek, Oregon, USA	Potentially Effective	High	*Oncorhynchus kisutch*	8	BACI	Abundance	juvenile	Replicated	Quantitative

Study citation	Location	Effectiveness rating	Critical appraisal	Species	No. of true post-treatment years	Study design	Outcome	Life stage	Replication	Outcome category
Rock material + Plant material cont.										
Vehanen et al. 2010d	Oulujoki watercourse, Finland	Potentially Effective	High	*Salmo trutta*	3	BACI	Abundance	juvenile	Replicated	Quantitative
Halyk 2008a	Marden Creek, Ontario, Canada	Potentially Effective	Low	*Salvelinus fontinalis*	1	BA	Abundance	age 0	unreplicated	Quantitative
Avery 1996f	Chaffee Creek, Wisconsin, USA	Potentially Effective	Low	*Salvelinus fontinalis*	4	BA	Abundance	redd	unreplicated	Semi-Quantitative
Avery 1996g	Waupee Creek, Wisconsin, USA	Potentially Effective	Low	*Salmo trutta*	3	BA	Abundance	redd	unreplicated	Quantitative
Floyd et al. 2009a	West River, Nova Scotia, Canada	Potentially Effective	Low	*Salmo salar*	2	CI	Abundance	fry	unreplicated	quantitative
Floyd et al. 2009b	West River, Nova Scotia, Canada	Potentially Effective	Low	*Salmo salar*	2	CI	Abundance	parr	unreplicated	quantitative
Floyd et al. 2009c	West River, Nova Scotia, Canada	Potentially Effective	Low	*Salmo salar*	1	BACI	Abundance	fry	unreplicated	quantitative
Floyd et al. 2009d	West River, Nova Scotia, Canada	Potentially Effective	Low	*Salmo salar*	1	BACI	Abundance	parr	unreplicated	quantitative
Vehanen et al. 2010e	Oulujoki watercourse, Finland	Potentially Ineffective	High	*Salmo trutta*	2	BACI	Abundance	age 0	replicated	Quantitative
Vehanen et al. 2010f	Oulujoki watercourse, Finland	Potentially Ineffective	High	*Salmo trutta*	3	BACI	Abundance	juvenile	replicated	Quantitative
Naito 2016c	Whatshan River, British Columbia, Canada	Ineffective	Medium	*Cottus cognatus*	5	BACI	Abundance	fry	pseudoreplicated	Quantitative approximation
Naito 2016d	Whatshan River, British Columbia, Canada	Ineffective	Medium	*Rhinichthys cataractae*	5	BACI	Abundance	fry	pseudoreplicated	Quantitative approximation
Avery 1996h	Waupee Creek, Wisconsin, USA	Ineffective	Low	*Salmo trutta*	3	BACI	Abundance	age 0	unreplicated	Quantitative
Triton Environmental. Consultants Ltd 2000	Spring Creek, British Columbia, Canada	Unclear	Low	*Oncorhynchus kisutch*	1	BA	Abundance	spawner	unreplicated	Qualitative

Study citation	Location	Effectiveness rating	Critical appraisal	Species	No. of true post-treatment years	Study design	Outcome	Life stage	Replication	Outcome category
Rock material + Plant material cont.										
Halyk 2008b	Marden Creek, Ontario, Canada	Unclear	Low	*Salvelinus fontinalis*	1	BA	Abundance	spawner	unreplicated	Semi-Quantitative
Halyk 2008c	Marden Creek, Ontario, Canada	Unclear	Low	*Salvelinus fontinalis*	1	BA	Abundance	fry	unreplicated	Semi-Quantitative
Naito 2016e	Whatshan River, British Columbia, Canada	Effective	Medium	*Cottus cognatus*	5	CI	Body Size	fry	pseudoreplicated	Quantitative
Naito 2016f	Whatshan River, British Columbia, Canada	Effective	Medium	*Oncorhynchus mykis*	5	CI	Body Size	fry	pseudoreplicated	Quantitative
Naito 2016g	Whatshan River, British Columbia, Canada	Ineffective	Medium	*Salvelinus fontinalis*	5	CI	Body Size	fry	pseudoreplicated	Quantitative
Rock material + Plant material + Human-made structures										
Nagata et al. 2002	Shakotan River, Japan	Potentially Effective	Medium	*Oncorhynchus masou*	1	CI	Abundance	age 0	pseudoreplicated	Quantitative
Hale 1969	Split Rok River, Minnesota, USA	Ineffective	Low	*Salvelinus fontinalis*	3	BACI	Abundance	age 0	unreplicated	Quantitative
Rock material + Plant material + Waterbody creation										
Island Stream and Salmon Enhancement Program 2002	Duck Creek, Stowe Creek, Cusheon Creek, Fulford Creek	Unclear	Low	*Oncorhynchus kisutch*	1	PT	Abundance	spawner	unreplicated	Quantitative
Rock material + Plant material + Waterbody modifications										
Kelly and Bracken 1998a	River Liffey, Ireland	Potentially Effective	Medium	*Salmo salar*	1	BACI	Abundance	juvenile	pseudoreplicated	Quantitative
Ward et al. 2003a	Keogh River and Waukwaas River, British Columbia, Canada	Potentially Effective	Medium	*Oncorhynchus kisutch*	1	CI	Abundance	fry	pseudoreplicated	Quantitative

Study citation	Location	Effectiveness rating	Critical appraisal	Species	No. of true post-treatment years	Study design	Outcome	Life stage	Replication	Outcome category
Rock material + Plant material + Waterbody modifications cont.										
Kelly and Bracken 1998b	River Liffey, Ireland	Potentially Ineffective	Medium	*Salmo trutta*	1	BACI	Abundance	juvenile	pseudoreplicated	Quantitative
Ward et al. 2003b	Keogh River and Waukwaas River, British Columbia, Canada	Potentially Ineffective	Medium	*Oncorhynchus mykis*	1	CI	Abundance	fry	pseudoreplicated	Quantitative
Island Stream and Salmon Enhancement Program 2002	Duck, Stowe, Cusheon, and Fulford Creek, British Columbia, Canada	Unclear	Low	*Oncorhynchus kisutch*	1	PT	Abundance	spawner	unreplicated	Quantitative
Rock material + Plant material + Waterbody modifications + Waterbody creation										
Taylor 1999	Caycuse River, British Columbia, Canada	Unclear	Low	*Oncorhynchus kisutch*	1	PT	Abundance	fry	unreplicated	Qualitative
Plant material + Human-made structures										
Wills 2004a	Au Sable River, Michigan, USA	Potentially Effective	Medium	*Micropterus dolomieui*	1	CI	Abundance	nest	replicated	Quantitative
Wills 2004b	Au Sable River, Michigan, USA	Potentially Effective	Medium	*Micropterus dolomieui*	1	CI	Survival	nest	replicated	Quantitative
Plant material + Waterbody modifications										
Lorenz et al. 2013	Various sites, Germany	Effective	Medium	*Various species*	1-19	CI	Abundance	age 0	replicated	Quantitative

Study citation	Location	Effectiveness rating	Critical appraisal	Species	No. of true post-treatment years	Study design	Outcome	Life stage	Replication	Outcome category
Plant material + Waterbody modifications cont.										
Avery 2004c	Price Creek, Wisconsin, USA	Potentially Effective	Low	*Salvelinus fontinalis*	1	BA	Abundance	age 0	unreplicated	Quantitative
Langler 2001j	Huntspill River, Somerset, England	Potentially Effective	Medium	*Abramis brama*	1	CI	Abundance	age 0	replicated	Quantitative approximation
Langler 2001k	Huntspill River, Somerset, England	Potentially Effective	Medium	*Gobio gobio*	1	CI	Abundance	age 0	replicated	Quantitative approximation
Langler 2001l	Huntspill River, Somerset, England	Potentially Effective	Medium	*Gymnocephalus cernuus*	1	CI	Abundance	age 0	replicated	Quantitative approximation
Langler 2001m	Huntspill River, Somerset, England	Potentially Effective	Medium	*Leucaspius delineatus*	1	CI	Abundance	age 0	replicated	Quantitative approximation
Langler 2001n	Huntspill River, Somerset, England	Potentially Effective	Medium	*Perca fluviatilis*	1	CI	Abundance	age 0	replicated	Quantitative approximation
Langler 2001o	Huntspill River, Somerset, England	Potentially Effective	Medium	*Rutilus rutilus*	1	CI	Abundance	age 0	replicated	Quantitative approximation
Plant material + Waterbody modifications + Waterbody creation										
Wright 1999a	Taylor River, British Columbia, Canada	Unclear	Low	*Oncorhynchus kisutch*	1	PT	Abundance	fry	unreplicated	Quantitative
Wright 1999b	Taylor River, British Columbia, Canada	Unclear	Low	*Oncorhynchus kisutch*	1	PT	Abundance	spawner	unreplicated	Quantitative
Waterbody modifications + Waterbody creation										
Cott 2004a	Stagg River, Northwest Territories, Canada	Unclear	Low	*Esox lucius*	3	PT	Abundance	age 0	unreplicated	Quantitative
Cott 2004b	Stagg River, Northwest Territories, Canada	Unclear	Low	*Esox lucius*	3	PT	Abundance	juvenile	unreplicated	Quantitative
Waterbody modifications + Human-made structures										
Lister 1980p	Judd Slough, British Columbia, Canada	Unclear	Low	*Oncorhynchus keta*	1	PT	Abundance	spawner	unreplicated	Quantitative approximation

Study citation	Location	Effectiveness rating	Critical appraisal	Species	No. of true post-treatment years	Study design	Outcome	Life stage	Replication	Outcome category
Waterbody modifications + Human-made structures cont.										
Lister 1980q	Judd Slough, British Columbia, Canada	Unclear	Low	*Oncorhynchus keta*	1	PT	Abundance	fry	unreplicated	Quantitative approximation
Lister 1980r	Lower Paradise, British Columbia, Canada	Unclear	Low	*Oncorhynchus keta*	1	PT	Abundance	spawner	unreplicated	Quantitative approximation
Lister 1980s	Lower Paradise, British Columbia, Canada	Unclear	Low	*Oncorhynchus keta*	1	PT	Abundance	fry	unreplicated	Quantitative approximation
Lister 1980t	Judd Slough, British Columbia, Canada	Unclear	Low	*Oncorhynchus keta*	1	PT	Survival	fry	unreplicated	Quantitative
Lister 1980u	Lower Paradise, British Columbia, Canada	Unclear	Low	*Oncorhynchus keta*	1	PT	Survival	fry	unreplicated	Quantitative

†Data sets that use a degraded impact site.
*Data sets that use a combination of species/ species groups.

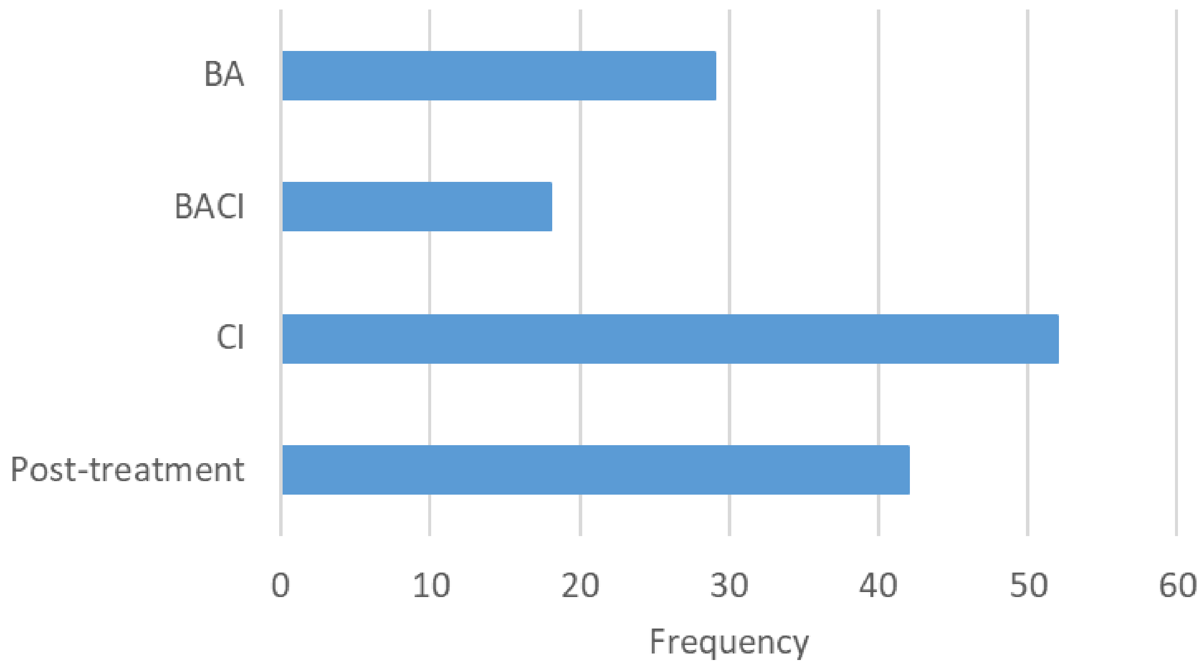

Figure 1. The number of studies per study design. The number of studies exceeds the total number of studies because some studies included more than one project with different study designs.

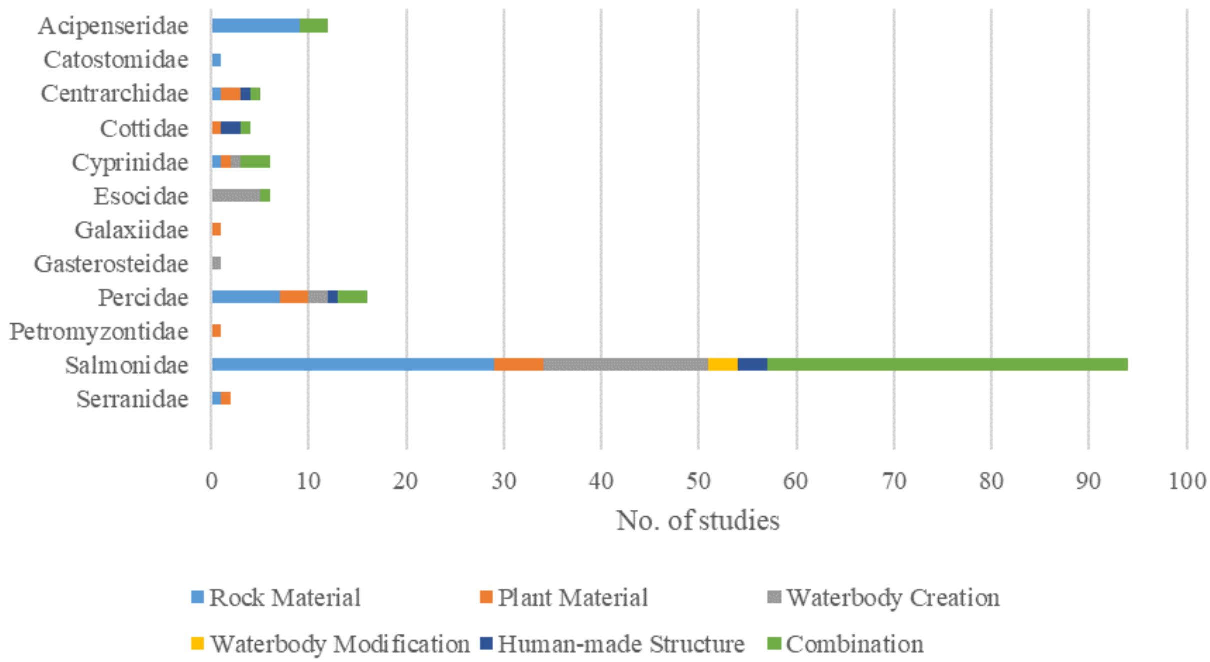

Figure 2. The number of studies per family in relation to the intervention type applied. Combination refers to any number of interventions applied simultaneously. The number of studies shown exceeds the total number of studies because data for multiple families or intervention categories were often presented within a study. Nine studies grouped several species across genera or families and were therefore not included in this figure.

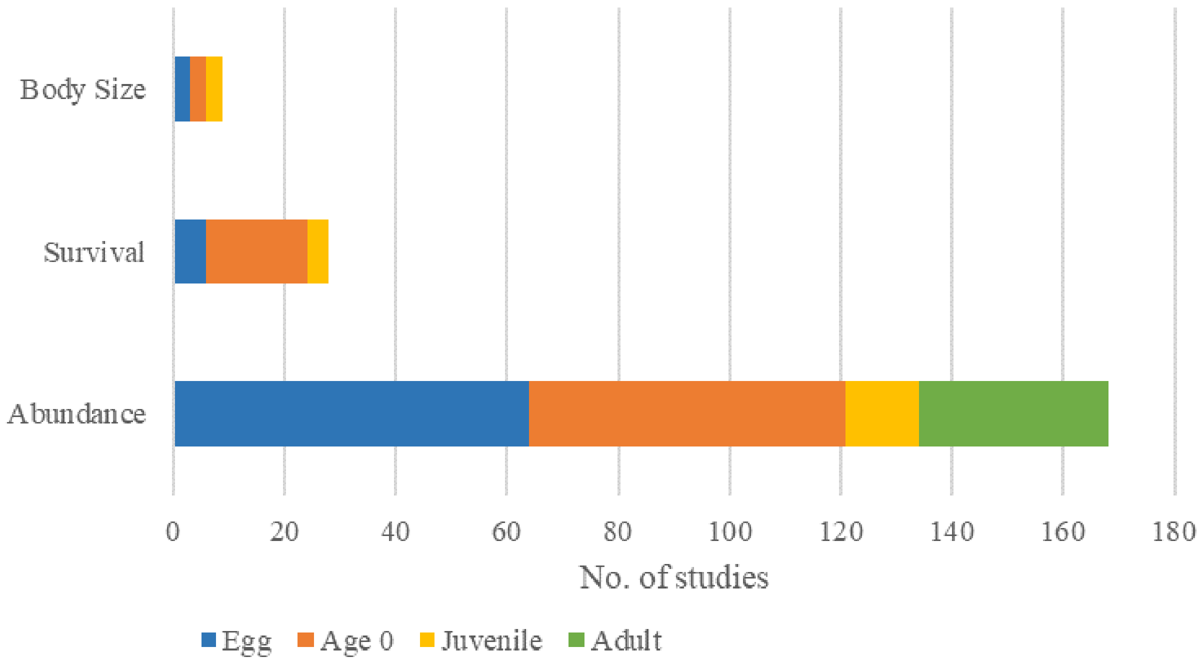

Figure 3. The number of studies per outcome metric in relation to the life stage presented. The number of studies shown exceeds the total number of included studies because data for multiple life stages within a particular outcome metric were often presented within a study.

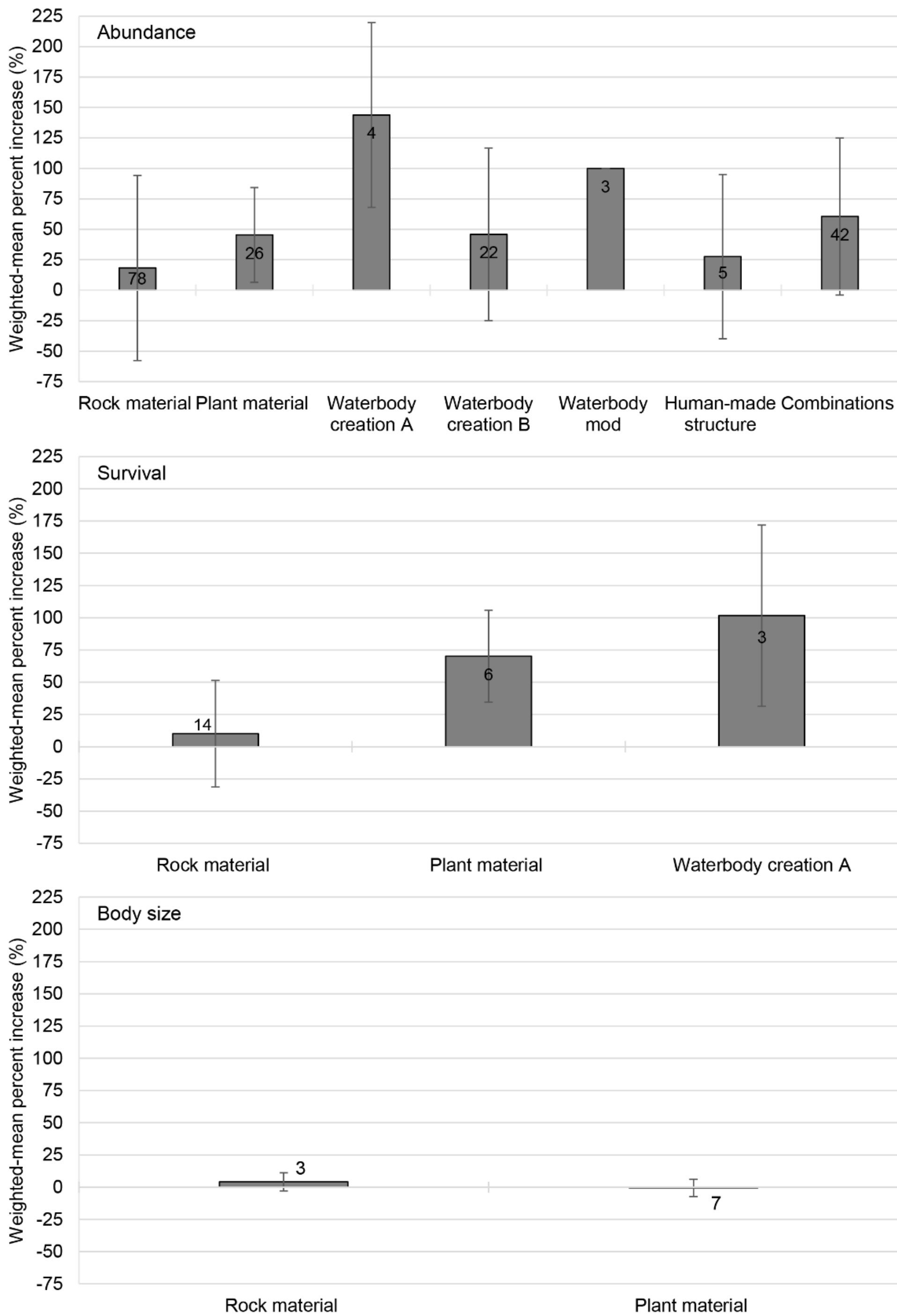

Figure 4. The weighted-mean percent increase (± standard deviation) in fish outcome metrics (top: abundance; middle: survival; bottom: body size) for spawning habitat creation or enhancement interventions. Values on bars are the number of data sets. A mean value >0% indicates that the outcome metric was higher/larger in treatment areas than in control areas (no intervention). Waterbody mod: waterbody modification. Waterbody creation: (A) comparator = a natural waterbody; (B) comparator = a nearby reference section within the same waterbody.

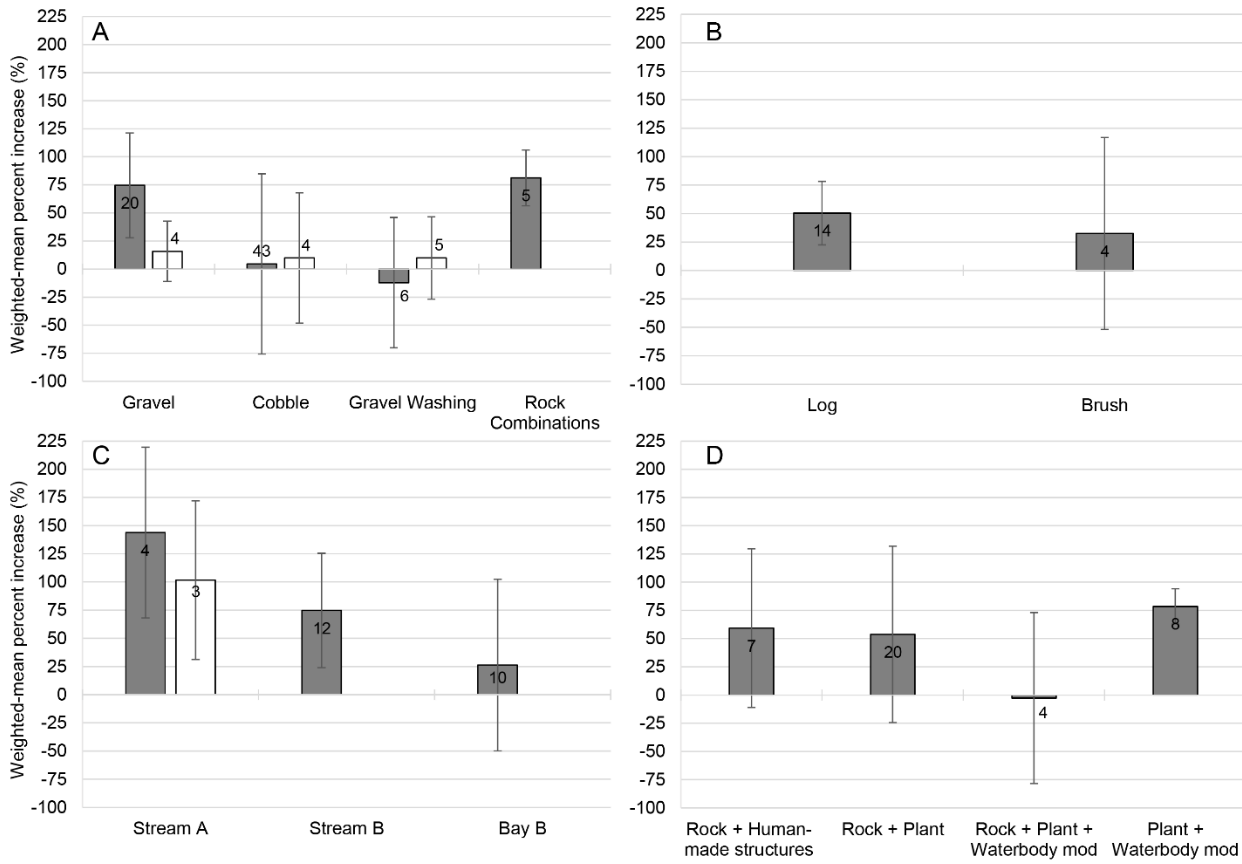

Figure 5. The weighted-mean percent increase (± standard deviation) in fish abundance (grey bars), and survival (white bars) in relation to specific types of spawning habitat creation or enhancement interventions (A) rock material, (B) plant material, (C) waterbody creation or extension of an existing waterbody, and (D) combinations of different interventions. Values on bars are the number of data sets. A mean value >0% indicates that the outcome metric was higher/larger in treatment areas than in control areas (no intervention). Waterbody mod: waterbody modification. Stream/Bay: (A) comparator = a natural waterbody; (B) comparator = a nearby reference section within the same waterbody.

APPENDIX A. ANNOTATED BIBLIOGRAPHY

Anderson, J.W., Ruediger, R.A., and Hudson, W.F. 1984. Design, placement and fish use of instream structures in southwestern Oregon. Pp. 165–180 in: T.J. Hassler, editor. Pacific North-west Stream Habitat Management Workshop. American Fisheries Society, Humboldt Chapter, Arcata, CA.

Study location: Oregon, USA

Target species/group: Chinook Salmon (*Oncorhynchus tshawytscha*)

Study Objective: This paper describes results of a large-scale enhancement project that involved developing 10 enhancement designs and the installation of 80 artificial (human-made) structures on four streams during 1981-1982. This study provides information on design feasibility, habitat changes, spawning use and rearing capability. Use of structures by adult Chinook Salmon was monitored by counting redd sites before and after installation of structures (for one of the streams). No explicit target outcome was stated.

Critical appraisal:

This study used a BA study design that included one pre-treatment and one true post-treatment monitoring period. Outcome information was reported as total counts of redd sites from all structures (seven areas selected for construction of 28 structures) for a single stream (Tioga Creek). Since a total count was used, there was no variance reported (by default lacked replication).

Effectiveness rating (% change in effectiveness): Potentially effective (100.0%)

Evidence suggests the intervention(s) could be effective, but the biological endpoint reported (i.e., abundance of redds) only confirms the use of spawning habitat and not necessarily success.

Andrew, F.J. 1981. Gravel cleaning to increase salmon production in rivers and spawning channels. In: Proceedings from the Conference - Salmon-spawning Gravel: A Renewable Resource in the Pacific Northwest? Washington State Water Research Center, Pullman, WA. Oct. 6-7, 1980. pp. 15-31.

Study location: British Columbia, Canada

Target species/group: Sockeye Salmon (*Oncorhynchus nerka*)

Study Objective: This study describes the results of spawning gravel cleaning, by either a spawning channel gravel cleaner or the velocity segregation method, on the Horsefly River Spawning Channel in September 1973. Egg-to-fry survival was determined seven months after cleaning for both gravel cleaning methods and compared to control areas where no gravel cleaning occurred. In addition, adult spawner presence was noted for cleaned and uncleaned areas of the spawning channel. No explicit target outcome was stated.

Critical appraisal:

Both projects listed below used a CI study design, that included one cleaned area and one uncleaned area for both the spawning channel gravel cleaner and velocity segregation methods of gravel cleaning

Project A:

Egg-to-fry survival was determined at both two months and seven months post-cleaning for both control and impact areas, using hydraulic egg samplers. For egg-to-fry survival in areas cleaned by the spawning channel gravel cleaner, 10 and 20 samples were taken for cleaned and uncleaned areas, respectively. For the velocity segregation method of gravel cleaning, 20 samples to determine egg-to-fry survival were taken for both cleaned and uncleaned areas. All samples were collected in the same channel and are considered pseudoreplicated but reported quantitative measures of outcome.

Project B:

Visual estimates were used to describe adult spawner presence (qualitative outcome measure); this data was not replicated.

Effectiveness rating (% change in effectiveness):

Project A: Egg-to-fry survival following gravel cleaning with spawning channel gravel cleaner: Potentially effective (12.3%)

Evidence suggests gravel cleaning by this method could be effective, but there were fewer than two years of post-intervention monitoring.

Project A: Egg-to-fry survival following gravel cleaning by velocity segregation method: Potentially ineffective (-14.8%)

Evidence suggests gravel cleaning by this method is potentially ineffective, but there were fewer than two years of post-intervention monitoring.

Project B: Adult spawner presence: Unclear (N/A)

Lack of evidence to determine the effect of gravel cleaning on adult spawner presence, as only qualitative data is presented for one-year post-intervention and authors were unable to conclude on effectiveness.

Avery, E.L. 1996. Evaluations of sediment traps and artificial gravel riffles constructed to improve reproduction of trout in three Wisconsin streams. North Am. J. Fish. Manag., 16: 282–293.

Study location: Wisconsin, USA

Target species/group: Brook Trout (*Salvelinus fontinalis*), Brown Trout (*Salmo trutta*)

Study objective: The objective of this study was to determine if sediment traps installed alone or in conjunction with gravel spawning riffles, rock sills, and addition of logs, would significantly improve natural reproduction of trout in 1.3-1.9 km segments of three Wisconsin streams. For Hay Creek, Chaffee Creek, and Waupee Creek, abundance of redds and density of age 0 trout per kilometer were recorded for both Brook Trout and Brown Trout. No explicit target outcome was stated.

Critical appraisal:

For all projects outlined below, studies had well-matching control and treatment samples, and the treatment and comparators were homogenous with respect to potential confounding factors (i.e., environment factors); however, all studies lacked replication at the level of intervention which resulted in a low validity rating for all projects.

Hay Creek

Project A: This study employed a BA study design to evaluate the effectiveness of sediment traps alone in increasing Brown Trout redd abundance (quantitative outcome).

Project B: These studies employed BACI study designs to evaluate the effectiveness of sediment traps alone in increasing both age 0 Brown Trout and Brook Trout density (both quantitative outcomes).

Chaffee Creek

Project C: This study employed a BA study design to evaluate the efficacy of sediment traps with gravel spawning riffles in increasing Brook Trout redd abundance (semi-quantitative outcome).

Project D: This study employed a BACI study design to evaluate the effectiveness of sediment traps with gravel spawning riffles in increasing age 0 Brown Trout density (quantitative outcome).

Waupee Creek

Project E: This study employed a BA study design to assess the effectiveness of sediment traps with gravel spawning riffles in increasing Brown Trout redd abundance (quantitative outcome).

Project F: These studies used a BACI design to evaluate the efficacy of sediment traps with gravel spawning riffles in increasing the abundance of age 0 Brown Trout and Brook Trout (quantitative outcomes).

Effectiveness rating (% change in effectiveness):

Hay Creek

Project A: Effectiveness of sediment traps alone on Brown Trout redd abundance: Potentially ineffective (-33.4%)

Evidence suggests the intervention could be ineffective, but the biological endpoint (i.e., number of redds) only confirms use of spawning habitat and not necessarily success.

Project B: Effectiveness of sediment traps alone on age 0 Brook Trout density: Ineffective (-100.0%)

There is quantitative evidence to conclude the intervention was not successful in increasing age 0 density.

Project B: Effectiveness of sediment traps alone on age 0 Brown Trout density: Ineffective (-100.0%)

There is quantitative evidence to conclude the intervention was not successful in increasing age 0 density.

Chaffee Creek

Project C: Effectiveness of sediment traps with gravel spawning riffles on the abundance of Brook Trout redds: Potentially effective (100.0%)

Evidence suggests the intervention could be effective; however only semi-qualitative evidence is presented.

Project D: Effectiveness of sediment traps with gravel spawning riffles on age 0 Brown Trout density: Effective (100.0%)

There is quantitative evidence to conclude that the intervention was successful in increasing age 0 density.

Waupee Creek

Project E: Effectiveness of sediment traps with gravel spawning riffles on the abundance of Brown Trout redds: Potentially effective (100.0%)

Evidence suggests the intervention could be effective, but the biological endpoint (i.e., number of redds) only confirms use of spawning habitat and not necessarily success.

Project F: Effectiveness of sediment traps with gravel spawning riffles on age 0, Brown Trout density: Ineffective (-100.0%)

There is quantitative evidence to conclude that the intervention was not successful in increasing age 0 density.

Project F: Effectiveness of sediment traps with gravel spawning riffles on age 0 Brook Trout density: Effective (100.0%)

There is quantitative evidence to conclude that the intervention was successful in increasing age 0 density.

Avery, E.L. 2004. A Compendium of 58 Trout Stream Habitat Development Evaluations in Wisconsin 1985-2000: Research Report 187 for Wisconsin Department of Natural Resources, Waupaca, WI.

Study Location: Wisconsin, USA

Target species/group: Brook Trout (*Salvelinus fontinalis*), Brown Trout (*Salmo trutta*)

Study objective: This paper describes three studies on different streams for which habitat compensation methods were tested for their effect on numbers of trout species (all age 0). In Big (Cataract) Creek the number of Brook Trout (smaller than six inches in length) was counted per mile following installation of a sediment trap and a rock-sill-gravel spawning riffle. In Lodi (Spring) Creek the number of Brown Trout (less than seven inches in length) was counted per mile following installation of rip-rap, current deflectors, and in-stream boulders to the creek. Finally, in Price Creek the number of Brook Trout (less than six inches in length) was counted per mile after the streambank was de-brushed and brush bundles and half logs were added to the creek. No explicit target outcome was stated.

Critical appraisal:

The studies on Project A, Big (Cataract) Creek, Project B, Lodi Creek, and Project C, Price creek employed CI, BACI, and BA study designs respectively, and used quantitative outcomes. All three studies lacked replication (at the level of intervention).

Effectiveness rating (% change in effectiveness):

Project A: Big (Cataract) Creek: Potentially effective (45.4%)

Project B: Lodi (Spring) Creek: Potentially effective (13.0%)

Project C: Price Creek: Potentially effective (100.0%)

For all three studies, quantitative evidence suggests the interventions were successful in increasing age 0 trout densities, but there were fewer than two years post-treatment monitoring. The authors also state there were no positive changes in the natural recruitment of trout or in the total population of trout that could be attributed to habitat development, as either no statistically significant difference was found after habitat development or control sites also saw similar increases in trout populations.

Barlaup, B.T., Gabrielsen, S.E., Skoglund, H., and Wiers, T. 2008. Addition of spawning gravel—a means to restore spawning habitat of Atlantic Salmon (*Salmo salar* L.), and anadromous and resident brown trout (*Salmo trutta* L.) in regulated rivers. River Res. Appl., 24: 543–550. doi:10.1002/rra.1127.

Study location: Norway

Target species/group: Atlantic Salmon (*Salmo salar*), Sea Trout (*Salmo trutta trutta*), Brown Trout (*Salmo trutta*), Various

Study objective: In various areas in a number of rivers in Norway, gravel was added to create spawning areas for salmonids. In each spawning area, the total number of nests was counted by visual observation. The number of Atlantic Salmon, Brown Trout, and Sea Trout nests were also counted to assess the success of gravel placement for salmonid spawning. No explicit target outcome was stated.

Critical appraisal: 🔴

All evaluations were assessed post-treatment only with no comparator and were given low overall validity ratings. The study was unreplicated.

Effectiveness rating (% change in effectiveness): Unclear (N/A)

The effectiveness of these interventions is unclear, because only post-intervention monitoring was performed with no comparator.

Bassett, C. 1988. Brevoort Lake Reef: 1988 Monitoring Report - St. Ignace Ranger District Hiawatch National Forest. Ministry of Natural Resources.

Study location: Michigan, USA

Target species/group: Walleye (*Sander vitreus*)

Study objective: A rock reef was created in a Michigan lake to support Walleye spawning. The effectiveness of this reef as spawning habitat was assessed by determining density and survival of Walleye eggs. No explicit target outcome was stated.

Critical appraisal: 🔴

This study was assessed post-treatment only with no comparator and was given a low overall validity rating. Basket samplers were used to determine egg density and survival (quantitative). The study was pseudoreplicated.

Effectiveness rating (% change in effectiveness): Unclear (N/A)

The effectiveness of this intervention is unclear, because only post-intervention monitoring was performed with no comparator.

Benoît, J., and Legault, M. 2002. Assessment of the feasibility of preventing reproduction of Lake Charr, *Salvelinus namaycush*, in shallow areas of reservoirs affected by drawdowns. Environ. Biol. Fishes, 64: 303–311. doi:10.1007/978-94-017-1352-8_28.

Study location: Quebec, Canada

Target species/group: Lake Trout (*Salvelinus namaycush*)

Study objective: This study compares artificial spawning sites with adjacent natural spawning sites of Lake Trout. Note, artificial spawning sites (impact sites) were previously degraded and compared to adjacent natural spawning sites (control sites). Artificial spawning sites were created using angular cobble and pebbles in deeper water along the lake shore in 1993. In 1995, two years after the spawning sites were created, the number of eggs per square meter was counted visually by scuba divers. No explicit target outcome was stated.

Critical appraisal:

This study used a CI study design that included two intervention sites and two comparator sites. The study was considered replicated, N=2. Control and intervention sites were moderately well matched, eggs were counted by scuba divers at both sites and means for number of eggs per square meter were calculated for the intervention and control sites.

Effectiveness rating (% change in effectiveness): Potentially effective (100.0%)

Evidence suggests that the intervention could be effective, but the biological endpoint reported (i.e., density of eggs) only confirms the use of spawning habitat and not necessarily success. Note here, that the percent change in effectiveness is greater than zero percent which indicates that the degraded impact sites that received the intervention had a positive proportional change relative to the natural-like condition.

Bonnell, R.G. 1991. Construction, operation, and evaluation of groundwater-fed side channels for Chum Salmon in British Columbia. In: Fisheries and Bioengineering Symposium. J. Colt and R.J. White, *eds*. Am. Fish. Soc. Symp. Bethesda, MD., 10: 109-124.

Study location: British Columbia, Canada

Target species/group: Chum Salmon (*Oncorhynchus keta*)

Study objective: Groundwater-fed side channels were created by grading down, deepening, and widening intermittent or relic side channels on river floodplains to intercept subsurface flow.

The constructed channels are rock-armoured and protected from floods by dykes or local landforms. This study uses data from 24 different side channels that were created. Some of the channels consisted of existing gravel substrates, whereas others were created and had graded gravel substrates added. For channels with existing or graded gravel substrates, a number of outcomes were measured: density of female spawners, potential egg deposition, percentage embryo survival, percentage fry survival, and annual fry production. No explicit target outcome was stated.

Critical appraisal: 🔴

These studies were assessed post-treatment only with no comparator and were given low overall validity ratings. The studies were pseudoreplicated.

Effectiveness rating (% change in effectiveness): Unclear (N/A)

The effectiveness of this intervention is unclear, because only post-intervention monitoring was performed with no comparator.

Bouckaert, E.K., Auer, N.A., Roseman, E.F., and Boase, J. 2014. Verifying success of artificial spawning reefs in the St. Clair-Detroit River System for lake sturgeon (*Acipenser fulvescens* Rafinesque, 1817). J. Appl. Ichthyol., 30: 1393–1401. doi:10.1111/jai.12603.

Study location: Ontario, Canada; Michigan, USA

Target species/group: Lake Sturgeon (*Acipenser fulvescens*)

Study objective: This study describes the construction of three reefs for Lake Sturgeon spawn. Fighting Island Reef (FIR), in the Detroit River, consists of 12 experimental reef beds (0.33 ha total) containing four repeating substrate treatments: limestone shot rock, sorted limestone, rounded igneous rock, and a mix of all three substrates. The North Channel Reef (NCR) is located in the North Channel of the lower St. Clair River where Lake Sturgeon spawn on a 0.25 ha bed of coal clinker. Middle Channel Reef (MCR) was constructed in the Lower St Clair River and consists of nine reef beds (0.4 ha total) containing three repeating substrate treatments: angular limestone, rounded igneous rock, and 1:1 mix of both substrates. At each reef the density of Lake Sturgeon eggs and number of larvae were determined. No explicit target outcome was stated.

Critical appraisal:

Project A: 🔴

The density of Lake Sturgeon eggs and CPUE of larvae on FIR was determined. This study was assessed post-treatment only with no comparator and was given a low overall validity rating. Egg mats and D-frame drift nets were used to determine egg density and CPUE of larvae. The study was replicated (n=7, n=8, respectively).

Project B: 🔴

The density of Lake Sturgeon eggs in NCR was determined. This study was assessed post-treatment only with no comparator and was given a low overall validity rating. Egg mats were used to determine egg density.

Project C:

The abundance of Lake Sturgeon larvae in NCR was determined. This study was assessed post-treatment only with no comparator and was given a low overall validity rating. D-frame drift nets were used to capture larvae. The study was unreplicated.

Project D:

The density of Lake Sturgeon eggs in MCR was determined. This study used a BA study design comparing egg density before and after reef construction. Egg mats were used to determine egg density. The study was unreplicated. It was given a low overall validity rating.

Project E:

The abundance of Lake Sturgeon larvae in MCR was determined. This study used a BA study design comparing egg density before and after reef construction. D-frame drift nets were used to capture larvae. The study was unreplicated. It was given a low overall validity rating.

Effectiveness rating (% change in effectiveness):

Project A: Density of Lake Sturgeon eggs in FIR: Unclear (N/A)

The effectiveness of this intervention is unclear, because only post-intervention monitoring was performed with no comparator.

Project A: CPUE of Lake Sturgeon larvae in FIR: Unclear (N/A)

The effectiveness of this intervention is unclear because only post-intervention monitoring was performed with no comparator.

Project B: Density of Lake Sturgeon eggs in NCR: Unclear (N/A)

The effectiveness of this intervention is unclear because only post-intervention monitoring was performed with no comparator.

Project C: Abundance of Lake sturgeon larvae in NCR: Unclear (N/A)

The effectiveness of this intervention is unclear because only post-intervention monitoring was performed with no comparator.

Project D: Density of Lake Sturgeon eggs in MCR: Potentially effective (100.0%)

The evidence suggests the reef constructed during this study is potentially effective at increasing Lake Sturgeon egg density compared with before the reef was constructed, however, fewer than three years of post-intervention monitoring were performed, and the biological endpoint reported (i.e., egg density) only confirms the use of spawning habitat and not necessarily success.

Project E: Abundance of Lake Sturgeon larvae in MCR: Potentially effective (100.0%)

The evidence suggests the reef constructed during this study is potentially effective at increasing Lake Sturgeon larvae abundance compared with before the reef was constructed, however, fewer than three years of post-intervention monitoring were performed.

Cederholm, C.J., Bilby, R.E., Bisson, P.A., Bumstead, T.W., Fransen, B.R., Scarlett, W.J., and Ward, J.W. 1997. Response of juvenile Coho Salmon and steelhead to placement of large woody debris in a coastal Washington stream. North Am. J. Fish. Manag., 17: 947–963.

Study location: Washington, USA

Target species/group: Coho Salmon (*Oncorhynchus kisutch*)

Study objective: This study compares the effect of two different methods of adding woody substrates to a stream on increasing the abundance of Coho Salmon juveniles. In the first method (Intervention 1), large, woody debris and boulders were added to a stream and anchored in place. Large woody debris abundance was increased to levels typical of streams in forests where no timber harvest had occurred. In all, 133 structures containing 200 logs were added to the engineered site. In the second, less expensive, approach (Intervention 2), logs added to this site were all red alder cut from the streambank and dropped into the channel. No explicit target outcome was stated.

Critical appraisal:

This study used a BACI study design, comparing Coho Salmon juvenile abundance before and after introduction of large, woody debris at impacted and control sites. Control and intervention sites were likely well-matched and homogenous with respect to confounding factors. Minnow traps were used to determine juvenile abundance. The study was pseudoreplicated and given medium overall study validity.

Effectiveness rating (% change in effectiveness):

Juvenile abundance at intervention 1: Potentially effective (100.0%)

The evidence suggests the intervention described in this study is potentially effective at increasing juvenile Coho Salmon density, however, the biological endpoint reported (i.e., abundance of juveniles) only confirms the use of spawning habitat and not necessarily success.

Juvenile abundance at intervention 2: Potentially effective (100.0%)

The evidence suggests the intervention described in this study is potentially effective at increasing juvenile Coho Salmon density, however, the biological endpoint reported (i.e., abundance of juveniles) only confirms the use of spawning habitat and not necessarily success.

Chiotti, J. 2012. Habitat Enhancement Projects in the St. Clair/Detroit River System. [Online] Available: https://www.fws.gov/fieldnotes/regmap.cfm?arskey=33274.

Study location: Michigan, USA

Target species/group: Lake Sturgeon (*Acipenser fulvescens*)

Study objective: In this study a spawning reef for Lake Sturgeon was created in the Detroit River through addition of rock to the river bed. The presence of Lake Sturgeon on the new reef was noted to determine success of the reef as a new spawning area. No explicit target outcome was stated.

Critical appraisal:

This study was assessed post-treatment only with no comparator and was given a low overall validity rating. Presence or absence of Lake Sturgeon was assessed using video cameras (qualitative). The study was unreplicated. This is an online article that is very vague and lacks specific detail.

Effectiveness rating (% change in effectiveness): Unclear (N/A)

The effectiveness of this intervention is unclear, because only post-intervention monitoring was performed with no comparator.

Cott, P.A. 2004. Northern Pike (*Esox lucius*) Habitat Enhancement in the Northwest Territories. Can. Tech. Rep. Fish. Aquat. Sci., 2528: i+32 pp.

Study location: Northwest Territories, Canada

Target species/group: Northern Pike (*Esox lucius*)

Study objective: Specialized Northern Pike spawning and nursery habitat was constructed by providing access to lower and middle ponds in the river watershed (well vegetated habitat previously inaccessible), constructing a new spawning and nursery pond, and constructing and enhancing access between all three ponds and the Stagg River. The number of YOY and juvenile Northern Pike was counted in the enhanced habitat. Target outcome specified: “no-net-loss” of fish habitat.

Critical appraisal:

These studies were assessed post-treatment only with no comparator and were given low overall validity ratings. Electrofishing and visual observations were used to count YOY and juvenile Northern Pike. The studies were unreplicated.

Effectiveness rating (% change in effectiveness): Unclear (N/A)

The effectiveness of this intervention is unclear, because only post-intervention monitoring was performed with no comparator.

Crispin, V., House, R., and Roberts, D. 1993. Changes in instream habitat, large woody debris, and salmon habitat after the restructuring of a coastal Oregon stream. North Am. J. Fish. Manag., 13: 96–102.

Study location: Oregon, USA

Target species/group: Coho Salmon (*Oncorhynchus kisutch*)

Study objective: The objectives of this study were to assess whether the installation of stream rehabilitation structures (mainly tree boles, some boulders and root wads) improved Coho Salmon production by determining the density of redds before and after habitat development. Post-intervention data on redd density was recorded every year for five years post-intervention. No explicit target outcome was stated.

Critical appraisal:

This study used a BA study design with six years of data pre-treatment, and five years of data post-treatment on the density of Chinook salmon redds. The study was not replicated.

Effectiveness rating (% change in effectiveness): Potentially effective (100.0%)

Evidence suggests the intervention could be effective, but the biological endpoint reported (i.e., density of redds) only confirms the use of spawning habitat and not necessarily success.

Crossman, J.A., and Hildebrand, L.R. 2014. Evaluation of spawning substrate enhancement for White Sturgeon in a regulated river: Effects on larval retention and dispersal. River Res. Appl., 30: 1–10. doi:10.1002/rra.2620.

Study location: British Columbia, Canada

Target species/group: White Sturgeon (*Acipenser transmontanus*)

Study objective: This study monitored the effect of large boulder addition to spawning sites on stocked White Sturgeon larvae dispersal and total length. Large boulders were added to the intervention site to cover 90% of the total area. These boulders were expected to remain in place even at higher discharges and to help retain the smaller cobble that was also added to the area. Outcome was measured in the form of total length of larvae and total number of larvae. Larvae were caught with drift nets. No explicit target outcome was stated.

Critical appraisal:

Both projects listed below use a CI study where the control and intervention sites were adjacent to each other and physically well-matched. Large, angular boulders and cobble were added at intervention sites. Equal numbers of stocked White Sturgeon larvae were released one day post-hatch at six locations in both the control and intervention sites.

Project A: 🟡

Total length of larvae was assessed at both the control and intervention site; 60 larvae were measured. The study is pseudoreplicated.

Project B: 🔴

Total number of larvae caught in drift nets was recorded for both the control and intervention sites (unreplicated). Drift nets were fished continuously throughout the study and were pulled and reset at four-hour intervals for the first 24 hours after stocking, then every six hours until 48 hours after stocking, and then twice daily for the remainder of the experiment from 3 July 2010 through 25 July 2010.

Effectiveness rating (% change in effectiveness):

Project A: Total length of larvae: Potentially effective (18.0%)

The evidence suggests this intervention is potentially effective, however, data was recorded for less than one-year post-intervention.

Project B: Total number of larvae: Potentially ineffective (-94.1%)

The evidence suggests this intervention is potentially ineffective, however, data was recorded for less than one-year post-intervention. Furthermore, the authors state that the intervention can result in enhanced conditions required for hiding at the yolk sac larvae stage (i.e., more larvae were collected at the control site than intervention site since the intervention site had improved substrate for hiding).

Day, R.E. 1983. An Evaluation of the Addition of Artificial Spawning Substrate on Yellow Perch Reproduction and Year Class Strength in Ferguson Reservoir. Ohio Department of Natural Resources, Division of Wildlife.

Study location: Ohio, USA

Target species/group: Yellow Perch (*Perca flavescens*)

Study objective: In this study, 52 coniferous trees were placed underwater throughout Ferguson Reservoir on 1 April in 1980 and on 2 April in 1981 and 1982. Thirteen groups of four trees were submerged; each group was arranged in a square configuration with a minimum distance of 6 m between any two trees. To assess Yellow Perch spawning, the CPUE of fry and YOY was determined, and the estimated number of juvenile males (age 2), and the number of egg strands was counted. No explicit target outcome was stated.

Critical appraisal:

Project A: 🔴

These two studies were assessed post-treatment only with no comparator and were given low overall validity ratings. Surface tows with plankton nets with an attached plankton bucket were used to calculate CPUE of Yellow Perch fry, and weekly trawling surveys were used to determine CPUE of YOY fish (quantitative approximations). The studies were pseudoreplicated.

Project B: 🔴

This study was assessed post-treatment only with no comparator and was given a low overall validity rating. Trap nets were used to catch adult Yellow Perch which were then used to determine the estimated number of juvenile males (quantitative approximations). The study was unreplicated.

Project C: 🔴

This study was assessed post-treatment only with no comparator and was given a low overall validity rating. Visual surveys were used to count egg strands (quantitative). The study was unreplicated.

Effectiveness rating (% change in effectiveness): Unclear (N/A)

The effectiveness of these interventions was unclear, because only post-intervention monitoring was performed with no comparator.

Driedger, K.L.F., Weber, L.P., Birtwell, I.K., and Janz, D.M. 2011. Growth, condition and energy stores of Arctic grayling fry inhabiting natural and artificial constructed Arctic tundra streams. Limnological 41: 63–69. doi:10.1016/j.limno.2010.07.003.

Study location: Northwest Territories, Canada

Target species/group: Arctic Grayling (*Thymallus arcticus*)

Study objective: In 1998, a 3.4 km long artificial stream was constructed that diverted water around two lakes with the goals of diverting water from a mine site and maintaining connectivity within the watershed for fish migration, and providing spawning and rearing habitat for local fish species, particularly Arctic Grayling. Fyke nets were used to capture Arctic Grayling juveniles and the length of juveniles was recorded in the artificial stream and compared with two reference streams. No explicit target outcome was reported.

Critical appraisal: 🟡

This study used a CI study design comparing the length and mass of Arctic Grayling juveniles in an artificial stream and two reference streams. Control and intervention sites are well-matched and homogenous with respect to confounding factors. Fyke nets were used to capture juveniles to record their length. The study was pseudoreplicated. It was given a medium overall validity rating.

Effectiveness rating (% change in effectiveness):

Length of juveniles: Potentially ineffective (-115.7%)

The evidence suggests the artificial stream created in this study is potentially ineffective at increasing the length of Arctic Grayling juveniles compared to a reference stream, however, fewer than three years of post-intervention monitoring were performed, and the biological endpoint reported (i.e., length of juveniles) only confirms the use of spawning habitat and not necessarily success.

Dumont, P., D'Amours, J., Thibodeau, S., Dubuc, N., Verdon, R., Garceau, S., Bilodeau, P., Mailhot, Y., and Fortin, R. 2011. Effects of the development of a newly created spawning ground in the Des Prairies River (Quebec, Canada) on the reproductive success of lake sturgeon (*Acipenser fulvescens*): Effects of the development of a newly created spawning ground. J. Appl. Ichthyol., 27(2): 394–404. doi:10.1111/j.1439-0426.2011.01718.x.

Study location: Quebec, Canada

Target species/group: Lake Sturgeon (*Acipenser fulvescens*)

Study objective: The purpose of this study was to test the effects of substrate addition on the creation of spawning grounds for Lake Sturgeon in an area of reservoir. Substrate included a layer of 20-30 cm of material surrounded by a protective layer of 30-50 cm of rock. Large boulders were also placed in the area to provide velocity breaks. The number of adult spawning Lake Sturgeon was counted before and after spawning ground creation. Additionally, Lake Sturgeon eggs were collected on spawning grounds and egg survival was measured. No explicit target outcome was stated.

Critical appraisal: 🔴

This paper used BA study designs to look at the change in catch-per-unit-effort (CPUE) of adult Lake Sturgeon spawners and Lake Sturgeon eggs before, and after, addition of substrate to create spawning grounds. The authors measured quantitative approximations of outcome in the form of CPUE and used egg CPUE values to further determine egg survival in the created spawning grounds. The spawning ground was studied for one year prior to enhancement, and three years post-enhancement and was not replicated. Gillnets were used to capture adult spawning Lake Sturgeon to determine the CPUE of spawners utilizing the new spawning beds. Egg trays and drift nets were used to calculate CPUE of Lake Sturgeon eggs and determine egg survival.

Effectiveness rating (% change in effectiveness):

Adult spawners: Potentially ineffective (-48.2%)

The evidence suggests the habitat development described in this study may potentially be ineffective in terms of recruiting adult spawners on spawning grounds compared to pre-development. However, the biological endpoint reported (i.e., abundance of spawners) only confirms the use of spawning habitat and not necessarily success.

Sturgeon eggs: Potentially ineffective (-99.3%)

The evidence suggests the habitat development described in this study may potentially be ineffective in terms of the number of eggs on spawning grounds compared to pre-development. However, the biological endpoint reported (i.e., abundance of eggs) only confirms the use of spawning habitat and not necessarily success.

Egg survival: Effective (100.0%)

The evidence suggests the intervention was effective at increasing egg survival compared to pre-development.

Dustin, D.L., and Jacobson, P.C. 2003. Evaluation of Walleye Spawning Habitat Improvement Projects in Streams: Investigational Report 502 for the Minnesota Department of Natural Resources, St. Paul, MN.

Study location: Minnesota, USA

Target species/group: Walleye (*Stizostedion vitreum*)

Study objective: This study aimed to improve Walleye stream spawning habitat in Pelican River and Ada Brook through the addition of cobble and gravel substrates to create riffle structures. "U"-shaped riffle designs were created to increase Walleye fry production in two streams, and both were evaluated for Walleye fry and egg production one year before and two years after creation. No explicit target outcome was stated.

Critical appraisal:

This study used a BACI study design for projects A (Pelican River) and B (Ada Brook). However, the studies were pseudoreplicated and there were potentially influential differences between treatment and control sites with respect to confounding factors.

Effectiveness rating (% change in effectiveness):

Project A: CPUE of fry in Pelican River: Potentially ineffective (-100.0%)

Evidence suggests the intervention might be ineffective at increasing fry production, however, there were only two years of post-intervention monitoring.

Project A: CPUE of eggs in Pelican River: Potentially ineffective (0.0%)

Evidence suggests the intervention might be ineffective at increasing egg production, however, there were only two years of post-intervention monitoring and the biological endpoint reported (i.e., abundance of eggs) only confirms the use of spawning habitat and not necessarily success.

Project B: CPUE of fry in Ada Brook: Potentially effective (80.7%)

Evidence suggests the intervention might be effective at increasing fry production, however, there were only two years of post-intervention monitoring.

Project B: CPUE of eggs in Ada Brook: Potentially ineffective (-99.7%)

Evidence suggests the intervention might be ineffective at increasing egg production, however there were only two years of post-intervention monitoring and the biological endpoint reported (i.e., abundance of eggs) only confirms the use of spawning habitat and not necessarily success.

Environment Illimité Inc. 2009. Investigations of Lake Sturgeon Spawning Activities at Iroquois Dam on the St. Lawrence River in 2008—Final Report for the New York Power Authority, White Plains, NY.

Study location: New York, USA

Target species/group: Lake Sturgeon (*Acipenser fulvescens*)

Study objective: This study describes the construction of two spawning beds for Lake Sturgeon. One spawning bed was installed just upstream of the dam and one was installed just downstream of the dam. Each bed is approximately 30 m wide and 30 m long and consists of clean gravel (5-10 cm). In addition, 10 large boulders were placed on the downstream end of each spawning bed to act as velocity breaks for staging sturgeon. At both the upstream and downstream spawning beds, the abundance of Lake Sturgeon eggs and larvae was determined. No explicit target outcome was stated.

Critical appraisal:

This study was assessed post-treatment only with no comparator and was given a low overall validity rating. Egg traps and drift nets were used to determine the abundance of Lake Sturgeon eggs and larvae, respectively (quantitative). The study was unreplicated.

Effectiveness rating (% change in effectiveness): Unclear (N/A)

The effectiveness of this intervention is unclear, because only post-intervention monitoring was performed with no comparator.

Fjeldstad, H.P., Barlaup, B.T., Stickler, M., Gabrielsen, S.E., and Alfredsen, K. 2012. Removal of weirs and the influence on physical habitat for salmonids in a Norwegian river. River Res. Appl., 28(6): 753–763. doi:10.1002/rra.1529.

Study location: Norway

Target species/group: Atlantic Salmon (*Salmo salar*)

Study objective: This study assesses the survival of Atlantic Salmon eggs to larva on created gravel spawning grounds in newly created stream habitat following weir removal. After the weir was removed, lake habitat changed into stream habitat, and three spawning areas were created by gravel addition. Authors report percentage egg survival to larval stage for two years post-intervention. No explicit target outcome was stated.

Critical appraisal:

This study used a BACI design, and had well matched control and intervention sites. However, the study was pseudoreplicated, and control and intervention sites were only moderately comparable with respect to confounding factors.

Effectiveness rating (% change in effectiveness): Potentially effective: (100%)

Evidence suggests the intervention reported is potentially effective at increasing Atlantic Salmon egg to larval survival, however, only two years of post-intervention monitoring is reported.

Floyd, T.A., MacInnis, C., and Taylor, B.R. 2009. Effects of artificial woody structures on Atlantic salmon habitat and populations in a Nova Scotia stream. River Res. Appl., 25(3): 272–282. doi:10.1002/rra.1154.

Study location: Nova Scotia, Canada

Target species/group: Atlantic Salmon (*Salmo salar*)

Study objective: Digger logs (that create plunge pools on the downstream side) and bank deflectors (which concentrate flow on one side of the channel) were added to a stream to recreate the pool-riffle sequence. Two areas were improved in this way, the first in 1995 (Project A), and the second in 2003 (Project B). The density of Atlantic Salmon fry and parr were determined.

Critical appraisal:

Project A:

CI study comparing density of fry and parr following habitat improvement nine years prior. Control and intervention sites were well-matched and homogenous with respect to confounding factors. The study was unreplicated and given a low overall study validity.

Project B:

A BACI study comparing density of fry and parr following habitat improvement one year prior. Control and intervention sites were well-matched and homogenous with respect to confounding factors. The study was unreplicated and given a low overall study validity.

Effectiveness rating (% change in effectiveness):

Project A: Density of fry in improved site versus control site nine years post-intervention: Potentially effective (62.4%)

The evidence suggests the intervention described in this study is potentially effective at increasing Atlantic Salmon fry density, however, fewer than three years of post-intervention monitoring were performed.

Project A: Density of parr in improved site versus control site nine years post-intervention: Potentially effective (100.0%)

The evidence suggests the intervention described in this study is potentially effective at increasing Atlantic Salmon parr density, however, fewer than three years of post-intervention monitoring were performed.

Project B: Density of fry in BACI study: Potentially effective (100.0%)

The evidence suggests the intervention described in this study is potentially effective at increasing Atlantic Salmon fry density, however, fewer than three years of post-intervention monitoring were performed.

Project B: Density of parr in BACI study: Potentially effective (100.0%)

The evidence suggests the intervention described in this study is potentially effective at increasing Atlantic Salmon parr density, however, fewer than three years of post-intervention monitoring were performed.

Fraser, F.J., Perry, E.A., and Lightly, D.T. 1983. Big Qualicum River Salmon Development Project Volume I: A Biological Assessment, 1959 - 1972. Can. Tech. Rep. Fish. Aquat. Sci. 1189.

Study location: British Columbia, Canada

Target species/group: Chum Salmon (*Onchorhynchus keta*)

Study objective: This study aimed to increase Chum Salmon production by creating two spawning channels. In the first channel spawning gravel 2 - 10 cm in diameter was added at a depth of 60 cm, and seven pools were created throughout the channel. In the second spawning channel, washed gravel 2-15 cm in diameter was added at a depth of 45-60 cm, a settling basin was added at the channel inlet, and the channel had a steeper gradient over the spawning area. Authors report percentage egg-to-fry survival in each spawning channel for seven years post-channel construction. No explicit target outcome was stated.

Critical appraisal: 🔴

This study used a CI study design, and intervention and comparator sites were homogenous with respect to confounding factors. However, the study was unreplicated, outcome was measured in quantitative approximations, and the control and impact sites were only moderately well-matched.

Effectiveness rating (% change in effectiveness):

Egg-to-fry survival in spawning channel 1: Ineffective (-109.6%)

Evidence suggests that spawning channel 1 was ineffective at increasing egg-to-fry survival compared to control spawning areas for Chum Salmon.

Egg-to-fry survival in spawning channel 2: Effective (200.0%)

Evidence suggests that spawning channel 2 was effective at increasing egg-to-fry survival compared to control spawning areas for Chum Salmon.

Geiling, W.D., Kelso, J.R.M., and Iwachewski, E. 1996. Benefits from incremental additions to walleye spawning habitat in the Current River, with reference to habitat modification as a walleye management tool in Ontario. Can. J. Fish. Aquat. Sci., 53(S1): 79–87.

Study location: Ontario, Canada

Target species/group: Walleye (*Stizostedion vitreum vitreum*)

Study objective: This study increased Walleye spawning area through addition of gravel (5-20 mm in diameter) and cobble (100-250 mm in diameter). Boulders were also placed over the gravel and cobble areas. The CPUE of adult spawners on the spawning grounds was recorded. No explicit target outcome was stated.

Critical appraisal:

This study used a BA study design, was pseudoreplicated, and reported outcomes as quantitative approximations in the form of CPUE. This study was given a medium validity rating.

Effectiveness rating (% change in effectiveness): Potentially effective (60.7%)

Evidence suggests the intervention reported is potentially effective at increasing Walleye spawner abundance on the spawning grounds. However, data is only reported for two years post-intervention and the biological endpoint reported (i.e., CPUE of adult spawners) only confirms the use of spawning habitat and not necessarily success.

Giannico, G.R., and Hinch, S.G. 2003. The effect of wood and temperature on juvenile Coho Salmon winter movement, growth, density and survival in side-channels. River Res. Appl., 19(3): 219–231. doi:10.1002/rra.723.

Study location: British Columbia, Canada

Target species/group: Coho Salmon (*Oncorhynchus kisutch*)

Study objective: This study focused on the effect of in-stream wood placement to improve Coho Salmon juvenile abundance, survival and weight, and increase the number of smolts that emigrated from the channel. This was done in two different side-channels, in two years. One half of each side-channel was randomly chosen and treated with 20 dense bundles of wood, whereas the other half remained untreated (control). Each bundle (diameter 1.20 to 1.60 m) consisted of one large alder root wad and 20 alder or willow branches tied with nylon rope. They were placed four meters apart and anchored to bank boulders and trees by nylon ropes. No explicit target outcome was stated.

Critical appraisal:

This study describes the effect of in-stream wood placement on juvenile abundance, survival, mass, and smolt emigration numbers in a treated versus un-treated section of a side channel. This was done in two different creeks (Upper Paradise and Mamquam) in two different years (1997 and 1998; both one-year post-intervention), totaling 16 studies. All of these studies were conducted in the same way and given the same critical appraisal. Studies used a CI study design where the control and intervention sites were well-matched and homogenous with respect to confounding factors. All juveniles and smolts were caught at counting fences installed at the end of the experimental side-channel sections. Fish caught at the fence were marked and sets of new marks were used every week to estimate survival. These studies were pseudoreplicated. They were given a medium overall validity rating.

Effectiveness rating (% change in effectiveness):

<u>Abundance of juveniles in Upper Paradise Creek 1997:</u> Potentially ineffective (-34.3%)

The evidence suggests that in-stream wood placement is potentially ineffective at increasing juvenile abundance in this creek, however, fewer than three years of post-intervention monitoring were performed, and the biological endpoint (i.e., abundance of juveniles) only confirms juvenile use of the habitat as a potential nursery area, and not necessarily effectiveness of the intervention to improve spawning success.

<u>Abundance of smolts in Upper Paradise Creek 1997:</u> Potentially ineffective (-5.7%)

The evidence suggests that in-stream wood placement is potentially ineffective at increasing smolt abundance in this creek, however, fewer than three years of post-intervention monitoring were performed, and the biological endpoint (i.e., abundance of smolts) only confirms juvenile use of the habitat as a potential nursery area, and not necessarily effectiveness of the intervention to improve spawning success.

<u>Survival of juveniles in Upper Paradise Creek 1997:</u> Potentially effective (100.0%)

The evidence suggests that in-stream wood placement is potentially effective at increasing juvenile survival in this creek, however, fewer than three years of post-intervention monitoring were performed, and the biological endpoint (i.e., survival of juveniles) only confirms juvenile use of the habitat as a potential nursery area, and not necessarily effectiveness of the intervention to improve spawning success.

Weight of juveniles in Upper Paradise Creek 1997: Potentially ineffective (-18.2%)

The evidence suggests that in-stream wood placement is potentially ineffective at increasing juvenile weight in this creek, however, fewer than three years of post-intervention monitoring were performed, and the biological endpoint (i.e., weight of juveniles) only confirms juvenile use of the habitat as a potential nursery area, and not necessarily effectiveness of the intervention to improve spawning success.

Abundance of juveniles in Upper Paradise Creek 1998: Potentially ineffective (-27.1%)

The evidence suggests that in-stream wood placement is potentially ineffective at increasing juvenile abundance in this creek, however, fewer than three years of post-intervention monitoring were performed, and the biological endpoint (i.e., abundance of juveniles) only confirms juvenile use of the habitat as a potential nursery area, and not necessarily effectiveness of the intervention to improve spawning success.

Abundance of smolts in Upper Paradise Creek 1998: Potentially ineffective (-38.5%)

The evidence suggests that in-stream wood placement is potentially ineffective at increasing smolt abundance in this creek, however, fewer than three years of post-intervention monitoring were performed, and the biological endpoint (i.e., abundance of smolts) only confirms juvenile use of the habitat as a potential nursery area, and not necessarily effectiveness of the intervention to improve spawning success.

Survival of juveniles in Upper Paradise Creek 1998: Potentially effective (18.2%)

The evidence suggests that in-stream wood placement is potentially effective at increasing juvenile survival in this creek, however, fewer than three years of post-intervention monitoring were performed, and the biological endpoint (i.e., survival of juveniles) only confirms juvenile use of the habitat as a potential nursery area, and not necessarily effectiveness of the intervention to improve spawning success.

Weight of juveniles in Upper Paradise Creek 1998: Potentially effective (0.9%)

The evidence suggests that in-stream wood placement is potentially effective at increasing juvenile weight in this creek, however, fewer than three years of post-intervention monitoring were performed, and the biological endpoint (i.e., weight of juveniles) only confirms juvenile use of the habitat as a potential nursery area, and not necessarily effectiveness of the intervention to improve spawning success.

Abundance of juveniles in Upper Mamquam Creek 1997: Potentially effective (100.0%)

The evidence suggests that in-stream wood placement is potentially effective at increasing juvenile abundance in this creek, however, fewer than three years of post-intervention monitoring were performed, and the biological endpoint (i.e., abundance of juveniles) only confirms juvenile use of the habitat as a potential nursery area, and not necessarily effectiveness of the intervention to improve spawning success.

Abundance of smolts in Upper Mamquam Creek 1997: Potentially effective (100.0%)

The evidence suggests that in-stream wood placement is potentially effective at increasing smolt abundance in this creek, however, fewer than three years of post-intervention monitoring were performed, and the biological endpoint (i.e., abundance of smolts) only confirms juvenile use of the habitat as a potential nursery area, and not necessarily effectiveness of the intervention to improve spawning success.

Survival of juveniles in Upper Mamquam Creek 1997: Potentially effective (100.0%)

The evidence suggests that in-stream wood placement is potentially effective at increasing juvenile survival in this creek, however, fewer than three years of post-intervention monitoring were performed, and the biological endpoint (i.e., survival of juveniles) only confirms juvenile use of the habitat as a potential nursery area, and not necessarily effectiveness of the intervention to improve spawning success.

Weight of juveniles in Upper Mamquam Creek 1997: Potentially ineffective (0.0%)

The evidence suggests that in-stream wood placement is potentially ineffective at increasing juvenile weight in this creek, however, fewer than three years of post-intervention monitoring were performed, and the biological endpoint (i.e., weight of juveniles) only confirms juvenile use of the habitat as a potential nursery area, and not necessarily effectiveness of the intervention to improve spawning success.

Abundance of juveniles in Upper Mamquam Creek 1998: Potentially effective (52.4%)

The evidence suggests that in-stream wood placement is potentially effective at increasing juvenile abundance in this creek, however, fewer than three years of post-intervention monitoring were performed, and the biological endpoint (i.e., abundance of juveniles) only confirms juvenile use of the habitat as a potential nursery area, and not necessarily effectiveness of the intervention to improve spawning success.

Abundance of smolts in Upper Mamquam Creek 1998: Potentially ineffective (-70.6%)

The evidence suggests that in-stream wood placement is potentially ineffective at increasing smolt abundance in this creek, however, fewer than three years of post-intervention monitoring were performed, and the biological endpoint (i.e., abundance of smolts) only confirms juvenile use of the habitat as a potential nursery area, and not necessarily effectiveness of the intervention to improve spawning success.

Survival of juveniles in Upper Mamquam Creek 1998: Potentially effective (75.0%)

The evidence suggests that in-stream wood placement is potentially effective at increasing juvenile survival in this creek, however, fewer than three years of post-intervention monitoring were performed, and the biological endpoint (i.e., survival of juveniles) only confirms juvenile use of the habitat as a potential nursery area, and not necessarily effectiveness of the intervention to improve spawning success.

<u>Weight of juveniles in Upper Mamquam Creek 1998:</u> Potentially ineffective (-24.3%)

The evidence suggests that in-stream wood placement is potentially ineffective at increasing juvenile weight in this creek, however, fewer than three years of post-intervention monitoring were performed, and the biological endpoint (i.e., weight of juveniles) only confirms juvenile use of the habitat as a potential nursery area, and not necessarily effectiveness of the intervention to improve spawning success.

Giannico, G.R., and Hinch, S.G. 2007. Juvenile coho salmon (*Oncorhynchus kisutch*) responses to salmon carcasses and in-stream wood manipulations during winter and spring. Can. J. Fish. Aquat. Sci., 64(2): 324–335.

Study location: British Columbia, Canada

Target species/group: Coho Salmon (*Oncorhynchus kisutch*)

Study objective: This study looked at the effects of in-stream wood placement for improving Coho Salmon spawning conditions. Experimental pens treated with in-stream wood received a bundle made of a single red alder log (0.3 m diameter, 3.0 m long) covered with 40 alder twigs and 10 western red cedar branches. Survival of Coho Salmon juveniles was determined and compared to a reference stream section with no in-stream wood placement. No explicit target outcome was stated.

Critical appraisal:

This study used a CI study design to compare survival of Coho Salmon juveniles in a stream section with wood placement to a reference section with no wood placement. Control and intervention sites were well-matched and homogenous with respect to confounding factors. Mark-recapture was used to determine juvenile survival. The study was well replicated (n=8) and was given medium overall study validity.

Effectiveness rating (% change in effectiveness):

Potentially effective (81.4%)

The evidence suggests that in-stream wood placement is potentially effective at increasing juvenile survival, however, fewer than three years of post-intervention monitoring were performed, and the biological endpoint (i.e., survival of juveniles) only confirms juvenile use of the habitat as a potential nursery area, and not necessarily effectiveness of the intervention to improve spawning success.

Hale, J.G. 1969. An evaluation of trout stream habitat improvement in a north shore tributary of Lake Superior. Minn. Fkh. Invest., 5: 37–50.

Study location: Minnesota, USA

Target species/group: Brook Trout (*Salvelinus fontinalis*)

Study objective: This study tested the effects of stream modifications on age 0 Brook Trout abundance. Multiple types of interventions were added to the stream, including: deflectors, shelters, log dams, rock dams, channel blocks, bank erosion controls, and spawning areas. These interventions were applied over five years from 1952 - 1957. Brook Trout abundance was recorded before the interventions in 1952, and for two years post-intervention in 1958-1960. No explicit target outcomes were stated.

Critical appraisal:

This study used a BACI study design. Control and intervention sites were well matched and were homogenous with respect to confounding factors. However, the study was not replicated and was given a low overall validity rating.

Effectiveness rating (% change in effectiveness): Ineffective (-28.9%)

The evidence presented in this study suggests the interventions applied were ineffective at increasing age 0 Brook Trout populations.

Halyk, L. 2008. Report on Brook Trout Spawning Bed Enhancements - Marden Creek 2008 – 2009 for Wellington County Stewardship Council.

Study location: Ontario, Canada

Target species/group: Brook Trout (*Salvelinus fontinalis*)

Study objective: This study aimed to improve spawning success of Brook Trout in Marden Creek through excavation to create a trench which was then filled with groundwater. Washed gravel was added to the trench and, to help reduce silt deposition, a rock and cedar bough deflector was installed along the inside bend to narrow the stream channel and increase stream velocities. The abundance of adult spawners, fry and age 0 Brook Trout was recorded one-year post-intervention.

Critical appraisal: Both projects listed below used a BA study design.

Project A:

Adult spawner abundance was measured to determine the effect of the intervention on the abundance of adult spawners and fry. These studies were unreplicated and the measured outcome was semi-quantitative. It was given a low validity rating.

Project B:

Fry abundance was measured to determine the effect of the intervention on age 0 Brook Trout. This study was also unreplicated but, reported quantitative measures of outcome. It was also given a low validity rating.

Effectiveness rating (% change in effectiveness):

<u>Project A: Adult spawner abundance:</u> Unclear (N/A)

The study only reports semi-quantitative outcome measures; it is unclear whether the intervention has an effect on adult spawner abundance.

<u>Project A: Fry abundance:</u> Unclear (N/A)

The study only reports semi-quantitative outcome measures; it is unclear whether the intervention has an effect on fry abundance.

<u>Project B: Age 0 abundance:</u> Potentially effective (100.0%)

The evidence suggests the intervention described in this study may be potentially effective at increasing age 0 Brook Trout abundance, however only two years of post-intervention monitoring were performed.

Hickford, M.J.H., and Schiel, D.R. 2013. Artificial spawning habitats improve egg production of a declining diadromous fish, *Galaxias maculatus* (Jenyns, 1842): Artificial spawning habitats for *Galaxias maculatus*. Restor. Ecol., 21(6): 686–694. doi:10.1111/rec.12008.

Study location: South Island, New Zealand

Target species/group: Common Galaxias (*Galaxias maculatus*)

Study objective: This study aimed to develop effective, inexpensive, and short-term restoration techniques for spawning habitat that could be readily implemented in place of more expensive, longer-term restoration techniques. One intervention technique was straw bales, groups of three bales were centered on the midpoint of the egg deposition band of the bank and egg density was measured. Mesh tubes filled with straw (straw tubes) and mesh tubes filled with moss (moss tubes) were also tested for their effect on egg density.

Critical appraisal:

This study used a CI study design. The study was replicated (n=2) and control and intervention sites were well-matched; however, they were not comparable with respect to confounding factors and thus the study was given low overall validity rating.

Effectiveness rating (% change in effectiveness):

<u>Straw bales:</u> Potentially effective (100.0%)

The evidence suggests that straw bales may be effective as a spawning habitat restoration method, however, the biological endpoint reported (i.e., density of eggs) only confirms the use of spawning habitat and not necessarily success.

Straw tubes: Potentially effective (100.0%)

The evidence suggests that straw tubes may be effective as a spawning habitat restoration method, however, the biological endpoint reported (i.e., density of eggs) only confirms the use of spawning habitat and not necessarily success.

Moss tubes: Potentially ineffective (-36.8%)

The evidence suggests that moss tubes may not be effective as a spawning habitat restoration method, however, the biological endpoint reported (i.e., density of eggs) only confirms the use of spawning habitat and not necessarily success.

Hoff, M.H. 1991. Effect of Increased Nesting Cover on Nesting and Reproduction of Smallmouth Bass in Northern Wisconsin Lakes. In: First International Smallmouth Bass Symposium. Mississippi State University, pp. 39-43.

Study location: Wisconsin, USA

Target species/group: Smallmouth Bass (*Micropterus dolomieu*)

Study objective: This study aimed to increase Smallmouth Bass nesting and reproduction in lakes by increasing nesting cover for males. Fifty half-log nesting cover devices (constructed of hardwood slabs and two, three core masonry blocks) were placed in each treatment lake. The density of nests per kilometer was determined before and after the intervention was applied. No explicit target outcome was stated.

Critical appraisal: 🔴

This study used a BACI study design, and control and intervention sites were well-matched. The study was unreplicated. It was given a low validity rating.

Effectiveness rating (% change in effectiveness): Potentially ineffective (-57.7%)

The evidence suggests the intervention described in this study is potentially ineffective, however, the biological endpoint reported (i.e., density of nests) only confirms the use of spawning habitat and not necessarily success.

House, R. 1996. An evaluation of stream restoration structures in a coastal Oregon stream, 1981-1993. North Am. J. Fish. Manag., 16: 272–281.

Study location: Oregon, USA

Target species/group: Coho Salmon (*Oncorhynchus kisutch*)

Study objective: Stream restoration work in a 1.7 km reach of East Fork Lobster Creek was completed in two phases (eight sites in 1981, three sites in 1987) and treated 41% of the reach. In total, 22 full-spanning structures were installed (15 constructed of gabions, 5 of boulders, and 2 of boulders and wood), and 10 partially spanning boulder groups and deflectors were installed. The effect of stream restoration on juvenile Coho Salmon abundance was determined before and after the intervention was applied and compared to a control area.

Critical appraisal:

This study used a BACI study design where control and intervention sites were well-matched and homogenous with respect to confounding factors. Electrofishing and beach seining of enclosed areas was used to determine juvenile abundance (quantitative). The study was replicated (n=10) and was given a high overall validity rating.

Effectiveness rating (% change in effectiveness): Potentially effective (100.0%)

The evidence suggests the intervention described in this study is potentially effective at increasing juvenile abundance in this creek, however, the biological endpoint (i.e., abundance of juveniles) only confirms juvenile use of the habitat as a potential nursery area, and not necessarily effectiveness of the intervention to improve spawning success.

House, R.A., and Boehne, P.L. 1985. Evaluation of instream enhancement structures for salmonid spawning and tearing in a coastal Oregon stream. North Am. J. Fish. Manag., 5: 283–295.

Study location: Oregon, USA

Target species/group: Salmonids, Coho Salmon (*Oncorhynchus kisutch*)

Study objective: This study aimed to determine changes in adult salmonid utilization and juvenile density and biomass due to enhancement. Three different interventions were applied (1) two gabions were constructed and random clusters and individual large boulders and logs were placed throughout the area, (2) one gabion was constructed and random clusters and individual large boulders and logs were placed throughout the area, (3) just boulders were placed into the area. For each intervention, the biomass of age 0 salmonids was calculated, the density of Coho Salmon fry was determined, and the density of salmonid fry including was determined.

Critical appraisal: All studies described in this paper followed a BACI study design where control and intervention sites were well-matched.

Project A:

For intervention (1), all studies were replicated (n=3) and were determined to have medium validity.

Project B:

For interventions (2) and (3), all studies were unreplicated and were determined to have low validity.

Effectiveness rating (%change in effectiveness):

Project A: Effect of intervention (1) on age 0 salmonid biomass: Potentially effective (100.0%)

The evidence suggests the intervention may be potentially effective at increasing age 0 salmonid fry biomass, however, only two years of post-intervention monitoring were performed.

Project A: Effect of intervention (1) on Coho Salmon fry density: Potentially effective (100.0%)

The evidence suggests the intervention described may potentially be effective at increasing Coho Salmon fry density, however, only two years of post-intervention monitoring were performed.

Project A: Effect of intervention (1) on trout fry density: Potentially Effective 57.1%)

The evidence suggests the intervention described may potentially be effective at increasing trout fry density, however, only two years of post-intervention monitoring were performed.

Project B: Effect of intervention (2) on age 0 salmonid biomass: Potentially effective (100.0%)

The evidence suggests the intervention may be potentially effective at increasing age 0 salmonid fry biomass, however, only two years of post-intervention monitoring were performed.

Project B: Effect of intervention (2) on Coho Salmon fry density: Potentially effective (100.0%)

The evidence suggests the intervention described may potentially be effective at increasing Coho Salmon fry density, however, only two years of post-intervention monitoring were performed.

Project B: Effect of intervention (2) on trout fry density: Potentially ineffective (-100.0%)

The evidence suggests the intervention described may potentially be ineffective at increasing trout fry density, however, only two years of post-intervention monitoring were performed.

Project B: Effect of intervention (3) on age 0 salmonid biomass: Potentially ineffective (-100.0%)

The evidence suggests the intervention may be potentially ineffective at increasing age 0 salmonid fry biomass, however, only two years of post-intervention monitoring were performed.

Project B: Effect of intervention (3) on Coho Salmon fry density: Potentially ineffective (-100.0%)

The evidence suggests the intervention described may potentially be ineffective at increasing Coho Salmon fry density, however, only two years of post-intervention monitoring were performed.

<u>Project B: Effect of intervention (3) on trout fry density:</u> Potentially ineffective (-42.9%)

The evidence suggests the intervention described may potentially be ineffective at increasing trout fry density, however, only two years of post-intervention monitoring were performed.

Hubert, W.A., and Joyce, M.P. 2005. Habitat associations of Age-0 Cutthroat Trout in a spring stream improved for adult salmonids. J. Freshw. Ecol., 20(2): 277–286. doi:10.1080/02705060.2005.9664967.

Study location: Wyoming, USA

Target species/group: Cutthroat Trout (*Oncorhynchus clarkii*)

Study objective: Heavy equipment had been used several years prior to this study to dig more than 50 pools (1.5-2.0 m deep) and place gravel and cobble between the pools to form riffles. The effectiveness of this as a potential spawning site for Cutthroat Trout was assessed by determining the proportions of sampled sites where age 0 Cutthroat Trout were observed. Fry abundance was determined in riffle, riffle margin, pool margin, and backwater habitats within this intervention area. No explicit target outcome was stated.

Critical appraisal: 🔴

These studies were assessed post-treatment only with no comparator and were given low overall validity ratings. Electrofishing was used to count age 0 Cutthroat Trout to determine the proportions of sampled sites where these fish were observed (quantitative). The study was replicated (n=10).

Effectiveness rating (% change in effectiveness): Unclear (N/A)

The effectiveness of this intervention is unclear, because only post-intervention monitoring was performed with no comparator.

Hunt, J., and Annett, C.A. 2002. Effects of habitat manipulation on reproductive success of individual Largemouth Bass in an Ozark Reservoir. North Am. J. Fish. Manag., 22(4): 1201–1208.

Study location: Arkansas, USA

Target species/group: Largemouth Bass (*Micropterus salmoides*)

Study objective: This study tested the effect of supplemental logs in a small Arkansas reservoir on the abundance of Largemouth Bass nests, number of nests with eggs, number of nests with eggs that hatched, and number of nests with fry. Supplemental logs were constructed from pressure-treated landscaping timbers threaded through openings of two concrete blocks, which elevated the logs approximately 30 cm above the substrate. Fifteen log and concrete block structures were installed in each of the two manipulated sections of habitat.

Critical appraisal: Each of the projects listed below used a CI study design where control and intervention sites were likely well matched and homogenous with respect to confounding factors.

Project A:

The effect of supplemental logs on Largemouth Bass nest abundance. This study was replicated (n=2) and was given medium validity rating.

Project B:

The effect of supplemental logs on Largemouth Bass eggs and age 0 abundance. These studies were unreplicated and were given low validity ratings.

Effectiveness rating (%change in effectiveness):

Project A: Number of nests: Potentially effective (10.6%)

The evidence suggests the intervention described may potentially be effective, however, fewer than three years of post-intervention monitoring were performed, and the biological endpoint reported (i.e., number of nests) only confirms the use of spawning habitat and not necessarily success.

Project B: Number of nests with eggs: Potentially effective (16.0%)

The evidence suggests the intervention described may potentially be effective, however, fewer than three years of post-intervention monitoring were performed, and the biological endpoint reported (i.e., number of nests with eggs) only confirms the use of spawning habitat and not necessarily success.

Project B: Number of nests with eggs that hatched: Potentially effective (26.2%)

The evidence suggests the intervention described may potentially be effective, however, fewer than three years of post-intervention monitoring were performed.

Project B: Number of nests with fry: Potentially ineffective (-45.5%)

The evidence suggests the intervention described may potentially be ineffective, however, fewer than three years of post-intervention monitoring were performed.

Hunt, J., Bacheler, N., Wilson, D., Videan, E., and Annett, C.A. 2002. Enhancing Largemouth Bass spawning: Behavioural and habitat considerations. In: American Fisheries Symposium. D.P. Philipp and M.S. Ridgway, *eds*. Am. Fish. Soc. Symp. pp. 277-290.

Study location: Kansas, USA

Target species/group: Largemouth Bass (*Micropterus salmoides*)

Study objective: The study created nest sites through gravel addition and the addition of either logs on concrete blocks or submerged small conifers and tested the effect on the percentage of nests in the area that was on or near these constructed sites. No explicit target outcome was stated.

Critical appraisal:

This study used a CI study design but, control and treatment sites were poorly matched. Potentially influential differences between the control and intervention sites could affect results. The study was unreplicated. It was given a low validity rating.

Effectiveness rating (%change in effectiveness): Potentially ineffective (-94.1%)

The evidence suggests the intervention described is potentially ineffective at promoting Largemouth Bass nesting, however, only one year of post-intervention monitoring was performed and the biological endpoint reported (i.e., nests) only confirms the use of spawning habitat and not necessarily success.

Hunt, R.L. 1988. A Compendium of 45 Trout Stream Habitat Evaluations in Wisconsin During 1953 -1985. Technical Bulletin No. 162 for Wisconsin Department of Natural Resources, Madison Wisconsin.

Study location: Wisconsin, USA

Target species/group: Brown Trout (*Salmo trutta*)

Study objective: A trout stream was modified with fencing, riprap, bank covers and current deflectors, and the density of age 0 Brown Trout was determined for three years before and three years after the intervention was applied. Target outcome specified: Two levels of success were determined: Level 1= post-development increases in the population variable of 25% or more and Level 2= increases in the population variable of 50% or more.

Critical appraisal:

This study used a BA study design but was unreplicated, and therefore given a low overall validity rating.

Effectiveness rating (%change in effectiveness): Effective (100.0%)

The evidence suggests the intervention described is effective at increasing density of age 0 Brown Trout.

Island Stream and Salmon Enhancement Program 2002. Salt Spring Island Small Stream and Watershed Restoration. HRSEP 2001/02 Final Report, DFO.

Study location: British Columbia, Canada

Target species/group: Coho Salmon (*Oncorhynchus kisutch*)

Study objective: This study describes two different intervention methods. The first intervention involved the placement of woody debris and boulders to repair erosion damage, and enlargement of an off-channel rearing pond. The second intervention involved complexing of large woody debris, boulder clusters, and gravel, and one small off-channel rearing pond was constructed. The number of adult Coho Salmon spawners was counted in both intervention sites. No explicit target outcome was stated.

Critical appraisal:

Both of these studies were assessed post-treatment only with no comparator and were given low overall validity ratings. Visual observations were used to count the number of adult Coho Salmon spawners. The study was unreplicated.

Effectiveness rating (% change in effectiveness): Unclear (N/A)

The effectiveness of these interventions is unclear, because only post-intervention monitoring was performed with no comparator.

Iversen, T.M., Kronvang, B., Madsen, B.L., Markmann, P., and Nielsen, M.B. 1993. Re-establishment of Danish streams: Restoration and maintenance measures. Aquat. Conserv. Mar. Freshw. Ecosyst., 3(2): 73–92. doi:10.1002/aqc.3270030203.

Study location: Denmark

Target species/group: Trout (*Salmo*)

Study objective: This study aimed to establish natural physical stream characteristics through stream restoration using excavation and the construction of rapids. Six rapids were constructed with downstream spawning grounds in the River Hjortvad. The density of trout fry was measured before and after the intervention was applied. No explicit target outcome was stated.

Critical appraisal:

This study used a BA study design, was pseudoreplicated, and lacked sufficient information to judge whether the intervention and comparator sites were well-matched with respect to confounding factors. Overall, it was given a low validity rating.

Effectiveness rating (% change in effectiveness): Potentially effective (100.0%)

The evidence suggests the intervention described here is potentially effective at increasing the density of trout fry, however, the number of years of monitoring was not recorded.

Johnson, J.H., LaPan, S.R., Klindt, R.M., and Schiavone, A. 2006. Lake sturgeon spawning on artificial habitat in the St Lawrence River. J. Appl. Ichthyol., 22(6): 465–470. doi:10.1111/j.1439-0426.2006.00812.x.

Study location: New York, USA

Target species/group: Lake Sturgeon (*Acipenser fulvescens*)

Study objective: Approximately 405 m^3 of washed limestone was added on a cooling water intake system in the St Lawrence River. The potential of this for Lake Sturgeon spawning was determined by counting the number of Lake Sturgeon eggs and determining egg-to-hatch survival. No explicit target outcome was stated.

Critical appraisal:

Project A: 🔴

This study was assessed post-treatment only with no comparator and was given a low overall validity rating. Egg trays were used to count the number of Lake Sturgeon eggs (quantitative). The study was unreplicated.

Project B: 🔴

This study was assessed post-treatment only with no comparator and was given a low overall validity rating. Emergent fry traps were used to calculate egg-to-fry survival (quantitative), and the study was replicated (n=6).

Effectiveness rating (% change in effectiveness): Unclear (N/A)

The effectiveness of this intervention is unclear, because only post-intervention monitoring was performed with no comparator.

Johnson, S.I., Rodgers, J.D., Solazzi, M.R., and Nickelson, T. E. 2005. Effects of an increase in large wood on abundance and survival of juvenile salmonids (*Oncorhynchus* Spp.) in an Oregon coastal stream. Can. J. Fish. Aquat. Sci., 62(2): 412–424.

Study location: Oregon, USA

Target species/group: Steelhead (*Oncorhynchus mykiss*), Cutthroat Trout (*Oncorhynchus clarkii*), Coho Salmon (*Oncorhynchus kisutch*)

Study objective: A total of 88 trees were placed throughout three reaches of a creek. Most placements consisted of three to eight trees and were located near the upper or lower entrances of old side channels or in natural bends where large debris would typically accumulate. The effect of addition on age 0+ steelhead and steelhead smolt abundance, juvenile steelhead survival rate, Cutthroat Trout smolt, age 0+ Coho Salmon, and Coho Salmon smolt abundance was determined before and after the intervention was applied and compared to a control area. No explicit target outcome was stated.

Critical appraisal:

These studies used BACI study designs where control and intervention sites were moderately matched and moderately homogenous with respect to confounding factors. Electrofishing and rotating screw traps were used as measurement methods for the outcomes (quantitative). These studies were pseudoreplicated. They were given a medium overall validity rating.

Effectiveness rating (% change in effectiveness):

<u>Steelhead age 0+ population:</u> Ineffective (-23.9%)

The evidence suggests the intervention described is ineffective at increasing steelhead age 0+ population.

<u>Steelhead smolt population</u>: Potentially effective (100.0%)

The evidence suggests the intervention described is potentially effective at increasing steelhead smolt population, however, the biological endpoint (i.e., smolt population) only confirms juvenile use of the habitat as a potential nursery area, and not necessarily effectiveness of the intervention to improve spawning success.

<u>Juvenile steelhead survival rate:</u> Potentially ineffective (-31.8%)

The evidence suggests the intervention described is potentially ineffective at increasing juvenile steelhead survival, however, the biological endpoint (i.e., juvenile survival) only confirms juvenile use of the habitat as a potential nursery area, and not necessarily effectiveness of the intervention to improve spawning success.

<u>Cutthroat Trout smolt population:</u> Potentially effective (100.0%)

The evidence suggests the intervention described is potentially effective at increasing Cutthroat Trout smolt population, however, the biological endpoint (i.e., smolt population) only confirms juvenile use of the habitat as a potential nursery area, and not necessarily effectiveness of the intervention to improve spawning success.

<u>Coho Salmon age 0+ population:</u> Effective (100.0%)

The evidence suggests the intervention described is effective at increasing Coho Salmon age 0+ population.

<u>Coho Salmon smolt population:</u> Potentially effective (100.0%)

The evidence suggests the intervention described is potentially effective at increasing Coho Salmon smolt population, however, the biological endpoint (i.e., smolt population) only confirms juvenile use of the habitat as a potential nursery area, and not necessarily effectiveness of the intervention to improve spawning success.

Jones, N.E., Tonn, W.M., Scrimgeour, G.J., and Katopodis, C. 2003. Productive capacity of an artificial stream in the Canadian Arctic: assessing the effectiveness of fish habitat compensation. Can. J. Fish. Aquat. Sci., 60(7): 849–863.

Study location: Northwest Territories, Canada

Target species/group: Arctic Grayling (*Thymallus arcticus*)

Study objective: A 3.4 km artificial stream was created by blasting out shield rock and water was diverted into the stream. The biomass of young-of-the-year (YOY; age 0) Arctic Grayling was assessed for three years after the stream was created and compared to a natural reference stream. No explicit target outcome was stated.

Critical appraisal:

This is a CI study where the control and intervention sites were well-matched and homogenous with respect to confounding factors. The study was pseudoreplicated.

Effectiveness rating (% change in effectiveness): Ineffective (-189.9%)

The evidence suggests that the artificial channel created in this study was ineffective at increasing biomass of age 0 Arctic Grayling.

Katt, J.D. 2009. Response of Walleye to the Addition of Spawning Substrate in a Nebraska Irrigation Reservoir. Masters thesis, University of Nebraska, Kearney Nebraska.

Study location: New England, USA

Target species/group: Walleye (*Stizostedion vitreum*)

Study objective: Walleye spawning habitat was created by constructing four reefs that averaged 56 m in length x 8 m in width. The reefs were covered in cobble-sized rock to a depth of 30 cm and were approximately 0.5-1.5 m below the surface. The CPUE of adult Walleye spawners and number of eggs per square meter per spawn night was recorded before and after reef construction. No explicit target outcome was stated.

Critical appraisal:

This study used a BA study design measuring CPUE of Walleye spawners (quantitative approximation outcome) and density of eggs (quantitative outcome) following spawning reef construction. The study is pseudoreplicated.

Effectiveness rating (% change in effectiveness):

<u>CPUE Walleye spawners:</u> Potentially ineffective (-5.0%)

The evidence suggests the reef constructed in this study is potentially ineffective at increasing CPUE of adult Walleye spawners, however, fewer than three years of post-intervention monitoring were conducted, and the biological endpoint reported (i.e., CPUE of spawners) only confirms the use of spawning habitat and not necessarily success.

<u>Density of Walleye eggs:</u> Potentially ineffective (0.0%)

The evidence suggests the reef constructed in this study is potentially ineffective at increasing density of Walleye eggs, however, fewer than three years of post-intervention monitoring were conducted, and the biological endpoint reported (i.e., egg density) only confirms the use of spawning habitat and not necessarily success.

Kelly, F.L., and Bracken, J.J. 1998. Fisheries enhancement of the Rye Water, a lowland river in Ireland. Aquat. Conserv. Mar. Freshw. Ecosyst., 8(1): 131–143. doi:10.1002/(SICI)1099-0755(199801/02)8:1<131::AID-AQC258>3.0.CO;2-H.

Study location: Ireland

Target species/group: Brown Trout (*Salmo trutta*), Atlantic Salmon (*Salmo salar*)

Study objective: The project was designed to improve Brown Trout and Atlantic Salmon habitat by narrowing and deepening a channel, creating meanders, pools, and cover, and stabilizing eroding stream banks. A dragline was used to remove excessive weed and silt from the channels and a hydraulic machine was used to excavate a channel within a channel. Clean gravel, suitable for salmonid spawning was exposed in over 1000 m of channel and large individual boulders were placed in pools to provide additional habitat. A continuous sheet of bedrock was excavated at intervals in section two, creating an additional series of runs and pools. These devices recreate the natural riverine features, such as the pool-riffle pattern and channel meandering, increasing the overall level of habitat diversity. The effectiveness of these stream improvements was assessed by determining the density of age 1+ Brown Trout and Atlantic Salmon before and after the intervention was applied and comparing them to a control site. No explicit target outcome was stated.

Critical appraisal:

These studies all used a BACI study design where the control and intervention sites are well-matched and homogenous with respect to confounding factors. Electrofishing was used to determine age 1+ density. The studies were pseudoreplicated and were given a medium overall validity rating.

Effectiveness rating (% change in effectiveness):

<u>Density of age 1+ Brown Trout:</u> Potentially ineffective (-83.2%)

The evidence suggests the intervention described is potentially ineffective at increasing age 1+ Brown Trout density, however, fewer than three years of post-intervention monitoring were performed, and the biological endpoint (i.e., juvenile density) only confirms juvenile use of the habitat as a potential nursery area, and not necessarily effectiveness of the intervention to improve spawning success.

<u>Density of age 1+ Atlantic Salmon:</u> Potentially effective (100.0%)

The evidence suggests the intervention described is potentially effective at increasing age 1+ Atlantic Salmon density, however, fewer than three years of post-intervention monitoring were performed, and the biological endpoint (i.e., juvenile density) only confirms juvenile use of the habitat as a potential nursery area, and not necessarily effectiveness of the intervention to improve spawning success.

Kerr, S.J. 1981. Artificial Lake Trout Spawning Shoal Construction on Wawa Lake: 1980 Lake Trout Spawning Investigation. Ontario Ministry of Natural Resources, Wawa, ON.

Study location: Ontario, Canada

Target species/group: Lake Trout (*Salvelinus namaycush*)

Study objective: In this study an artificial Lake Trout spawning shoal was created through addition of rock to an area of the lake. The effectiveness of this shoal for Lake Trout spawning was assessed by counting the number of adult Lake Trout spawners. No explicit target outcome was stated.

Critical appraisal:

This study was assessed post-treatment only with no comparator and was given a low overall validity rating. Set nets were used to determine the abundance of Lake Trout spawners on the artificial shoal (quantitative). The study was unreplicated.

Effectiveness rating (% change in effectiveness): Unclear (N/A)

The effectiveness of this intervention is unclear, because only post-intervention monitoring was performed with no comparator.

Kevern, N.R., Biener, W.E., VanDerLaan, S.R., and Cornelius, S.D. 1985. Preliminary evaluation of an artificial reef as a fishery management strategy in Lake Michigan. In: *Artificial Reefs: Marine and Freshwater Applications* (eds. D'Itri, F.M.). Lewis Publishers, Inc., Chelsea, MI, pp. 443–458.

Study location: Michigan, USA

Target species/group: Yellow Perch (*Perca flavescens*)

Study objective: In this study, quarried dolomite rock was used to create a spawning reef for Yellow Perch. The presence of Yellow Perch eggs was recorded for the created reef and for a reference area. No explicit target outcome was stated.

Critical appraisal:

This study used a CI study design where control and intervention sites were likely well-matched and homogenous with respect to confounding factors. The study was unreplicated and a qualitative outcome was reported, so the study was given a low overall validity.

Effectiveness rating (% change in effectiveness): Potentially effective (N/A)

This study reported vague qualitative outcomes for created reefs and reference sites suggesting that more eggs were present on the created reef. This intervention is potentially effective.

Klassen, H.D., and Northcote, T.G. 1988. Use of gabion weirs to improve spawning habitat for Pink Salmon in a small logged watershed. North Am. J. Fish. Manag., 8: 36–44.

Study location: British Columbia, Canada

Target species/group: Pink Salmon (*Oncorhynchus gorbuscha*)

Study objective: This study aimed to provide spawning habitat for Pink Salmon by installing V-shaped gabion weirs, in tandem, and pit-run gravel was placed at the site to provide spawning substrate. The abundance of Pink Salmon eggs was determined by a hydraulic egg sampler and egg survival (ratio of live to dead eggs) was determined to measure the success of the newly created spawning habitat, which was compared to a reference natural spawning site. No explicit target outcome was stated.

Critical appraisal: For both projects outlined below a CI study design was used in which control and intervention sites were likely well-matched, however, they are only moderately well matched with respect to confounding factors.

<u>Project A:</u>

Pink Salmon egg abundance. This component of the study was unreplicated and was given a low overall validity rating.

<u>Project B:</u>

Egg survival. This component of the study was pseudoreplicated. It was given a medium validity rating.

Effectiveness rating (% change in effectiveness):

<u>Project A: Egg abundance:</u> Potentially ineffective (-24.0%)

The evidence suggests the intervention described in this study is potentially ineffective at increasing Pink Salmon egg abundance compared to natural spawning reference sites. However, less than one year of post-intervention monitoring was performed and the biological endpoint reported (i.e., abundance of eggs) only confirms the use of spawning habitat and not necessarily success.

Project B: Egg survival: Potentially effective (15.8%)

The evidence suggests the intervention described in this study is potentially effective at increasing Pink Salmon egg survival compared to natural spawning areas. However, less than one year of post-intervention monitoring was performed.

Knaepkens, G., Bruyndoncx, L., Coeck, J., and Eens, M. 2004. Spawning habitat enhancement in the European bullhead (*Cottus gobio*), an endangered freshwater fish in degraded lowland rivers. Biodivers. Conserv., 13(13): 2443–2452. doi:10.1023/B:BIOC.0000048448.17230.40.

Study location: Flanders, Belgium

Target species/group: European Bullhead (*Cottus gobio*)

Study objective: This study aimed to evaluate the use of artificial spawning substrates by European Bullhead. Ceramic tiles were added to channelized and (remaining) meandering parts of two anthropogenically perturbated lowland rivers in Flanders. The number of European Bullhead eggs in each river was counted. No explicit target outcome was stated.

Critical appraisal:

This study was assessed post-treatment only with no comparator and was given a low overall validity rating. The number of ceramic tiles with egg clusters was counted.

Effectiveness rating (% change in effectiveness): Unclear (N/A)

The effectiveness of this intervention is unclear, because only post-intervention monitoring was performed with no comparator.

LaHaye, M., Branchaud, A., Gendron, M., Verdon, R., and Fortin, R. 1992. Reproduction, early life history, and characteristics of the spawning grounds of the lake sturgeon (*Acipenser fulvescens*) in Des Prairies and L'Assomption rivers, near Montréal, Quebec. Can. J. Zool., 70: 1681–1689. doi:10.1139/z92-234.

Study location: Quebec, Canada

Target species/group: Lake Sturgeon (*Acipenser fulvescens*)

Study objective: This study compares enhanced spawning grounds to spawning grounds in a separate river that has not been physically altered by human activities. The CPUE of Lake

Sturgeon eggs is compared between the two spawning grounds (natural and enhanced). No explicit target outcome is stated.

Critical appraisal:

This study uses a CI study design to compare an enhanced Lake Sturgeon spawning ground to a natural spawning ground unaffected by human activities. The control and intervention sites were in separate rivers but, were well matched and homogenous with respect to confounding factors. The authors used drift nets to determine CPUE of Lake Sturgeon eggs (quantitative approximation).

Effectiveness rating (% change in effectiveness): Potentially effective (100.0%)

The evidence suggests the intervention described here is potentially effective at increasing CPUE of Lake Sturgeon eggs compared with non-enhanced spawning grounds. However, fewer than three years of post-intervention monitoring were performed, and the biological endpoint reported (i.e., abundance of eggs) only confirms the use of spawning habitat and not necessarily success.

Langler, G.J., and Smith, C. 2001. Effects of habitat enhancement on 0-group fishes in a lowland river. Regul. Rivers Res. Manag., 17(6): 677–686. doi:10.1002/rrr.627.

Study location: Somerset, England

Target species/group: Common Bream (*Abramis brama*), Common Carp (*Cyprinus carpio*), Northern Pike (*Esox lucius*), Three-spined Stickleback (*Gasterosteus aculeatus*), Gudgeon (*Gobio gobio*), Eurasian Ruffe (*Gymnocephalus cernuus*), Sunbleak (*Leucaspius delineatus*), European Perch (*Perca fluviatilis*), Common Roach (*Rutilus rutilus*)

Study objective: This study looked at the effect of two different types of stream modifications on a number of species present in the waterbody. The first intervention is the creation of bays at one- or two-year intervals; two bays were completed in 1996 and another six bays were completed in 1997. The second modification included extending two areas of bank to a gradient of 1:6; one of which was planted with *Phragmites australis* and *Salix sp*. in 1996, while the other was planted in 1997. The CPUE of a number of different species (age 0) was determined by electrofishing and compared with a reference site. No explicit target outcome was stated.

Critical appraisal:

The studies described in this paper used a CI study design where control and intervention sites were well-matched and homogenous with respect to confounding factors. The study was replicated (n=2) and used electrofishing to determine the CPUE for a number of species (quantitative approximation).

Effectiveness rating (% change in effectiveness):

<u>Common Bream, bay creation intervention:</u> Potentially effective (100.0%)

The evidence suggests that the intervention described may potentially be effective at increasing CPUE of age 0 Common Bream, however, fewer than three years of post-intervention monitoring were performed.

Common Carp, bay creation intervention: Potentially effective (100.0%)

The evidence suggests that the intervention described may potentially be effective at increasing CPUE of age 0 Common Carp, however, fewer than three years of post-intervention monitoring were performed.

Northern Pike, bay creation intervention: Potentially ineffective (-100.0%)

The evidence suggests that the intervention described is potentially ineffective at increasing CPUE of age 0 Northern Pike; however, fewer than three years post-intervention monitoring were performed.

Three-spined Stickleback, bay creation intervention: Potentially ineffective (0.0%)

The evidence suggests that the intervention described may potentially be ineffective at increasing CPUE of age 0 Three-spined Stickleback, however, fewer than three years of post-intervention monitoring were performed.

Gudgeon, bay creation intervention: Potentially ineffective (-17.8%)

The evidence suggests that the intervention described may potentially be ineffective at increasing CPUE of age 0 Gudgeon, however, fewer than three years of post-intervention monitoring were performed.

Eurasian Ruffe, bay creation intervention: Potentially ineffective (-15.9%)

The evidence suggests that the intervention described may potentially be ineffective at increasing CPUE of age 0 Eurasian Ruffe, however, fewer than three years of post-intervention monitoring were performed.

Sunbleak, bay creation intervention: Potentially effective (100.0%)

The evidence suggests that the intervention described may potentially be effective at increasing CPUE of age 0 Sunbleak, however, fewer than three years of post-intervention monitoring were performed.

European Perch, bay creation intervention: Potentially effective (100.0%)

The evidence suggests that the intervention described may potentially be effective at increasing CPUE of age 0 European Perch, however, fewer than three years of post-intervention monitoring were performed.

Common Roach, bay creation intervention: Potentially ineffective (-67.5%)

The evidence suggests that the intervention described may potentially be ineffective at increasing CPUE of age 0 Common Roach, however, fewer than three years of post-intervention monitoring were performed.

Common Bream, riparian modification: Potentially effective (100.0%)

The evidence suggests that the intervention described may potentially be effective at increasing CPUE of age 0 Common Bream, however, fewer than three years of post-intervention monitoring were performed.

Gudgeon, riparian modification: Potentially effective (100.0%)

The evidence suggests that the intervention described may potentially be effective at increasing CPUE of age 0 Gudgeon, however, fewer than three years of post-intervention monitoring were performed.

Eurasian Ruffe, riparian modification: Potentially effective (17.9%)

The evidence suggests that the intervention described may potentially be effective at increasing CPUE of age 0 Eurasian Ruffe, however, fewer than three years of post-intervention monitoring were performed.

Sunbleak, riparian modification: Potentially effective (100.0%)

The evidence suggests that the intervention described may potentially be effective at increasing CPUE of age 0 Sunbleak, however, fewer than three years of post-intervention monitoring were performed.

European Perch, riparian modification: Potentially effective (100.0%)

The evidence suggests that the intervention described may potentially be effective at increasing CPUE of age 0 European Perch, however, fewer than three years of post-intervention monitoring were performed.

Common Roach, riparian modification: Potentially effective (68.2%)

The evidence suggests that the intervention described may potentially be effective at increasing CPUE of age 0 Common Roach, however, fewer than three years of post-intervention monitoring were performed.

Linløkken, A. 1997. Effects of instream habitat enhancement on fish populations of a small Norwegian Stream. Nord. J. Freshw. Res., 73: 50–59.

Study location: Norway

Target species/group: Brown Trout (*Salmo trutta*)

Study objective: This study describes interventions applied to a river in which the experimental section was excavated, and four weirs were constructed to create pools. The four weirs were placed in two pairs and created 10 m wide by 15 m long pools that were 1.5 m in depth. The abundance of age 0 Brown Trout was then determined by electrofishing and compared to a control reference site. No explicit target outcomes were stated.

Critical appraisal:

This is a CI study design in which the control and intervention sites are likely well-matched but, moderately comparable with respect to confounding factors. The study was pseudoreplicated. It was given an overall medium validity rating.

Effectiveness rating (% change in effectiveness): Effective (100.0%)

The evidence suggests the intervention described in this study is effective at increasing the number of age 0 Brown Trout when compared to a reference section.

Lister, D.B., Marshall, D.E., and Hicke, D.G. 1980. Chum Salmon Survival and Production at Seven Improved Groundwater-fed Spawning Areas. Can. MS. Rep. Fish. Aquat. Sci., 1595: x +58 pp.

Study location: British Columbia, Canada

Target species/group: Chum Salmon (*Oncorhynchus keta*)

Study objective: This study describes habitat improvements at seven different Chum Salmon spawning sites in British Columbia. At each site, the number of adult spawners, abundance of fry, and survival of fry was determined. At Judd Slough the stream bed profile was altered to produce a more even gradient overall, coarse material was excavated from the stream and placed on banks to improve stability, and low wood drop structures were installed to increase water depth in shallow areas. Judd Slough Pond was created through excavation and gravel addition. The study site at Lower Paradise Creek was deepened and widened and five laminated wood drop structures were installed in the channel to produce a spawning depth of 20-30 cm and to control gradient. Worth Creek was widened and deepened in the upper 150 m of the stream and a 45 cm layer of graded gravel was added, wood drop structures were added to provide adequate depth for spawning and large boulders were placed along the bank to prevent erosion. Railroad Creek was deepened and widened through excavation and 45-90 cm graded gravel was added, large rocks were placed along the banks and one drop structure was added near the downstream end. In Hopedale Slough Pond 1, excavation and addition of graded gravel was performed. Finally, Billy Harris Slough was cleared of a longstanding obstruction to adult Chum Salmon, excavated to enlarge and deepen the channel, and divided into three sections by rock groins; native gravel was also replaced with graded gravel and wooden weirs were installed.

Critical appraisal:

Project A:

These studies were assessed post-treatment only with no comparator and were given low overall validity ratings. Tag and carcass recovery, and live traps, were used to determine estimates of adult Chum Salmon and fry populations, respectively (quantitative approximation). The study was unreplicated.

Project B: 🔴

These studies were assessed post-treatment only with no comparator and were given low overall validity ratings. Fry survival was calculated from both potential and net egg deposition (quantitative), which is considered an appropriate/reliable measurement method for the outcome in this study. The intervention was applied at an appropriate spatial/temporal scale relative to the target species and waterbody. The study was unreplicated.

Effectiveness rating (% change in effectiveness): Unclear (N/A)

The effectiveness of this intervention is unclear, because only post-intervention monitoring was performed with no comparator.

Lorenz, A.W., Stoll, S., Sundermann, A., and Haase, P. 2013. Do adult and YOY fish benefit from river restoration measures? Ecol. Eng., 61(A): 174–181. doi:10.1016/j.ecoleng.2013.09.027.

Study location: Germany

Target species/group: Various

Study objective: A section of stream was modified in a number of ways; bank and bed fixations were removed, large woody debris was installed, and a more longitudinal and lateral river profile was established. In most reaches a meandering or multiple-channel pattern, depending on the river-type, was established by excavation of a new channel or re-connection of backwaters. The number of young-of-the-year fishes was determined per 100 m^2 and compared to an unrestored stream section. No explicit target outcome was stated.

Critical appraisal: 🟡

This study used a CI study design where control and intervention sites are well-matched and homogenous with respect to confounding factors. The number of YOY fishes per 100 m^2 (quantitative outcome) in both restored and unrestored reaches were determined, and the study was replicated (n=36).

Effectiveness rating (% change in effectiveness): Effective (77.0%)

The evidence suggests the intervention described in this study is effective at increasing the number of age 0 fishes when compared to an unrestored section.

Luhta, P.L., Huusko, A., and Louhi, P. 2012. Re-building brown trout populations in dredged boreal forest streams: in-stream restoration combined with stocking of young trout. Freshw. Biol., 57(9): 1966–1977. doi:10.1111/j.1365-2427.2012.02850.x.

Study location: Finland

Target species/group: Brown Trout (*Salmo trutta*)

Study objective: This study aimed to increase in-stream structural complexity by constructing various habitat enhancement structures, such as current deflectors, boulder dams, and gravel beds. Excavations were also dug to serve as resting sites for adult fish. The density of age 0 Brown Trout was determined per 100 m^2 by electrofishing and compared to reference section with no intervention. No explicit target outcome was stated.

Critical appraisal:

This is a CI study in which the control and intervention sites are moderately well-matched and homogenous with respect to confounding factors. The study was replicated (n=4). It was given a medium overall validity rating.

Effectiveness rating (% change in effectiveness): Effective (100.0%)

The evidence suggests the intervention described in this study is effective at increasing the number of age 0 Brown Trout when compared to a reference section.

MacInnis, C., Floyd, T.A., and Taylor, B.R. 2008. Large woody debris structures and their influence on Atlantic Salmon spawning in a stream in Nova Scotia, Canada. North Am. J. Fish. Manag., 28(3): 781–791. doi:10.1577/M07-077.1.

Study location: Nova Scotia, Canada

Target species/group: Atlantic Salmon (*Salmo salar*)

Study objective: This study describes the restoration of Atlantic Salmon spawning habitat through the use of two structures: digger logs (a structure simulating a fallen bankside tree) and bank deflectors (large, wooden triangles filled with rocks, designed to redirect water flow toward the far bank, thereby narrowing the channel and encouraging the formation of meanders). Visual counts were used to assess the number of salmon redds, which was compared with another natural salmon spawning stream as an unrestored reference site. No explicit target outcomes were stated.

Critical appraisal:

This study uses a CI study design where the control and intervention sites are well-matched and homogenous with respect to confounding factors. Visual counts were used to assess the number of salmon redds (quantitative outcome). The study was unreplicated. It was given a low overall validity rating.

Effectiveness rating (% change in effectiveness): Potentially effective (100.0%)

The intervention described in this study is potentially effective at increasing the number of Atlantic Salmon redds, but the biological endpoint reported (i.e., number of redds) only confirms the use of spawning habitat and not necessarily success.

Mangan, M.T., Brown, M.L., and St. Sauver, T.R. 2005. Yellow Perch use of introduced spawning habitat. J. Freshw. Ecol., 20(2): 381–388. doi:10.1080/02705060.2005.9664978.

Study location: South Dakota, USA

Target species/group: Yellow Perch (*Perca flavescens*)

Study objective: This study looked at the effectiveness of tree reefs, of various tree types, age, and location, for Yellow Perch spawning habitat. Tree reefs were placed into Little Brush and Dry wetlands prior to the spawning season in 2002 and 2003. The reefs were constructed of three to four conifer trees (spruce and fir and/or pine) of equivalent size. In 2002 and 2003, tree reefs were placed in inshore and offshore locations. Trees were classified as short needle (spruce and fir) or long needle (pine) for comparison of tree types. In 2003, new trees were paired with older trees from the previous year and re-deployed to measure the effect of tree age (residual versus new) on Yellow Perch usage. The mean number of Yellow Perch egg masses was determined for each tree reef. No explicit target outcome was stated.

Critical appraisal:

This study was assessed post-treatment only with no comparator and was given a low overall validity rating. Visual counts were used to count Yellow Perch egg clusters on reefs. The study was replicated, in all cases, with n>7.

Effectiveness rating (% change in effectiveness): Unclear (N/A)

The effectiveness of this intervention is unclear, because only post-intervention monitoring was performed with no comparator.

Manny, B.A. 2006. Monitoring Element of the Bell Isle/Detroit River Sturgeon Habitat Restoration, Monitoring and Education Project. Research Completion Report, University of Michigan, Ann Arbour, MI.

Study location: Michigan, USA

Target species/group: Various

Study objective: This study describes construction of spawning beds from limestone "shot rock" 16-24 inches in diameter, rounded igneous rock 6-10 inches in diameter, and coal cylinders 1-3 inches in diameter. Each bed was 50x80x2 feet in size and was placed on the river bottom using a GPS-guided dredge on a studded barge. Egg mats were used to calculate the

CPUE of eggs on the spawning beds before and after reef construction. No explicit target outcome was stated.

Critical appraisal:

This study used a BA study design calculating the CPUE of fish eggs (quantitative approximation) using egg mats before and after construction of an artificial reef designed to enhance fish spawning. However, the study was not replicated. It was given a low overall validity rating.

Effectiveness rating (% change in effectiveness): Potentially effective (47.2%)

The intervention described in this study is potentially effective at increasing the CPUE of fish eggs on spawning beds, but fewer than three years of post-intervention monitoring were performed, and the biological endpoint reported (i.e., CPUE of eggs) only confirms the use of spawning habitat and not necessarily success.

Marsden, J.E., Binder, T.R., Johnson, J., He, J., Dingledine, N., Adams, J., Johnson, N.S., Buchinger, T.J., and Krueger, C.C. 2016. Five-year evaluation of habitat remediation in Thunder Bay, Lake Huron: Comparison of constructed reef characteristics that attract spawning lake trout. Fish. Res., 183: 275–286. doi:10.1016/j.fishres.2016.06.012.

Study location: Ontario, Canada

Target species/group: Lake Trout (*Salvelinus namaycush*)

Study objective: This study describes the construction of 29 reefs between 2010 and 2011. The reefs were constructed using angular crushed limestone, 64-256 mm in size, from a nearby quarry. The number of Lake Trout eggs and fry, and movement of adult spawners (i.e., density) was determined on the constructed reefs and compared to one natural high-quality reef. No explicit target outcome was stated.

Critical appraisal:

This study uses a CI study design where the control and intervention sites are moderately well-matched and homogenous with respect to confounding factors. The study was considered unreplicated. It was given a low overall validity rating.

Effectiveness rating (% change in effectiveness):

<u>Total number of eggs:</u> Potentially ineffective (-70.2%)

The evidence suggests the constructed reef described in this study is potentially ineffective at increasing the number of Lake Trout eggs compared to a natural reef, however, the biological endpoint reported (i.e., abundance of eggs) only confirms the use of spawning habitat and not necessarily success.

Total number of fry: Effective (100.0%)

The evidence suggests the constructed reef described in this study is effective at increasing the abundance of Lake Trout fry compared to a natural reef.

Positions of adult spawners per square meter: Potentially effective (100.0%)

The evidence suggests the constructed reef described in this study is potentially effective at increasing the movement of Lake Trout spawners compared to a natural reef, however, the biological endpoint reported (i.e., movement of Lake Trout spawners) only confirms the use of spawning habitat and not necessarily success.

Marsden, J.E., and Chotkowski, M.A. 2001. Lake trout spawning on artificial reefs and the effect of zebra mussels: Fatal attraction? J. Gt. Lakes Res., 27: 33–43. doi:10.1016/S0380-1330(01)70621-1.

Study location: Michigan, USA

Target species/group: Lake Trout (*Salvelinus namaycush*)

Study objective: This study describes Lake Trout spawning on a newly constructed artificial reef. The reef was constructed from a breakwater of blocks of limestone. At the base of the outside of the breakwater a bedding of sub-angular stone extends out 3-13 m; this stone resembles rubble-cobble substrates found on natural spawning reefs in the Great Lakes. Lake Trout egg and fry CPUE was compared between the artificial reef and a natural reef. No explicit target outcome was stated.

Critical appraisal: Both projects listed below used a CI design where the control and impact sites were moderately well-matched but, were not comparable with respect to confounding factors thus giving the studies a low overall validity rating. Egg nets and fry traps were used to determine the CPUE of eggs and fry (quantitative approximation).

Project A:

CPUE of Lake Trout eggs. This study was replicated (n=3) but, because control and reference sites were not comparable with respect to confounding factors, the study was given a low validity rating.

Project B:

CPUE of Lake Trout fry. This study was pseudoreplicated and control and reference sites were not comparable with respect to confounding factors. The study was given a low validity rating.

Effectiveness rating (% change in effectiveness):

Project A: CPUE of Lake Trout eggs: Potentially ineffective (-85.1%)

The evidence suggests the constructed reef described in this study may potentially be ineffective at increasing Lake Trout egg abundance compared with natural spawning reefs. However, fewer than three years of post-intervention monitoring were performed, and the biological endpoint reported (i.e., abundance of eggs) only confirms the use of spawning habitat and not necessarily success.

<u>Project B: CPUE of Lake Trout fry:</u> Potentially effective (100.0%)

The evidence suggests the constructed reef described in this study may potentially be effective at increasing Lake Trout fry abundance compared with natural spawning reefs. However, fewer than three years of post-intervention monitoring were performed.

Marsden, J.E., Perkins, D.L., and Krueger, C.C. 1995. Recognition of spawning areas by lake trout: Deposition and survival of eggs on small, man-made rock piles. J. Gt. Lakes Res., 21(1): 330–336.

Study location: Ontario, Canada

Target species/group: Lake Trout (*Salvelinus namaycush*)

Study Objective: The purpose of this study was to identify characteristics of spawning site selection by Lake Trout and to associate these characteristics with egg incubation success. Six rock piles (rock material), 4.5 m in diameter, were constructed 80 m from a natural spawning reef. Egg deposition and survival to hatching were measured on, and adjacent to, the rock piles and on the nearby natural cobble reef. No explicit target outcome was stated.

Critical appraisal:

This study used a CI study design that included six treatment sites where rocks were added; all rock piles ~30 m apart. All control site information for the database came from areas immediately adjacent to treatment sites. Mean egg abundance was measured from two mesh bags placed on each of the six rock piles and compared to a similar number of mesh bags/sites adjacent to the rock piles (controls; sand/pea-sized gravel substrate) in 1990. Mean number of eggs hatched was measured from five incubators deployed on one rock pile (only one rock pile had a control) and compared to the same number of incubators adjacent to the rock pile in 1991. There was one true post-treatment monitoring for egg abundance, but two true post-treatment monitoring years for survival to hatching. Because outcome means and variances were not from independent replicates (i.e., rock piles and adjacent controls were subplots in close proximity), data were considered pseudoreplicated.

Effectiveness rating (% change in effectiveness):

<u>Egg abundance:</u> Potentially effective (100.0%)

Evidence suggests the intervention could be effective but, the biological endpoint reported (i.e., abundance of eggs) only confirms the use of spawning habitat and not necessarily success.

<u>Egg survival:</u> Potentially effective (100.0%)

Quantitative evidence suggests that the intervention was potentially effective in increasing egg survival but, there were only two years post-treatment monitoring.

Martin, N.V. 1955. The effect of drawdowns on lake trout reproduction and the use of artificial spawning beds. Proceedings of the Twentieth North American Wildlife Conference. 20: 263-

Study location: Ontario, Canada

Target species/group: Lake Trout (*Salvelinus namaycush*)

Study objective: Spawning beds were created for Lake Trout through rock placement into the lake. The rock was washed to remove rock powder and dirt before placing into the lake. Large rocks were used at the bottom of the bed and increasingly smaller rocks nearer the surface. Three beds were made which varied in size. The density of eggs per egg pail was determined to assess the effectiveness of the spawning beds. No explicit target outcome was stated.

Critical appraisal:

This study was assessed post-treatment only with no comparator and was given a low overall validity rating. Egg pails were used to determine Lake Trout egg density. The studies were pseudoreplicated.

Effectiveness rating (% change in effectiveness): Unclear (N/A)

The effectiveness of this intervention is unclear, because only post-intervention monitoring was performed with no comparator.

Merz, J.E., and Setka, J.D. 2004. Evaluation of a spawning habitat enhancement site for Chinook Salmon in a regulated California river. North Am. J. Fish. Manag., 24(2): 397–407. doi:10.1577/M03-038.1.

Study location: California, USA

Target species/group: Chinook Salmon (*Oncorhynchus tshawytscha*)

Study objective: This study describes the effect of clean river gravel placement to enhance Chinook Salmon spawning. Approximately 976 m^3 of cleaned gravel was placed into the river and the number of Chinook Salmon redds was visually counted before and after intervention. No explicit target outcome was stated.

Critical appraisal:

This study uses a BA study design, but only semi-quantitative results are presented (quantitative results are given for after intervention, but only qualitative results are given for before intervention). Chinook Salmon redds were visually counted. The study was unreplicated. It was given a low overall validity rating.

Effectiveness rating (% change in effectiveness): Potentially effective (100.0%)

The evidence suggests the placement of cleaned spawning gravel is effective at increasing the number of Chinook Salmon redds on the site compared with before the gravel was added. However, only semi-quantitative results are presented, and the biological endpoint reported (i.e., abundance of redds) only confirms the use of spawning habitat and not necessarily success.

Merz J.E., Setka, J.D., Pasternack, G.B., and Wheaton, J.M. 2004. Predicting benefits of spawning-habitat rehabilitation to salmonid (Oncorhynchus spp.) fry production in a regulated California river. Can. J. Fish. Aquat. Sci., 61(8):1433-1446.

Study location: California, USA

Target species/group: Chinook salmon (*Oncorhynchus tshawytscha*)

Study objective: This study aimed to improve Chinook Salmon spawning habitat by adding washed river rock in berms, staggered bar, riffle, or complex channel geometry configurations. The authors measured percentage survival to alevin stage and length of Chinook Salmon larvae in the enhanced and unenhanced reaches of the stream. No explicit target outcome was stated.

Critical appraisal:

This study used a CI study design where control and intervention sites were well-matched and homogenous with respect to confounding factors. Egg tubes were used to collect larvae for length measurements and survival estimates. The study was replicated (n=4) and was given an overall validity rating of medium.

Effectiveness rating (% change in effectiveness):

Percentage survival to alevin: Potentially effective (31.8%)

The evidence suggests the intervention described in this study is potentially effective at increasing survival of Chinook Salmon to alevin stage, however, fewer than three years of post-intervention monitoring were performed.

Length of larvae: Potentially effective (0.4%)

The evidence suggests the intervention described in this study is potentially effective at increasing length of Chinook Salmon larvae, however, fewer than three years of post-intervention monitoring were performed.

Moerke, A.H., and Lamberti, G.A. 2003. Responses in fish community structure to restoration of two Indiana streams. North Am. J. Fish. Manag., 23: 748–759. doi:10.1577/M02-012.

Study location: Indiana, USA

Target species/group: Various, Rainbow Trout (*Salmo gairdneri*), Brown Trout (*Salmo trutta*)

Study objective: This study tested the effect of reconnecting two historical meanders to create a channelized stream. Electrofishing was used to count the number of redds in the restored and a control, unrestored section. The study also compared the number of age 0 Brown Trout and Rainbow Trout before and after restoration. No explicit target outcome was stated.

Critical appraisal:

<u>Project A:</u>

The number of fish redds (of various species) in the restored section versus an unrestored section were compared using a CI study design where the control and intervention sites were well matched and homogenous with respect to confounding factors. The study was replicated (n=2) and was given medium overall validity.

<u>Project B:</u>

The number of age 0 Rainbow and Brown trout before and after stream restoration were compared using a BA study design. Electrofishing was used to determine the abundance of age 0 Rainbow and Brown trout (quantitative outcome). However, the study was unreplicated and was given low overall validity rating.

Effectiveness rating (% change in effectiveness):

<u>Project A: Number of fish redds in control and intervention sites:</u> Potentially effective (100.0%)

The evidence suggests the intervention described in this study is potentially effective at increasing the number of fish redds compared to an unrestored section, but the biological endpoint reported (i.e., abundance of redds) only confirms the use of spawning habitat and not necessarily success.

<u>Project B: Number of age 0 Rainbow Trout before and after intervention:</u> Ineffective (-71.4%)

The evidence suggests the intervention described in this study is ineffective at increasing the abundance of age 0 Rainbow Trout compared with before restoration.

<u>Project B: Number of age 0 Brown Trout before and after intervention:</u> Effective (100.0%)

The evidence suggests the intervention described in this study is effective at increasing the abundance of age 0 Brown Trout compared with before restoration.

Moreau, J.K. 1984. Anadromous salmonid habitat enhancement by boulder placement in Hurdygurdy Creek, California. Pp. 97 - 116 in: T.J. Hassler, editor. Pacific North-west Stream Habitat Management Workshop. American Fisheries Society, Humboldt Chapter, Arcata, CA.

Study location: California, USA

Target species/group: Rainbow Trout (*Salmo gairdneri*)

Study objective: This study aimed to enhance Rainbow Trout habitat by boulder placement. Boulder structures placed included mid-channel boulder clusters, wing deflectors, and weirs. The number of Rainbow Trout redds was compared in the restored habitat and unrestored habitat. No explicit target outcome was stated.

Critical appraisal:

This study used a CI study design where control and intervention sites were likely well-matched and homogenous with respect to confounding factors. Electrofishing and two-pass snorkeling surveys were used to determine the number of Rainbow Trout redds in the restored and unrestored section (quantitative outcome). The study was unreplicated. It was given a low overall validity rating.

Effectiveness rating (% change in effectiveness): Potentially effective (87.4%)

The evidence presented in this study suggests that the intervention may potentially be effective at increasing the number of Rainbow Trout redds in the restored stream section compared to unrestored sections, however, fewer that three years of post-intervention monitoring were performed, and the biological endpoint reported (i.e., abundance of redds) only confirms the use of spawning habitat and not necessarily success.

Mueller, M., Pander, J., and Geist, J. 2014. The ecological value of stream restoration measures: An evaluation on ecosystem and target species scales. Ecol. Eng., 62: 129–139. doi:10.1016/j.ecoleng.2013.10.030.

Study location: Germany

Target species/group: Brown Trout (*Salmo trutta*), Common Minnow (*Phoxinus phoxinus*), European Grayling (*Thymallus thymallus*)

Study objective: This study evaluates the success of four different stream substratum restoration treatments on fish species. The first intervention was gravel introduction of 16-32 mm grain size, inserted into the river. The second intervention was gravel introduction of 8-16 mm grain size. For the third intervention a sickle-formed constrictor was constructed using chalkstone boulders with a void size of 0.6-0.8 m placed in the shape of two opposed sickles on both bank sides reducing the river width to 35%. In the fourth intervention the treatment was carried out by mechanically relocating 50 m^2 of clogged gravel with an excavator. For each intervention egg survival of Brown Trout was determined, and the number of redds of Brown

Trout, Common Minnow, and European Grayling, was determined and compared with a control, unrestored reach. No explicit target outcome was stated.

Critical appraisal:

Project A:

This study of the survival of Brown Trout eggs at each of the four intervention sites used a CI study design where the control and intervention sites were well-matched and homogenous with respect to confounding factors. Egg sandwich boxes were used to determine egg survival of Brown Trout (quantitative outcome). These studies were replicated (n=6) and were given medium overall study validity.

Project B:

This study measured the number of redds of Brown Trout, Common Minnow, and European Grayling at all intervention sites combined (used total counts) using a CI study design where the control and intervention sites were well-matched and homogenous with respect to confounding factors. Visual walking surveys were used to determine the number of redds (quantitative outcome), but was considered unreplicated because redds were counted across all sites (not averaged), and thus given a low validity rating.,

Effectiveness rating (% change in effectiveness):

Project A: Survival of Brown Trout eggs at intervention 1: Potentially effective (15.2%)

The evidence presented suggests the intervention described may potentially be effective at increasing Brown Trout egg survival, however, fewer than three years of post-treatment monitoring were performed.

Project A: Survival of Brown Trout eggs at intervention 2: Potentially ineffective (-10.9%)

The evidence presented suggests the intervention described may potentially be ineffective at increasing Brown Trout egg survival, however, fewer than three years of post-treatment monitoring were performed.

Project A: Survival of Brown Trout eggs at intervention 3: Potentially ineffective (-2.2%)

The evidence presented suggests the intervention described may potentially be ineffective at increasing Brown Trout egg survival, however, fewer than three years of post-treatment monitoring were performed.

Project A: Survival of Brown Trout eggs at intervention 4: Potentially ineffective (-8.7%)

The evidence presented suggests the intervention described may potentially be ineffective at increasing Brown Trout egg survival, however, fewer than three years of post-treatment monitoring were performed.

Project B: Number of Common Minnow redds at intervention 1: Potentially effective (100.0%)

The evidence presented suggests the intervention described may potentially be effective at increasing Common Minnow redd abundance, however, fewer than three years of post-treatment monitoring were performed, and the biological endpoint reported (i.e., abundance of redds) only confirms the use of spawning habitat and not necessarily success.

Project B: Number of European Grayling redds at intervention 1: Potentially effective (100.0%)

The evidence presented suggests the intervention described may potentially be effective at increasing European Grayling redd abundance, however, fewer than three years of post-treatment monitoring were performed, and the biological endpoint reported (i.e., abundance of redds) only confirms the use of spawning habitat and not necessarily success.

Project B: Number of Brown Trout redds at intervention 1: Potentially effective (100.0%)

The evidence presented suggests the intervention described may potentially be effective at increasing Brown Trout redd abundance, however, fewer than three years of post-treatment monitoring were performed, and the biological endpoint reported (i.e., abundance of redds) only confirms the use of spawning habitat and not necessarily success.

Project B: Number of Common Minnow redds at intervention 2: Potentially ineffective (0.0%)

The evidence presented suggests the intervention described may potentially be ineffective at increasing Common Minnow redd abundance, however, fewer than three years of post-treatment monitoring were performed, and the biological endpoint reported (i.e., abundance of redds) only confirms the use of spawning habitat and not necessarily success.

Project B: Number of European Grayling redds at intervention 2: Potentially effective (100.0%)

The evidence presented suggests the intervention described may potentially be effective at increasing European Grayling redd abundance, however, fewer than three years of post-treatment monitoring were performed, and the biological endpoint reported (i.e., abundance of redds) only confirms the use of spawning habitat and not necessarily success.

Project B: Number of Brown Trout redds at intervention 2: Potentially effective (100.0%)

The evidence presented suggests the intervention described may potentially be effective at increasing Brown Trout redd abundance, however, fewer than three years of post-treatment monitoring were performed, and the biological endpoint reported (i.e., abundance of redds) only confirms the use of spawning habitat and not necessarily success.

Project B: Number of Common Minnow redds at intervention 3: Potentially ineffective (0.0%)

The evidence presented suggests the intervention described may potentially be ineffective at increasing Common Minnow redd abundance, however, fewer than three years of post-treatment monitoring were performed, and the biological endpoint reported (i.e., abundance of redds) only confirms the use of spawning habitat and not necessarily success.

Project B: Number of European Grayling redds at intervention 3: Potentially ineffective (0.0%)

The evidence presented suggests the intervention described may potentially be ineffective at increasing European Grayling redd abundance, however, fewer than three years of post-treatment monitoring were performed, and the biological endpoint reported (i.e., abundance of redds) only confirms the use of spawning habitat and not necessarily success.

<u>Project B: Number Brown Trout redds at intervention 3:</u> Potentially ineffective (-100.0%)

The evidence presented suggests the intervention described may potentially be ineffective at increasing Brown Trout redd abundance, however, fewer than three years of post-treatment monitoring were performed, and the biological endpoint reported (i.e., abundance of redds) only confirms the use of spawning habitat and not necessarily success.

<u>Project B: Number of Common Minnow redds at intervention 4:</u> Potentially ineffective (0.0%)

The evidence presented suggests the intervention described may potentially be ineffective at increasing Common Minnow redd abundance, however, fewer than three years of post-treatment monitoring were performed, and the biological endpoint reported (i.e., abundance of redds) only confirms the use of spawning habitat and not necessarily success.

<u>Project B: Number of European Grayling redds at intervention 4:</u> Potentially ineffective (0.0%)

The evidence presented suggests the intervention described may potentially be ineffective at increasing European Grayling redd abundance, however, fewer than three years of post-treatment monitoring were performed, and the biological endpoint reported (i.e., abundance of redds) only confirms the use of spawning habitat and not necessarily success.

<u>Project B: Number of Brown Trout redds at intervention 4:</u> Potentially ineffective (-100.0%)

The evidence presented suggests the intervention described may potentially be ineffective at increasing Brown Trout redd abundance, however, fewer than three years of post-treatment monitoring were performed, and the biological endpoint reported (i.e., abundance of redds) only confirms the use of spawning habitat and not necessarily success.

Nagata, M., Omori, H., and Yanai, S. 2002. Restoration of spawning and rearing habitats for Masu Salmon, *Oncorhynchus masou* in a channelized stream. Fish. Sci., 68: 1707–1710. doi:10.2331/fishsci.68.sup2_1707.

Study location: Hokkaido, Japan

Target species/group: Masu salmon (*Oncorhynchus masou*)

Study objective: In this study a lattice structure of logs, V and straight structures were installed and gravel 5-10 cm in diameter was added to improve stream spawning conditions for Masu Salmon. Biomass of age 0 salmon was determined by castnet and electrofishing and compared to an unrestored habitat. No explicit target outcome was stated.

Critical appraisal:

This study used a CI study design where the control and intervention sites were likely well-matched. The study was pseudoreplicated and was given medium overall validity.

Effectiveness rating (% change in effectiveness): Potentially effective (65.9%)

The evidence suggests that the intervention applied in this study is potentially effective at increasing age 0 salmon biomass compared to an unrestored section, however, fewer than three years of post-intervention monitoring were performed.

Naito, G. 2016. Lower Whatshan River Fish Habitat Enhancement Physical and Biological Effectiveness Monitoring 2015 (Year 10). Report 304-02-07 for BC Hydro.

Study location: British Columbia, Canada

Target species/group: Slimy Sculpin (*Cottus cognatus*), Brook Trout (*Salvelinus fontinalis*), Longnose Dace (*Rhinichthys cataractae*), Rainbow Trout (*Oncorhynchus mykiss*)

Study objective: In this study, enhancement work was conducted at a total of 31 sites in a river reach. These sites consisted of twelve triangular log jams, six lateral log jams, eight boulder groups, three single or double boulder placements, and two single or multiple log placements. Estimated fry abundance of four fish species was calculated before and after intervention, and in a control, unrestored stream. Fry length of the four fish species was also compared between the restored and unrestored stream reaches. No explicit target outcome was stated.

Critical appraisal:

<u>Project A:</u>

BACI study on the estimated abundance of Slimy Sculpin, Brook Trout, Longnose Dace, and Rainbow Trout fry in a restored stream reach. The control and intervention sites used in this study were likely well-matched and moderately homogenous with respect to confounding factors. Electrofishing was used to estimate abundance (quantitative approximation). The study was pseudoreplicated and given medium overall validity.

<u>Project B:</u>

CI study comparing fry length of the four fish species in restored and unrestored reaches. The control and intervention sites used in this study were likely well-matched and moderately homogenous with respect to confounding factors. Electrofishing was used to estimate length (quantitative outcome). The study was pseudoreplicated and was given medium overall validity.

Effectiveness rating (% change in effectiveness):

<u>Project A: BACI study on the effect of the intervention on estimated Slimy Sculpin fry abundance:</u> Ineffective (-39.0%)

The evidence suggests the intervention described here is ineffective at increasing Slimy Sculpin fry abundance.

<u>Project A: BACI study on the effect of the intervention on estimated Brook Trout fry abundance:</u> Effective (40.9%)

The evidence suggests the intervention described here is effective at increasing Brook Trout fry abundance.

<u>Project A: BACI study on the effect of the intervention on estimated Longnose Dace fry abundance:</u> Ineffective (-100.0%)

The evidence suggests the intervention described here is ineffective at increasing Longnose Dace fry abundance.

<u>Project A: BACI study on the effect of the intervention on estimated Rainbow Trout fry abundance:</u> Effective (100.0%)

The evidence suggests the intervention described here is effective at increasing Rainbow Trout fry abundance.

<u>Project B: CI study on the length of Slimy Sculpin fry in restored and unrestored reaches:</u> Potentially effective (8.4%)

The evidence suggests the intervention described here is potentially effective at increasing Slimy Sculpin fry length.

<u>Project B: CI study on the length of Brook Trout fry in restored and unrestored reaches:</u> Potentially ineffective (-6.5%)

The evidence suggests the intervention described here is potentially ineffective at increasing Brook Trout fry length.

<u>Project B: CI study on the length of Rainbow Trout fry in restored and unrestored reaches:</u> Potentially effective (0.5%)

The evidence suggests the intervention described here is potentially effective at increasing Rainbow Trout fry length.

Nash, K.T., Hendry, K., and Cragg-Hine, D. 1999. The use of brushwood bundles as fish spawning media. Fish. Manag. Ecol., 6: 349–356. doi:10.1046/j.1365-2400.1999.00153.x.

Study location: Manchester, England

Target species/group: European Perch (*Perca fluviatilis*), Common Roach (*Rutilus rutilus*)

Study objective: This study aimed to investigate what types of structures, introduced into polluted Manchester docks, were most effective at providing spawning structures for fish in the waterbody. One of six types of brush bundles was added to the habitat, either lime, pear willow, thin willow, sycamore, conifer spruce, laurel, or one of two types of plastic netting (ten 0.2 m strands of netting tied to a brick providing an open structure, or a 10 m length of netting loosely wound around a 0.5 m long weight providing a dense structure). For each structure, the total number of Yellow Perch egg clusters (ribbons) was counted, and the density of Common Roach eggs was determined. No explicit target outcome was stated.

Critical appraisal: 🔴

All of the studies outlined in this paper were assessed post-treatment only with no comparator and were given a low overall validity rating. Visual counts were used to count Yellow Perch egg clusters and Common Roach eggs on reefs. The study was replicated, in all cases with n=2-4.

Effectiveness rating (% change in effectiveness): Unclear (N/A)

The effectiveness of this intervention is unclear, because only post-intervention monitoring was performed with no comparator.

New York State Department of Environmental Conservation. 2015. Lake Sturgeon Spawning Beds at Iroquois Dam and Moses-Saunders Power Dam: 2014 Monitoring and Habitat Management Activities. Report to the New York Power Authority and the Technical Advisory Council for St. Lawrence– FDR Power Project: FERC NO. 2000.

Study location: New York, USA

Target species/group: Lake Sturgeon (*Acipenser fulvescens*)

Study objective: This study is a continuation of NYSDEC (2014) and NYSDEC (2013), looking at the effectiveness of four created Lake Sturgeon spawning beds (two beds were upstream and downstream of the Iroquois Dam, and two in the tail waters of the Moses Saunders Power Dam), to provide additional spawning habitat. These beds consisted of gravel 5-10 cm in diameter, and 10 large boulders were placed at the downstream end of each bed to serve as a velocity break for staging Lake Sturgeon. The success of these spawning beds was determined by counting the number of adult spawning Lake Sturgeon. No explicit target outcome was stated.

Critical appraisal: 🔴

These studies were assessed post-treatment only with no comparator and were given low overall validity ratings. Video monitoring using underwater cameras was used to visually count spawning Lake Sturgeon. The studies were pseudoreplicated.

Effectiveness rating (% change in effectiveness): Unclear (N/A)

The effectiveness of this intervention was unclear, because only post-intervention monitoring was performed with no comparator.

Nilsson, J., Engstedt, O., and Larsson, P. 2014. Wetlands for northern pike (*Esox lucius* L.) recruitment in the Baltic Sea. Hydrobiologia 721(1): 145–154. doi:10.1007/s10750-013-1656-9.

Study location: Sweden

Target species/group: Northern Pike (*Esox lucius*)

Study objective: This study describes a number of interventions, four of which involved flooding of various habitats, and three of which involved stream restoration and improvement efforts. Flooded habitat interventions, Project A (Kronobäck grassland), included flooded terrestrial vegetation (grasses and sedges), flooded phragmite belts, flooded submerged macrophytes, and flooded non-vegetated areas. The stream restorations, Project B, were at Törnebybäcken wetland, where the reeds were removed with the root mat and approximately 0.2 m of sediment, at Lervik where the stream was widened to approximately 75 m by digging a shallow pond of 1.5 ha and removing 200 m of northern bank, and at Kronobäck grassland, where formerly flooded grasslands of approximately 3.2 ha were restored by constructing an adjustable embankment near the outlet to the sea; before this restoration, approximately 0.5 ha was flooded annually. For each of the four flooded habitat interventions, the number of Northern Pike larvae per site was determined. For the three stream restorations, the number of emigrating Northern Pike juveniles was counted. No explicit target outcome was stated.

Critical appraisal:

<u>Project A:</u>

Flooded habitat interventions were assessed post-treatment only with no comparator and were given a low overall validity rating. The white plate method was used to visually count larvae, which is considered a moderately appropriate measurement method for the outcome in this instance. The intervention was applied at an appropriate spatial/temporal scale relative to the target species and waterbody. The study was replicated, in all cases with n=8.

<u>Project B:</u>

Stream improvement intervention studies used a BA study design, comparing the number of Northern Pike juveniles in the area before and after the intervention was applied. Downstream mesh traps were used to capture and count emigrating Northern Pike juveniles. The outcomes reported were an estimation of the number of juveniles and were semi-qualitative. These studies were unreplicated and were given a low overall validity rating.

Effectiveness rating (% change in effectiveness):

<u>Project A: Flooded habitat interventions:</u> Unclear (N/A)

The effectiveness of this intervention is unclear, because only post-intervention monitoring was performed and there was no comparator.

Project B: Törnebybäcken wetland interventions: Potentially ineffective (N/A)

The evidence suggests the intervention described is potentially ineffective at increasing the number of Northern Pike juveniles in the stream, however, semi-qualitative data is presented and fewer than three years of post-intervention monitoring were performed.

Project B: Lervik Stream interventions: Potentially ineffective (N/A)

The evidence suggests the intervention described is potentially ineffective at increasing the number of Northern Pike juveniles in the stream, however, semi-qualitative data is presented and fewer than three years of post-intervention monitoring were performed.

Project B: Kronobäck grassland interventions: Potentially effective (N/A)

The evidence suggests the intervention described is potentially effective at increasing the number of Northern Pike juveniles in the stream, however, semi-qualitative data is presented and fewer than three years of post-intervention monitoring were performed.

Ortlepp, J., and Mürle, U. 2003. Effects of experimental flooding on brown trout (*Salmo trutta fario* L.): The River Spöl, Swiss National Park. Aquat. Sci., 65(3): 232–238. doi:10.1007/s00027-003-0666-5.

Study location: Graubünden, Switzerland

Target species/group: Brown Trout (*Salmo trutta fario*)

Study objective: In this study, controlled flushings from artificial flooding of the reservoir were conducted to reduce the amount of fines (63-190 µm size class) in the upper layer of the river bed. The number of adult Brown Trout spawners and redds was counted before and after the intervention. No explicit target outcome was stated.

Critical appraisal:

This study used a BA study design. Visual surveys were used to count the number of redds and electrofishing was used to determine the abundance of adult spawners (quantitative outcomes). The study was unreplicated. It was given a low overall validity rating.

Effectiveness rating (% change in effectiveness):

Number of adult Brown Trout spawners: Potentially ineffective (-11.3%)

The evidence suggests the intervention described is potentially ineffective at increasing the number of Brown Trout spawners in the area compared to pre-restoration. However, fewer than three years of post-intervention monitoring were performed, and the biological endpoint reported (i.e., number of spawners) only confirms the use of spawning habitat and not necessarily success.

Number of Brown Trout redds: Potentially effective (100.0%)

The evidence suggests the intervention described is potentially effective at increasing the number of Brown Trout redds in the area compared to pre-restoration. However, fewer than three years of post-intervention monitoring were performed, and the biological endpoint reported (i.e., abundance of redds) only confirms the use of spawning habitat and not necessarily success.

Palm, D., Brännäs, E., Lepori, F., Nilsson, K., and Stridsman, S. 2007. The influence of spawning habitat restoration on juvenile brown trout (*Salmo trutta*) density. Can. J. Fish. Aquat. Sci., 64(3): 509–515. doi:10.1139/f07-027.

Study location: Norrbotten County, Sweden

Target species/group: Brown Trout (*Salmo trutta*)

Study objective: In this study, a 10 km long section of the stream was restored by replacing approximately 90% of the boulders that were previously removed and piled along the banks, back into the stream. Approximately 600 m^3 of boulders 40-70 cm in diameter were replaced. In addition, between 1992 and 2002, 85 patches of gravel were reconstructed in the uppermost 5 km of the section. For the rock replacement intervention, age 0 Brown Trout density was compared before and after the intervention was applied, and egg-to-fry survival was compared in the restored section to a controlled hatch (not a restored site). The same two outcomes were measured (density and egg-to-fry survival) for the rock-and-gravel replacement intervention. No explicit target outcome was stated.

Critical appraisal:

Project A:

This study of age 0 Brown Trout density before and after intervention used a BA study design and compared age 0 Brown Trout density (quantitative outcome) following rock replacement intervention and rock-and-gravel replacement intervention. Electrofishing was used to determine Brown Trout abundance. The studies were pseudoreplicated and were given a medium overall validity rating.

Project B:

This study of egg-to-fry survival in restored versus control hatchery conditions used a CI study design and compared egg-to-fry survival between rock replacement and rock-and-gravel replacement to a controlled hatch but, there are potentially influential differences between the control and intervention sites, so the study was given a low overall validity rating. Egg incubators were used to determine egg survival (quantitative outcome) and the studies were pseudoreplicated.

Effectiveness rating (% change in effectiveness):

Project A: Rock-and-gravel replacement effect on age 0 Brown Trout density: Potentially effective (100.0%)

The evidence suggests the intervention described is potentially effective at increasing age 0 Brown Trout density, however, fewer than three years of post-intervention monitoring were conducted.

Project A: Rock replacement effect on age 0 Brown Trout density: Potentially ineffective (-11.9%)

The evidence suggests the intervention described is potentially ineffective at increasing age 0 Brown Trout density, however, fewer than three years of post-intervention monitoring were conducted.

Project B: Rock-and-gravel replacement effect on egg-to-fry survival: Potentially ineffective (-86.6%)

The evidence suggests the intervention described is potentially ineffective at increasing egg-to-fry survival, however, fewer than three years of post-intervention monitoring were conducted.

Project B: Rock replacement effect on egg-to-fry survival: Potentially ineffective (-97.8%)

The evidence suggests the intervention described is potentially ineffective at increasing egg-to-fry survival, however, fewer than three years of post-intervention monitoring were conducted.

Peck, J.W. 1986. Dynamics of reproduction by hatchery Lake Trout on a man-made spawning reef. J. Gt. Lakes Res., 12: 293–303. doi:10.1016/S0380-1330(86)71729-2.

Study location: Michigan, USA

Target species/group: Lake Trout (*Salvelinus namaycush*)

Study objective: Granite and limestone rock was used to anchor and cover a discharge pipe. This study looked at the potential of this rock to act as a spawning site for Lake Trout. Lake Trout spawning was assessed by determining the abundance of adult spawners and fry, and Lake Trout egg density. No explicit target outcome was stated.

Critical appraisal: These studies were assessed post-treatment only with no comparator and were given a low overall validity rating.

Project A: 🔴

Gill nets were used to assess numbers of adult spawners and the studies were unreplicated.

Project B: 🔴

Egg pails were used to determine Lake Trout egg density and fry abundance and the studies were pseudoreplicated.

Effectiveness rating (% change in effectiveness): Unclear (N/A)

The effectiveness of these interventions is unclear, because only post-intervention monitoring was performed with no comparator.

Pedersen, M.L., Kristensen, E.A., Kronvang, B., and Thodsen, H. 2009. Ecological effects of re-introduction of salmonid spawning gravel in lowland Danish streams. River Res. Appl., 25(5): 626–638. doi:10.1002/rra.1232.

Study location: Denmark

Target species/group: Brown Trout (*Salmo trutta*)

Study objective: This study evaluated gravel reinstallation as a long-term rehabilitation method. Three rivers were re-meandered in experimental sections; the upstream section of each river was left un-meandered as a control. For each river, the number of redds, density of fry per 100 m^2, and density of YOY per 100 m^2 for Brown Trout was determined. No explicit target outcome was stated.

Critical appraisal:

For each of the projects outlined below, a CI study design was used in which the control and intervention sites were well-matched and homogenous with respect to confounding factors. Visual counts were used to count the number of redds, and electrofishing was used to determine the density of fry and YOY Brown Trout (quantitative outcomes).

Project A:

This study of the number of redds in Gels Å River was unreplicated. It was given a low overall validity rating.

Project B:

These studies of the density of fry and YOY brown trout in Gels Å River were pseudoreplicated. They were given medium overall validity rating.

Project C:

This study of the number of redds in Stensbæk River was unreplicated. It was given a low overall validity rating.

Project D:

These studies of the density of fry and YOY Brown Trout in Stensbæk River were pseudoreplicated. They were given medium overall validity rating.

Project E: 🔴

This study of the number of redds in Ryds Å River was unreplicated. It was given a low overall validity rating.

Project F: 🟡

These studies of the density of fry and YOY Brown Trout in Ryds Å River were pseudoreplicated. They were given medium overall validity rating.

Effectiveness rating (% change in effectiveness):

Project A: Number of redds in Gels Å River: Potentially effective (100.0%)

The evidence suggests the intervention described is potentially effective at increasing the number of redds compared to an unrestored section, however, the biological endpoint reported (i.e., abundance of redds) only confirms the use of spawning habitat and not necessarily success.

Project B: Density of Brown Trout fry in Gels Å River: Effective (6.5%)

The evidence suggests the intervention described is effective at increasing Brown Trout fry density.

Project B: Density of YOY Brown Trout in Gels Å River: Effective (55.5%)

The evidence suggests the intervention described is effective at increasing Brown Trout YOY density.

Project C: Number of redds in Stensbæk River: Potentially effective (99.5%)

The evidence suggests the intervention described is potentially effective at increasing the number of redds compared to an unrestored section, however, the biological endpoint reported (i.e., abundance of redds) only confirms the use of spawning habitat and not necessarily success.

Project D: Density of Brown Trout fry in Stensbæk River: Effective (100.0%)

The evidence suggests the intervention described is effective at increasing Brown Trout fry density.

Project D: Density of YOY Brown Trout in Stensbæk River: Effective (100.0%)

The evidence suggests the intervention described is effective at increasing Brown Trout YOY density.

<u>Project E: Number of redds in Ryds Å River:</u> Potentially effective (100.0%)

The evidence suggests the intervention described is potentially effective at increasing the number of redds compared to an unrestored section, however, the biological endpoint reported (i.e., abundance of redds) only confirms the use of spawning habitat and not necessarily success.

<u>Project F: Density of Brown Trout fry in Ryds Å River:</u> Effective (100.0%)

The evidence suggests the intervention described is effective at increasing Brown Trout fry density.

<u>Project F: Density of YOY Brown Trout in Ryds Å River:</u> Effective (81.1%)

The evidence suggests the intervention described is effective at increasing Brown Trout YOY density.

Piller, K.R., and Burr, B.M. 1999. Reproductive biology and spawning habitat supplementation of the relict darter, *Etheostoma chienense*, a federally endangered species. Environ. Biol. Fishes, 55: 145–155.

Study location: Kentucky, USA

Target species/group: Relict Darter (*Etheostoma chienense*)

Study objective: In this study, half-cylindrical ceramic tiles were added to several stretches of a stream to increase potential nest productivity of Relict Darter. The clutch size of the eggs attached to the artificial structures was compared to natural structures. No explicit target outcome was stated.

Critical appraisal:

This study used a CI study design where the control and intervention sites were well-matched and homogenous with respect to confounding factors. To determine the size of egg clusters (quantitative outcome), eggs were removed from the water and counted/photographed. The study was given a medium overall validity rating.

Effectiveness rating (% change in effectiveness): Potentially effective (42.9%)

The evidence suggests the intervention described in this study is potentially effective at increasing egg cluster size compared with natural substrate, however, fewer than three years of post-intervention monitoring were performed, and the biological endpoint reported (i.e., size of egg clusters) only confirms the use of spawning habitat and not necessarily success.

Pondella, D.J., Allen, L.G., Craig, M.T., and Gintert, B. 2006. Evaluation of eelgrass mitigation and fishery enhancement structures in San Diego Bay, California. Bull. Mar. Sci., 78: 115–131.

Study location: California, USA

Target species/group: Barred Sand Bass (*Paralabrax nebulifer*)

Study objective: This study describes the construction of four reefs and an eelgrass (*Zostera marina*) transplant area, in a San Diego estuary. The outer two reefs (reefs 1 and 4) were formed in a "horseshoe design," which consisted of cobble added along their upper perimeter in the shape of a horseshoe. Reefs 1 and 3 were constructed of quarry rock, while reefs 2 and 4 were constructed with recycled concrete blocks. Between the channel and the shoreline, eelgrass was transplanted (eelgrass enhancement). Directly across the bay there is a shoal on which a persistent eelgrass bed was found and used as a reference (eelgrass reference). The other reference in the study was the submerged Zuniga Jetty that borders the outer channel of the harbour directly across from Pt. Loma. The number of adult Barred Sand Bass spawners was counted on the reefs and in the eelgrass transplant area and compared to control areas.

Critical appraisal:

Project A:

This study determined the density of Barred Sand Bass spawners on artificial reefs versus a control. It used a CI study design where the control and intervention sites were likely well-matched and homogenous with respect to confounding factors. Visual surveys conducted by divers were used to count spawners. The study was replicated (n=4) and was given medium overall validity rating.

Project B:

This study determined the density of Barred Sand Bass spawners on eelgrass transplant areas versus a control. It used a CI study design where the control and intervention sites were likely well-matched and homogenous with respect to confounding factors. Visual surveys conducted by divers were used to count spawners. The study was pseudoreplicated and was given a medium overall validity rating.

Effectiveness rating (% change in effectiveness):

Project A: Density of Barred Sand Bass spawners on artificial reefs versus control: Potentially effective (100.0%)

The evidence suggests the artificial reefs constructed in this study are potentially effective at increasing the number of adult Barred Sand Bass spawners, however, the biological endpoint reported (i.e., number of spawners) only confirms spawning habitat use and not necessarily spawning success.

Project B: Density of Barred Sand Bass spawners on eelgrass transplant area versus control: Potentially ineffective (-92.7%)

The evidence suggests the eelgrass transplant area is potentially ineffective at increasing the number of adult Barred Sand Bass spawners, however, the biological endpoint reported (i.e., number of spawners) only confirms spawning habitat use and not necessarily spawning success.

Roni, P. 2003. Responses of benthic fishes and giant salamanders to placement of large woody debris in small Pacific Northwest streams. North Am. J. Fish. Manag., 23(4): 1087–1097. doi:10.1577/M02-048.

Study location: Washington/Oregon, USA

Target species/group: Lamprey (*Entosphenus tridentatus* and *Lampetra spp.*), Reticulate Sculpin (*Cottus perplexus*), Torrent Sculpin (*Cottus rhotheus*)

Study objective: In this study large woody debris was placed in multiple streams to improve habitat conditions for species. The mean number, and average length, of lamprey, Reticulate Sculpin, and Torrent Sculpin was determined in each stream and compared to control streams in which large woody debris was not placed. No explicit target outcome was stated.

Critical appraisal:

This study used a CI study design where the control and intervention sites were well-matched and homogenous with respect to confounding factors. Electrofishing was used to capture fish to determine abundance and lengths (quantitative outcomes).

Effectiveness rating (% change in effectiveness):

Number of lamprey: Potentially effective (70.5%)

The evidence suggests the intervention described in this study is potentially effective at increasing the abundance of lamprey larvae compared to unrestored streams, however, it is unclear how many years were monitored post-intervention.

Number of Reticulate Sculpin: Potentially effective (54.1%)

The evidence suggests the intervention described in this study is potentially effective at increasing the abundance of age 0 Reticulate Sculpin compared to unrestored streams, however, it is unclear how many years were monitored post-intervention.

Length of Torrent Sculpin: Potentially effective (24.2%)

The evidence suggests the intervention described in this study is potentially effective at increasing the abundance of age 0 Torrent Sculpin compared to unrestored streams, however, it is unclear how many years were monitored post-intervention.

Length of lamprey: Potentially effective (8.5%)

The evidence suggests the intervention described in this study is potentially effective at increasing the length of lamprey larvae compared to unrestored streams, however, it is unclear how many years were monitored post-intervention.

Length of Reticulate Sculpin: Potentially ineffective (-5.0%)

The evidence suggests the intervention described in this study is potentially effective at increasing the length of age 0 Reticulate Sculpin compared to unrestored streams, however, it is unclear how many years were monitored post-intervention.

Length of Torrent Sculpin: Potentially effective (0.3%)

The evidence suggests the intervention described in this study is potentially effective at increasing the length of age 0 Torrent Sculpin compared to unrestored streams, however, it is unclear how many years were monitored post-intervention.

Roni, P., Van Slyke, D., Miller, B.A., Ebersole, J.L., and Pess, G. 2008. Adult Coho Salmon and steelhead use of boulder weirs in southwest Oregon streams. North Am. J. Fish. Manag., 28(3): 970–978. doi:10.1577/M07-085.1.

Study location: Oregon, USA

Target species/group: Coho Salmon (*Oncorhynchus kisutch*) and steelhead (*Oncorhynchus mykiss)*

Study objective: In this study, boulders and boulder weirs were placed within a number of stream channels to improve habitat for spawning Coho Salmon. The number of Coho Salmon redds and spawners, and steelhead redds were surveyed for restored and unrestored streams. No explicit target outcome was stated.

Critical appraisal:

Project A: 🟡

The number of Coho Salmon redds (replicated study n=10), and Coho Salmon spawners (n=7) were determined in restored versus unrestored streams in Oregon for one year (CI study design). Control and intervention sites were well-matched and homogenous with respect to confounding factors. r

Project B: 🟡

The number of adult Coho Salmon spawners, the peak number of Coho Salmon redds, and the total number of steelhead redds, were determined in five restored and three unrestored reference streams over five years (CI study design). Control and intervention sites were likely well-matched and homogenous with respect to confounding factors. The study was given a medium overall validity rating.

Effectiveness rating (% change in effectiveness):

Project A: The number of Coho Salmon redds in restored (n=10) versus unrestored (n=10) streams in Oregon for one year 2004-2005: Potentially effective (100.0%)

The evidence suggests the intervention described in this study is potentially effective at increasing the number of Coho Salmon redds compared with unrestored reaches, however, fewer than three years of post-intervention monitoring were performed, and the biological endpoint reported (i.e., abundance of redds) only confirms the use of spawning habitat and not necessarily success.

Project A: The number of Coho Salmon spawners in restored (n=10) versus unrestored (n=10) streams in Oregon for one year 2004-2005: Potentially effective (100.0%)

The evidence suggests the intervention described in this study is potentially effective at increasing the number of Coho Salmon spawners compared with unrestored reaches, however, fewer than three years of post-intervention monitoring were performed, and the biological endpoint reported (i.e., abundance of spawners) only confirms the use of spawning habitat and not necessarily success.

Project B: The number of Coho Salmon spawners in restored (n=5) versus unrestored (n=3) streams in West Fork of the Smith River in Oregon for five years 2001-2005: Potentially effective (43.2%)

The evidence suggests the intervention described in this study is potentially effective at increasing the number of Coho Salmon spawners compared with unrestored reaches, however, the biological endpoint reported (i.e., abundance of spawners) only confirms the use of spawning habitat and not necessarily success.

Project B: The peak number of Coho Salmon redds in restored (n=5) versus unrestored (n=3) streams in West Fork of the Smith River in Oregon for five years 2001-2005: Potentially effective (38.5%)

The evidence suggests the intervention described in this study is potentially effective at increasing the number of Coho Salmon redds compared with unrestored reaches, however, the biological endpoint reported (i.e., abundance of redds) only confirms the use of spawning habitat and not necessarily success.

Project B: The total number of steelhead redds in restored (n=5) versus unrestored (n=3) streams in West Fork of the Smith River in Oregon for five years 2001-2005: Potentially effective (35.5%)

The evidence suggests the intervention described in this study is potentially effective at increasing the number of steelhead redds compared with unrestored reaches, however, the biological endpoint reported (i.e., abundance of redds) only confirms the use of spawning habitat and not necessarily success.

Roseman, E.F., Manny, B., Boase, J., Child, M., Kennedy, G., Craig, J., Soper, K., and Drouin, R. 2011. Lake sturgeon response to a spawning reef constructed in the Detroit river. J. Appl. Ichthyol., 27(2, SI): 66–76. doi:10.1111/j.1439-0426.2011.01829.x.

Study location: Ontario, Canada

Target species/group: Lake Sturgeon (*Acipenser fulvescens*), Walleye (*Sander vitreous*), Sucker (*Catostomus commersonii*), Lake Whitefish (*Coregonus clupeaformis*)

Study objective: In this study spawning areas were placed in the Detroit River for Lake Sturgeon. The spawning substrates used included large diameter (10-50 cm) broken limestone, small to medium sized (5-10 cm) broken limestone, and rounded rock 10-25 cm in diameter. Four reproductive substrates that were placed in the river consisted of the above three substrates individually plus a mixture of all three of these substrates, in equal proportions. Each substrate treatment was replicated three times in the 12 beds constructed across the channel width. The density of eggs per square meter from four fish species was determined for the spawning area and compared with a reference site. No explicit target outcome was stated.

Critical appraisal: 🔴

The study described here uses a BA study design where the control and intervention sites are well-matched and homogenous with respect to confounding factors. Egg matts were used to determine egg density (quantitative outcome). The study was, however, unreplicated. It was given a low overall validity rating.

Effectiveness rating (% change in effectiveness):

<u>Density of Lake Sturgeon eggs in intervention versus control sites:</u> Potentially effective (100.0%)

The evidence suggests the intervention described is potentially effective at increasing the density of Lake Sturgeon eggs compared with control sites, however, fewer than three years of post-intervention monitoring were performed, and the biological endpoint reported (i.e., density of eggs) only confirms the use of spawning habitat and not necessarily success.

<u>Density of Walleye eggs in intervention versus control sites:</u> Potentially effective (100.0%)

The evidence suggests the intervention described is potentially effective at increasing the density of Walleye eggs compared with control sites, however, fewer than three years of post-intervention monitoring were performed, and the biological endpoint reported (i.e., density of eggs) only confirms the use of spawning habitat and not necessarily success.

<u>Density of Sucker eggs in intervention versus control sites:</u> Potentially effective (51.6%)

The evidence suggests the intervention described is potentially effective at increasing the density of Sucker eggs compared with control sites, however, fewer than three years of post-intervention monitoring were performed, and the biological endpoint reported (i.e., density of eggs) only confirms the use of spawning habitat and not necessarily success.

<u>Density of Lake Whitefish eggs in intervention versus control sites:</u> Potentially ineffective (-90.2%)

The evidence suggests the intervention described is potentially ineffective at increasing the density of Lake Whitefish eggs compared with control sites, however, fewer than three years of post-intervention monitoring were performed, and the biological endpoint reported (i.e., density of eggs) only confirms the use of spawning habitat and not necessarily success.

Saunders, J.W., and Smith, M.W. 1962. Physical alteration of stream habitat to improve Brook Trout production. Trans. Am. Fish. Soc., 91: 185–188. doi:10.1577/1548-8659(1962)91[185:PAOSHT]2.0.CO;2.

Study location: Prince Edward Island, Canada

Target species/group: Brook Trout (*Salvelinus fontinalis*)

Study objective: Habitat restoration of a brook was conducted by creation of dams, deflectors and covers in the waterbody, all of which were created using materials found in, or along, the bank. The effect of this on spawning of Brook Trout was assessed by determining the standing crop of age 0 fish. No explicit target outcome was stated.

Critical appraisal:

This study used a BA study design to compare the standing crop of age 0 Brook Trout (quantitative outcome) before restoration efforts and after. Electrofishing was used to catch fish. The study was unreplicated. It was given a low overall validity rating.

Effectiveness rating (% change in effectiveness): Potentially effective (9.4%)

The evidence suggests the intervention described in this study is potentially effective at increasing the abundance of age 0 Brook Trout compared with before the intervention was applied, however, fewer than three years of post-intervention monitoring were performed.

Scruton, D.A., Clarke, K.D., Roberge, M.M., Kelly, J.F., and Dawe, M.B. 2005. A case study of habitat compensation to ameliorate impacts of hydroelectric development: effectiveness of re-watering and habitat enhancement of an intermittent flood overflow channel. J. Fish Biol., 67(B): 244–260. doi:10.1111/j.0022-1112.2005.00920.x.

Study location: Newfoundland, Canada

Target species/group: Brook Trout (*Salvelinus fontinalis*)

Study objective: Stream restoration efforts attempted to improve spawning of Brook Trout through the addition of suitable sized spawning gravel (25-65 mm), placement of low head barriers to create pools and reduce water velocity, and the addition of boulders to provide heterogenous flows and depth, and to stabilize gravel. The success of these interventions on improving spawning conditions were tested by electrofishing to determine the density of age 0 Brook Trout and compared to an unrestored, main-stem reach of the river. No explicit target outcome was stated.

Critical appraisal:

This study used a CI study design in which the control and intervention sites were well-matched and homogenous with respect to confounding factors. Electrofishing was used to determine the density of age 0 Brook Trout (quantitative outcome). The study was pseudoreplicated. It was given a medium validity rating.

Effectiveness rating (% change in effectiveness): Effective (100.0%)

The evidence presented in this study suggests the intervention is effective at increasing the density of age 0 Brook Trout compared with unrestored areas.

Shackle, V.J., Hughes, S., and Lewis, V.T. 1999. The influence of three methods of gravel cleaning on brown trout, *Salmo trutta*, egg survival. Hydrol. Process., 13(3): 477–486.

Study location: England

Target species/group: Brown Trout (*Salmo trutta*)

Study objective: This study investigated three methods of gravel cleaning to improve gravel habitat for Brown Trout egg survival to hatching. Method one for gravel cleaning was tractor rotovating with two passes over each strip of gravel, method two was high-pressure jet washing, and method three was pump washing. Egg boxes were used to determine the number of live eggs per 100 eggs placed in the box. No explicit target outcome was stated.

Critical appraisal:

This study used a CI study comparing egg survival in gravel washed by three different methods to control, uncleaned gravel. Control and intervention sites were well-matched and homogenous with respect to confounding factors. Egg boxes used to determine the number of live eggs per 100 placed in the box. The study was replicated (n=5) and was given a medium validity rating.

Effectiveness rating (% change in effectiveness):

<u>Gravel cleaning method one:</u> Potentially effective (36.2%)

The evidence suggests this method of gravel cleaning is potentially effective at increasing Brown Trout egg survival, however, fewer than three years of post-intervention monitoring were performed.

<u>Gravel cleaning method two:</u> Potentially effective (47.8%)

The evidence suggests this method of gravel cleaning is potentially effective at increasing Brown Trout egg survival, however, fewer than three years of post-intervention monitoring were performed.

Gravel cleaning method three: Potentially effective (78.2%)

The evidence suggests this method of gravel cleaning is potentially effective at increasing Brown Trout egg survival, however, fewer than three years of post-intervention monitoring were performed.

Sheng, M.D., Foy, M., and Fedorenko, A.Y. 1990. Coho Salmon Enhancement in British Columbia Using Improved Groundwater-fed Side Channels. Can. MS. Rep. Fish. Aquat. Sci., 2071: 81 pp.

Study location: British Columbia, Canada

Target species/group: Coho Salmon (*Oncorhynchus kisutch*)

Study objective: Six groundwater-fed spawning channels, originally created for Chum Salmon spawning, were assessed for their potential for Coho Salmon spawning by counting the number of adult Coho Salmon spawners. Three of these spawning channels were also assessed for smolt (age 0) Coho Salmon density. No explicit target outcome was stated.

Critical appraisal:

Project A:

These studies were assessed post-treatment only with no comparator and were given low overall validity ratings. Visual estimates by fisheries officers were used to determine adult Coho Salmon escapement (quantitative approximation). The study was unreplicated.

Project B:

These studies were assessed post-treatment only with no comparator and were given low overall validity ratings. Smolt traps were used to determine smolt density (quantitative). The study was pseudoreplicated.

Effectiveness rating (% change in effectiveness): Unclear (N/A)

The effectiveness of these interventions is unclear, because only post-intervention monitoring was performed with no comparator.

Sternecker, K., Wild, R., and Geist, J. 2013. Effects of substratum restoration on salmonid habitat quality in a subalpine stream. Environ. Biol. Fishes, 96(12): 1341–1351. doi:10.1007/s10641-013-0111-0.

Study location: Bavaria, Germany

Target species/group: Brown Trout (*Salmo trutta*)

Study objective: This study applied a substratum restoration technique using a walking excavator. Substratum within the riverbed was mixed up for one hour with the excavator shovel to a depth of 0.5-0.6 m. The excavator shovel loosened collimated and sclerotic substratum and dropped it from a height of approximately one meter. Consequently, the accumulated fine sediment was washed downstream. The success of this for Brown Trout egg survival to hatch was tested by comparing percentage survival before and after intervention. No explicit target outcome was stated.

Critical appraisal:

This study used a BA study design to compare Brown Trout egg survival before and after restoration. Egg sandwich boxes were used to estimate survival. The study was pseudoreplicated and was given a medium overall validity.

Effectiveness rating (% change in effectiveness): Potentially effective (100.0%)

The evidence suggests the restoration technique described is potentially effective at increasing Brown Trout egg survival, however, fewer than three years of post-intervention monitoring were performed.

Taylor, S. 1999. Nitinat Lake Watershed Restoration Program: Caycuse River Tsuk-si-stay Channel As-built Construction Report. Report for Ditidaht Fish Nation and DFO, B.C.

Study location: British Columbia, Canada

Target species/group: Coho Salmon (*Oncorhynchus kisutch*)

Study objective: This study describes the creation of an artificially enhanced spawning channel. The general sequence of events to create the channel was: remove the brush, remove the topsoil (to dump sites), remove the first pass of gravel to the ground water table, remove the second pass of gravel to grade (all gravel used on berm) and then complexing with rock and wood. Effectiveness of the channel was assessed by visual observations of Coho Salmon fry. No explicit target outcome was stated.

Critical appraisal:

This study was assessed post-treatment only with no comparator and was given a low overall validity rating. Visual observations were used to comment on the presence of Coho Salmon fry (qualitative outcome). The study was unreplicated.

Effectiveness rating (% change in effectiveness): Unclear (N/A)

The effectiveness of this intervention is unclear, because only post-intervention monitoring was performed with no comparator.

Toft, J.D., Ogston, A.S., Heerhartz, S.M., Cordell, J.R., and Flemer, E.E. 2013. Ecological response and physical stability of habitat enhancements along an urban armored shoreline. Ecol. Eng., 57: 97–108. doi:10.1016/j.ecoleng.2013.04.022.

Study location: Washington, USA

Target species/group: Various

Study objective: This study describes two different types of intervention. In the first intervention an approximately 290 m long habitat bench was created out of coarse-grained, angular sediment to simulate a natural shallow water habitat in the low inter-tidal area along the existing face of the Seattle seawall. In the second intervention, along the remaining stretch of shoreline north of the existing seawall, an approximately 100 m long pocket beach was excavated from a stretch of riprap armouring and surfaced with pebbles and cobbles. Density of all fish species per square meter was determined by snorkel surveys. Snorkel surveys were completed before and after intervention, and in control (unrestored) areas.

Critical appraisal:

This study used a BACI study design. The control and intervention sites were well-matched and homogenous with respect to confounding factors. The study was pseudoreplicated. It was given medium overall validity.

Effectiveness rating (% change in effectiveness):

<u>Intervention 1:</u> Effective (100.0%)

The evidence suggests the first intervention described in this study is effective at increasing fish density.

<u>Intervention 2:</u> Effective (100.0%)

The evidence suggests the second intervention described in this study is effective at increasing fish density.

Triton Environmental Consultants 2000. Spring Creek Habitat Restoration Project: Report on Activities 1999/2000. Report on Activities, DFO.

Study location: British Columbia, Canada

Target species/group: Coho Salmon (*Oncorhynchus kisutch*)

Study objective: This study describes a habitat restoration effect which involved addition of rocks, spawning gravel, cobbles, and wood to improve conditions for spawning Coho Salmon. The number of pairs of adult spawners was counted via visual surveys before and after restoration.

Critical appraisal: 🔴

This study uses a BA study design; however, pre-intervention data is presented as a qualitative outcome and post-intervention data is presented as a quantitative outcome. Visual surveys were used count number of spawning pairs of Coho Salmon. The study was unreplicated and was given a low overall validity rating.

Effectiveness rating (% change in effectiveness): Unclear (N/A)

Only qualitative data was presented for the comparator and author conclusions were unclear as to the effectiveness of the intervention.

Vehanen, T., Huusko, A., MäKi-Petäys, A., Louhi, P., Mykrä, H., and Muotka, T. 2010. Effects of habitat rehabilitation on brown trout (*Salmo trutta*) in boreal forest streams: Rehabilitation of forest streams. Freshw. Biol., 55(10): 2200–2214. doi:10.1111/j.1365-2427.2010.02467.x.

Study location: Finland

Target species/group: Brown Trout (*Salmo trutta*)

Study objective: This study describes stream restoration to improve Brown Trout habitat in six streams. In late summer 2001, one reach in each stream was rehabilitated using stones (cobbles and boulders). Another section was rehabilitated using stones and large woody debris (LWD). The density of age 0+, 1+ and 2+ Brown Trout was reported at both the boulder only, and boulder with LWD intervention sites. No explicit target outcome was stated.

Critical appraisal: 🟢

This study used a BACI study design where the control and intervention sites were well-matched and homogenous with respect to confounding factors. Electrofishing was used to collect and count Brown Trout juveniles. The intervention was replicated (n=6). The study was given a high overall validity rating.

Effectiveness rating (% change in effectiveness):

<u>Density of age 0+ Brown Trout at boulder only intervention:</u> Potentially ineffective (-100.0%)

The evidence suggests the intervention described is potentially ineffective at increasing age 0+ Brown Trout density, however, fewer than three years of post-intervention monitoring were performed.

<u>Density of age 0+ Brown Trout at boulder and LWD intervention:</u> Potentially ineffective (-100.0%)

The evidence suggests the intervention described is potentially ineffective at increasing age 0+ Brown Trout density, however, fewer than three years of post-intervention monitoring were performed.

<u>Density of age 1+ Brown Trout at boulder only intervention:</u> Potentially ineffective (-100.0%)

The evidence suggests the intervention described is potentially ineffective at increasing age 1+ Brown Trout density, however, the biological endpoint (i.e., juvenile density) only confirms juvenile use of the habitat as a potential nursery area, and not necessarily effectiveness of the intervention to improve spawning success.

<u>Density of age 1+ Brown Trout at boulder and LWD intervention:</u> Potentially ineffective (-100.0%)

The evidence suggests the intervention described is potentially ineffective at increasing age 1+ Brown Trout density, however, the biological endpoint (i.e., juvenile density) only confirms juvenile use of the habitat as a potential nursery area, and not necessarily effectiveness of the intervention to improve spawning success.

<u>Density of age 2+ Brown Trout at boulder only intervention:</u> Potentially effective (100.0%)

The evidence suggests the intervention described is potentially effective at increasing age 2+ Brown Trout density, however, the biological endpoint (i.e., juvenile density) only confirms juvenile use of the habitat as a potential nursery area, and not necessarily effectiveness of the intervention to improve spawning success.

<u>Density of age 2+ Brown Trout at boulder and LWD intervention:</u> Potentially effective (19.6%)

The evidence suggests the intervention described is potentially effective at increasing age 2+ Brown Trout density, however, the biological endpoint (i.e., juvenile density) only confirms juvenile use of the habitat as a potential nursery area, and not necessarily effectiveness of the intervention to improve spawning success.

Vogele, L.E., and Rainwater, W.C. 1975. Use of Brush Shelters as Cover by Spawning Black Basses (Micropterus) in Bull Shoals Reservoir. Trans. Am. Fish. Soc., 104(2): 264–269. doi:10.1577/1548-8659(1975)104<264:UOBSAC>2.0.CO;2.

Study location: Arkansas, USA

Target species/group: Largemouth Bass (*Micropterus salmoides*), Smallmouth Bass (*Micropterus dolomieu*), Spotted Bass (*Micropterus punctulatus*)

Study objective: In this study, brush shelters were added to selected areas in two coves to improve spawning habitat for three bass species. The success of the habitat improvements was monitored through scuba diving surveys, counting the number of bass nests for each of the three species, and compared with an unrestored area. No explicit target outcome was stated.

Critical appraisal: 🔴

This study used a CI study design where the control and intervention sites are well-matched and homogenous with respect to confounding factors. Scuba diving surveys were used to determine the number of bass nests for Largemouth, Smallmouth, and Spotted bass (quantitative outcome). The study was unreplicated. It was given a low overall validity rating.

Effectiveness rating (% change in effectiveness):

<u>Number of Largemouth Bass nests:</u> Potentially effective (100.0%)

The evidence suggests the intervention described in this study is potentially effective at increasing the number of Largemouth Bass nests, however, fewer than three years of post-intervention monitoring were performed, and the biological endpoint reported (i.e., number of nests) only confirms the use of spawning habitat and not necessarily success.

<u>Number of Smallmouth Bass nests:</u> Potentially effective (22.5%)

The evidence suggests the intervention described in this study is potentially effective at increasing the number of Smallmouth Bass nests, however, fewer than three years of post-intervention monitoring were performed, and the biological endpoint reported (i.e., number of nests) only confirms the use of spawning habitat and not necessarily success.

<u>Number of Spotted Bass nests:</u> Potentially effective (100.0%)

The evidence suggests the intervention described in this study is potentially effective at increasing the number of Spotted Bass nests, however, fewer than three years of post-intervention monitoring were performed, and the biological endpoint reported (i.e., number of nests) only confirms the use of spawning habitat and not necessarily success.

Wagner, W.C. 1990. Evaluation of a man-mad Walleye spawning reef. Fisheries Research Report, No. 1959. Michigan Department of Natural Resources.

Study location: Michigan, USA

Target species/group: Walleye (*Stizostedion vitreum*)

Study objective: This study describes the addition of rocks onto a hard, sand-bottom area of a lake to create spawning habitat for Walleye. Success of this intervention was monitored by determining the abundance of Walleye eggs and fry both before and after rock addition. CPUE of Walleye eggs was also compared from the intervention site to a control, sand-bottom site in the lake. No explicit target outcome was stated.

Critical appraisal:

Project A:

This is a BA study testing the effect of rock placement on a sand-bottom area of the lake. Egg pails were used to determine egg and fry abundance. The outcome reported is semi-quantitative, as authors remark that there was an absence of eggs/fry in the area before intervention. The study was unreplicated. It was given a low overall validity rating.

Project B:

This study compared the area of rock placement to a control sand-bottom area with no rock, thus using a CI study design where control and intervention sites were well-matched and homogenous with respect to confounding factors. Egg pails were used to determine CPUE of Walleye eggs (quantitative approximation). The study was unreplicated. It was given a low overall validity rating.

Effectiveness rating (% change in effectiveness):

Project A: BA study, Walleye egg abundance: Potentially effective (100.0%)

The evidence suggests the intervention described is potentially effective at increasing Walleye egg abundance compared to before the intervention was applied, however only semi-quantitative data is reported. The biological endpoint reported (i.e., number of eggs) only confirms use of spawning habitat and not necessarily success.

Project A: BA study, Walleye fry abundance: Potentially effective (100.0%)

The evidence suggests the intervention described is potentially effective at increasing Walleye fry abundance compared to before the intervention was applied, however, only semi-quantitative data is reported.

Project B: CI study, Walleye egg CPUE: Potentially effective (100.0%)

The evidence suggests the intervention described is potentially effective at increasing Walleye egg CPUE compared to a control area, however, the biological endpoint reported (i.e., CPUE of eggs) only confirms the use of spawning habitat and not necessarily success.

Ward, B.R., McCubbing, D.J.F., and Slaney, P.A. 2003. Stream restoration for anadromous salmonids by the addition of habitat and nutrients. In: *Salmon on the Edge* (eds. Mills, D.). Wiley-Blackwell, pp. 235 – 254.

Study location: British Columbia, Canada

Target species/group: Steelhead (*Oncorhynchus mykiss*), Coho Salmon (*Oncorhynchus kisutch*)

Study objective: This study evaluated salmonid response to watershed rehabilitation treatments in the Keogh River, and compared responses to the neighbouring, unrestored

Waukwaas River. The restoration techniques used included addition of large woody debris and boulders to the river, and nutrient addition to the water as slow-release briquettes. Restoration took place gradually from 1997-2001, gradually expanding the restored area of the river until the whole watershed was treated. The effect of this on age 0 steelhead and Coho Salmon density was determined and compared with a control, unrestored watershed. No explicit target outcome was stated.

Critical appraisal: ⬤ (yellow)

This study used a CI study design where control and intervention sites were well-matched and homogenous with respect to confounding factors. Electrofishing and minnow traps were used as measurement assessment methods for the outcome. The study was pseudoreplicated. It was given a medium overall validity rating.

Effectiveness rating (% change in effectiveness):

Density of age 0 steelhead: Potentially ineffective (-51.3%)

The evidence suggests the intervention described in this study is potentially ineffective at increasing age 0 steelhead density compared with unrestored areas, however, fewer than three years of post-intervention monitoring were performed.

Density of age 0 Coho Salmon: Potentially effective (23.7%)

The evidence suggests the intervention described in this study is potentially effective at increasing age 0 Coho Salmon density compared with unrestored areas, however, fewer than three years of post-intervention monitoring were performed.

Weber, D.T., and Imler, R.L. 1974. An Evaluation of Artificial Spawning Beds for Walleye. Special Report Number 34, Colorado Division of Wildlife.

Study location: Colorado, USA

Target species/group: Walleye (*Stizostedion vitreum*)

Study objective: In this study, Walleye spawning beds were created from stone and clean gravel of the appropriate sizes and percentages. The abundance and length of YOY Walleye was determined and compared before and after the intervention was applied. No explicit target outcome was stated.

Critical appraisal: ⬤ (red)

This study used a BA study design where the control and intervention sites were well-matched and homogenous with respect to confounding factors. Electrofishing was used to determine Walleye YOY abundance and length (quantitative). The study was unreplicated (abundance outcome) and pseudoreplicated (length outcome). It was given a low overall validity rating.

Effectiveness rating (% change in effectiveness):

<u>Abundance of YOY Walleye:</u> Effective (100.0%)

The evidence suggests the intervention described is effective at increasing YOY Walleye abundance compared with before the intervention was applied.

<u>Length of YOY Walleye:</u> Potentially effective (12.1%)

The evidence suggests the intervention described is potentially effective at increasing YOY Walleye length compared with before the intervention was applied.

West, C.J., and Mason, J.C. 1987. Evaluation of Sockeye Salmon production from the Babine Lake Development Project. In: Sockeye Salmon Population Biology and Future Management, H.D. Smith, L. Margolis, and C.C. Wood, *eds.* Can. Spec. Publ. Fish. Aquat. Sci. 96: 176 – 190.

Study location: British Columbia, Canada

Target species/group: Sockeye Salmon (*Oncorhynchus nerka*)

Study objective: This study looks at the Babine Lake Development Project and assesses the productivity of Fulton and Pinkut spawning channels, two artificial spawning channels designed to improve Sockeye Salmon productivity. Target outcome specified: The Babine Lake Development Project was anticipated to produce 100 million additional fry which would, in turn, produce some 30 million smolts and 1.25 million adults. In this study fan traps and fences were used to count the number of Sockeye Salmon fry produced at each of these spawning channels and compared to the natural creeks running beside each spawning channel.

Critical appraisal:

This study used a CI study design to compare Sockeye Salmon fry production in two artificially enhanced spawning channels with their respective natural creeks. Enumeration at fences and fan traps were used to estimate fry abundance. The studies were unreplicated, however, and were given low overall validity ratings.

Effectiveness rating (% change in effectiveness):

<u>Fulton spawning channel:</u> Effective (101.8%)

The evidence suggests the artificially enhanced spawning channel is effective at increasing Sockeye Salmon fry production compared with the natural creek.

<u>Pinkut spawning channel:</u> Effective (200.0%)

The evidence suggests that the artificially enhanced spawning channel is effective at increasing Sockeye Salmon fry production compared with the natural creek.

West, D.C., James, A.R., and James, A.H. 1965. Habitat Improvement to Enhance Anadromous Fish Production. Oregon State Game Commission, Portland, OR.

Study location: Oregon, USA

Target species/group: Chinook Salmon (*Oncorhynchus tshawytscha*)

Study objective: Gravel was introduced in a previously dredged creek, and the potential of this for Chinook Salmon spawning was assessed. The number of Chinook Salmon redds was counted in the gravel-introduced area and compared with a control area of natural gravel. No explicit target outcome was stated.

Critical appraisal:

This study used a CI study design and compared the number of Chinook Salmon redds in an area of introduced gravel compared to an area of natural gravel. There was poor matching between the control and intervention sites. Observation surveys were used to count the number of Chinook Salmon redds. The study was unreplicated and was given a low overall validity rating.

Effectiveness rating (% change in effectiveness): Potentially effective (100.0%)

The evidence suggests the intervention described in this study is potentially effective at increasing the number of Chinook Salmon redds compared with an area of natural gravel, however, the biological end point reported (i.e., number of redds) only confirms the use of spawning habitat and not necessarily success.

Wills, T.C., Bremigan, M.T., and Hayes, D.B. 2004. Variable effects of habitat enhancement structures across species and habitats in Michigan reservoirs. Trans. Am. Fish. Soc., 133(2): 399–411. doi:10.1577/02-139.

Study location: Michigan, USA

Target species/group: Smallmouth Bass (*Micropterus dolomieu*)

Study objective: In this study, Smallmouth Bass nesting and cover sites were constructed using half logs arranged perpendicular to the shoreline, five meters apart. AquaCribs, a box-shaped shelter device constructed of corrugated plastic, were placed in clusters varying in number from 3 to 10 suspended one meter above the bottom over a depth interval of 2.7-5.5 m. The number of Smallmouth Bass nests per hectare, and the percentage of nests that survived to produce fry was determined and compared to a reference, unrestored site. No explicit target outcome was stated.

Critical appraisal:

This study used a CI study design where the control and intervention sites were well-matched and homogenous with respect to confounding factors. Snorkeling was used to count nests. The study was replicated (n=2) and was given a medium overall validity rating.

Effectiveness rating (% change in effectiveness):

Density of nests: Potentially effective (61.3%)

The evidence suggests the intervention described in this study is potentially effective at increasing the density of Smallmouth Bass nests, however, fewer than three years of post-intervention monitoring were performed, and the biological endpoint reported (i.e., density of nests) only confirms the use of spawning habitat and not necessarily success.

Nest survival to produce fry: Potentially effective (28.9%)

The evidence suggests the intervention described in this study is potentially effective at increasing nest survival to produce fry, however, fewer than three years of post-intervention monitoring were performed.

Wilson, D.A. 1976. Salmon Spawning Habitat Improvement Study. Project Completion Report, 1-93-D. Washington State Department of Fisheries, Olympia, WA.

Study location: Washington, USA

Target species/group: Chinook Salmon (*Oncorhynchus tshawytscha*), Chum Salmon (*Oncorhynchus keta*)

Study objective: In a Chinook Salmon spawning river, gravel cleaning was performed to improve spawning habitat. In two Chum Salmon spawning rivers gravel replacement was performed to improve spawning conditions. Finally, in another Chum Salmon spawning river, gabion weirs were installed to improve spawning conditions. Spawning improvements were monitored by determining survival of age 0 Chinook Salmon, abundance of adult Chum Salmon spawners and the density of Chum Salmon fry. No explicit target outcome was stated.

Critical appraisal:

Project A:

This is a CI assessing the survival of age 0 Chinook Salmon in restored and control areas where the control and intervention sites were likely well-matched and homogenous with respect to confounding factors. The study was pseudoreplicated. It was given a low overall validity rating.

Project B:

This is BA study design comparing the number of adult Chum Salmon spawners at peak spawning before and after the intervention was applied. Visual counts were used to count Chum Salmon spawners. The study was unreplicated. It was given a low overall validity rating.

Project C:

There are two studies, a BA and a CI study, comparing the abundance of Chum Salmon fry before and after intervention was applied, and at the intervention site, compared to a control site (both studies used the same intervention site). It is unclear how the authors measured fry abundance. The study was pseudoreplicated and was given a medium overall validity rating.

Project D:

This study used a BA study design. The intervention was the same as in Project C, but on a different river. Chum Salmon fry abundance was assessed using a hydraulic sampler. The study was pseudoreplicated, but there were potentially influential differences in confounding factors in before- and after-intervention sampling that may have affected results. The study was given low overall validity.

Project E:

This study used a CI study design where the control and intervention sites were likely well-matched and homogenous with respect to confounding factors. A hydraulic sampler was used to assess abundance of Chum Salmon fry. The study was pseudoreplicated and was given a medium overall validity rating.

Effectiveness rating (% change in effectiveness):

Project A: Survival of age 0 Chinook Salmon in an area where gravel cleaning was performed versus a control area: Potentially effective (54.2%)

The evidence suggests the intervention described is potentially effective at increasing survival of age 0 Chinook Salmon, however, fewer than three years of post-intervention monitoring were performed.

Project B: Number of adult Chum Salmon spawners before and after gravel replacement: Potentially effective (7.2%)

The evidence suggests the intervention described is potentially effective at increasing abundance of adult Chum Salmon spawners, however, fewer than three years of post-intervention monitoring were performed, and the biological endpoint reported (i.e., number of spawners) only confirms the use of spawning habitat and not necessarily success.

Project C: Density of Chum Salmon fry before and after gravel replacement: Potentially effective (79.3%)

The evidence suggests the intervention described is potentially effective at increasing abundance of Chum Salmon fry, however, fewer than three years of post-intervention monitoring were performed.

Project C: Density of Chum Salmon fry in area of gravel replacement versus control area: Potentially effective (7.6%)

The evidence suggests the intervention described is potentially effective at increasing abundance of Chum Salmon fry, however, fewer than three years of post-intervention monitoring were performed.

Project D: Density of Chum Salmon fry before and after gravel replacement (different river): Potentially effective (100.0%)

The evidence suggests the intervention described is potentially effective at increasing abundance of Chum Salmon fry, however, fewer than three years of post-intervention monitoring were performed.

Project E: Density of Chum Salmon fry in an area where gabion weirs were installed versus control area: Potentially effective (95.1%)

The evidence suggests the intervention described is potentially effective at increasing abundance of Chum Salmon fry, however, fewer than three years of post-intervention monitoring were performed.

Wissmar, R.C. 2008. Realities of fish habitat improvements in a developed river. Am. Fish. Soc. Symp. 49: 1925 – 1930.

Study location: Washington, USA

Target species/group: Sockeye Salmon (*Oncorhynchus nerka*)

Study objective: This study describes the construction of three spawning channels for Sockeye Salmon. The success of these channels was assessed by determining the survival of age 0 Sockeye Salmon, and the density of female adult spawners, in the created channels and compared to the main stream. No explicit target outcome was stated.

Critical appraisal:

These two studies used a CI study design. Control and intervention sites were moderately comparable with respect to confounding factors; the paper lacked sufficient information to judge whether they were homogenous with respect to confounding factors. The study was unreplicated. It was given a low overall validity rating.

Effectiveness rating (% change in effectiveness):

Survival of age 0 Sockeye Salmon: Potentially ineffective (-156.4%)

The evidence suggests the created spawning channel is potentially ineffective at increasing survival of age 0 Sockeye Salmon compared with the natural main stream, however, it is unclear how many years of post-intervention monitoring were performed.

Density of female spawning Sockeye Salmon: Potentially effective (200.0%)

The evidence suggests the created spawning channel is potentially effective at increasing density of female spawners compared with the natural main stream, however, it is unclear how many years of post-intervention monitoring were performed.

Wright, M.C. 1999. Ground Water Channel Lower Taylor River As-built Construction Report 1999 for Forest Renewal British Columbia.

Study location: British Columbia, Canada

Target species/group: Coho Salmon (*Oncorhynchus kisutch*)

Study objective: The primary objective of this project was to increase the productive capacity of the Taylor River Watershed by (1) rehabilitating the upper reach of tributary 5000.101.1 and pond #2 to improve flow and fish access into pond #2, (2) develop a ground water channel between pond #2 and tributary 5000.105 to increase the spawning and rearing capacity of the area, and (3) connect isolated ponds to the new channel (5000.101.1.2). The effectiveness of this intervention was tested by counting the number of Coho Salmon fry and spawners. No explicit target outcome was stated.

Critical appraisal: 🔴

These studies were assessed post-treatment only with no comparator and were given low overall validity ratings. Minnow traps and spawner surveys were conducted to count the number of Coho Salmon fry and adult spawners, respectively (quantitative outcomes). The study was unreplicated.

Effectiveness rating (% change in effectiveness): Unclear (N/A)

The effectiveness of this intervention is unclear, because only post-intervention monitoring was performed with no comparator.

Yauck, J. 2009. Oak Creek Power Plant artificial reef. Bay View Compass. [Online] Available: http://bayviewcompass.com/oak-creek-power-plant-artificial-reef [accessed 14 May 2014].

Study location: Wisconsin, USA

Target species/group: Yellow Perch (*Perca flavescens*)

Study objective: This study describes the construction of Oak Creek reef, an artificial reef built with the intent of becoming a spawning ground for Yellow Perch and trout. Oak Creek reef is a cluster of six parallel reefs made from quarried limestone. The presence of Yellow Perch eggs was noted after construction of the reef. No explicit target outcome was stated.

Critical appraisal: 🔴

This study was assessed post-treatment only with no comparator and was given a low overall validity rating. Visual observations were used to determine the presence of Yellow Perch eggs (qualitative outcome). The study was unreplicated.

Effectiveness rating (% change in effectiveness): Unclear (N/A)

The effectiveness of this intervention is unclear, because only post-intervention monitoring was performed with no comparator.

Zeh, M., and Dönni, W. 1994. Restoration of spawning grounds for trout and grayling in the river High-Rhine. Aquat. Sci., 56(1): 59–69. doi:10.1007/BF00877435.

Study location: Germany

Target species/group: Grayling (*Thymallus thymallus*), Brown Trout (*Salmo trutta fario*), Rainbow Trout (*Oncorhynchus mykiss*)

Study objective: This study tested the addition of 10 m^3 of washed gravel into an impounded section of the River High-Rhine for its potential as a spawning ground for salmonids. For Grayling, Brown Trout, and Rainbow Trout, the number of live eggs and live larvae was counted and compared with a control, unrestored area. No explicit target outcome was stated.

Critical appraisal: 🔴

This study used a CI study design, however, there was poor evidence of matching between sites. There are also potentially influential differences in confounding factors between the control and intervention sites. The study was unreplicated. It was given a low overall validity rating.

Effectiveness rating (% change in effectiveness):

<u>Number of Grayling eggs:</u> Potentially effective (100.0%)

The evidence suggests the intervention described is potentially effective at increasing abundance of Grayling eggs compared to a control site, however, fewer than three years of post-intervention monitoring were performed, and the biological endpoint reported (i.e., egg abundance) only confirms the use of spawning habitat and not necessarily success.

<u>Number of Brown Trout eggs:</u> Potentially ineffective (0.0%)

The evidence suggests the intervention described is potentially ineffective at increasing abundance of Brown Trout eggs compared to a control site, however, fewer than three years of post-intervention monitoring were performed, and the biological endpoint reported (i.e., egg abundance) only confirms the use of spawning habitat and not necessarily success.

<u>Number of Rainbow Trout eggs:</u> Potentially ineffective (0.0%)

The evidence suggests the intervention described is potentially ineffective at increasing abundance of Rainbow Trout eggs compared to a control site, however, fewer than three years of post-intervention monitoring were performed, and the biological endpoint reported (i.e., egg abundance) only confirms the use of spawning habitat and not necessarily success.

Number of Grayling larvae: Potentially effective (100.0%)

The evidence suggests the intervention described is potentially effective at increasing abundance of Grayling larvae compared to a control site, however, fewer than three years of post-intervention monitoring were performed.

Number of Brown Trout larvae: Potentially ineffective (0.0%)

The evidence suggests the intervention described is potentially ineffective at increasing abundance of Brown Trout larvae compared to a control site, however, fewer than three years of post-intervention monitoring were performed.

Number of Rainbow Trout larvae: Potentially ineffective (0.0%)

The evidence suggests the intervention described is potentially ineffective at increasing abundance of Rainbow Trout larvae compared to a control site, however, fewer than three years of post-intervention monitoring were performed.

Zeug, S.C., Sellheim, K., Watry, C., Rook, B., Hannon, J., Zimmerman, J., Cox, D., and Merz, J. 2014. Gravel augmentation increases spawning utilization by anadromous salmonids: A case study from California, USA. River Res. Appl., 30(6): 707–718. doi:10.1002/rra.2680.

Study location: California, USA

Target species/group: Chinook Salmon (*Oncorhynchus tshawytscha*), steelhead (*Oncorhynchus mykiss*)

Study objective: This study evaluated the use of three gravel augmentation sites constructed in 2008, 2009, and 2010 (one augmentation per year) in terms of the percent total of Chinook Salmon and steelhead redds. No explicit target outcome was stated.

Critical appraisal:

This study used a BA study design to compare the percentage of total redds of Chinook Salmon and steelhead before and after gravel augmentation. Boat, walking and snorkel surveys were used to count redds. The study was replicated (n=4) and was given a medium overall validity rating.

Effectiveness rating (% change in effectiveness):

Percent Chinook Salmon redds: Potentially effective (100.0%)

The evidence suggests that gravel augmentation in this study is potentially effective at increasing the percentage of Chinook Salmon redds, however, fewer than three years of post-intervention monitoring were performed.

<u>Percent steelhead redds:</u> Potentially effective (100.0%)

The evidence suggests that gravel augmentation in this study is potentially effective at increasing the percentage of steelhead redds, however, fewer than three years of post-intervention monitoring were performed.