

MANAGEMENT BRIEF

Importance of Coarse Woody Habitat Complexity to Yellow Perch Egg Skein Deposition and Survival

Stephen J. Grausgruber,*  Michael J. Weber,  and Joseph E. Morris 

Department of Natural Resource Ecology and Management, Iowa State University, 339 Science Hall II, Ames, Iowa 50011, USA

Abstract

Habitat introductions are often implemented in aquatic systems to meet fishery management goals. Conifer trees have been used to augment spawning habitat for Yellow Perch *Perca flavescens* to support and suspend their unique egg skeins above the lake bottom in hopes of increasing reproduction and recruitment; however, little is known about the influence of tree characteristics on the reproductive success of Yellow Perch. Our objective was to evaluate the effects of tree complexity on the skein deposition and survival rates of Yellow Perch. In February 2020, 30 eastern red cedar *Juniperus virginiana* trees were manipulated to one of five complexities (from 1 = least complex [all branches removed] to 5 = most complex [all branches retained]; $n = 6$ per complexity) and placed on the ice. After ice-off and tree submersion, we conducted snorkeling surveys every 2 d from March 31 to May 5, 2020, and recorded the number and viability of the skeins. We observed 35 Yellow Perch egg skeins. Yellow Perch preferred to deposit their egg skeins on tree complexities 4 and 5, whereas deposition on tree complexities 1, 2, and 3 was random. The nest survival models estimated that skeins that were deposited on tree complexities 1, 2, and 5 had a 27-d survival estimate of 0.07 (95% CI = 0.06 to 0.08) that was lower ($\beta = -1.29$; 95% CI = -2.32 to -0.27) than that for skeins that were deposited on complexities 3 and 4, with a survival estimate of 0.48 (95% CI = 0.43 to 0.52). Our results indicate that Yellow Perch prefer to deposit their egg skeins on intermediate cedar tree complexities that resulted in increased skein deposition and survival. Given our results, once introduced trees have deteriorated below an intermediate complexity, managers should consider supplemental introductions of more complex trees that benefit the reproduction of Yellow Perch.

eggs, an incubation period, and hatching into the larval stage (Moyle and Cech 2016). The survival of fertilized eggs is a crucial component of reproduction and can be influenced by various biotic and abiotic environmental variables (Dahlberg 1979; Pepin 1991; Haddy and Pankhurst 2000), predation (Baily and Houde 1989; Paradis et al. 1996; Steinhart et al. 2004), and habitat characteristics (Fitzsimons 1995; Bardonnnet and Baglinière 2000; Hickford et al. 2010). Suitable habitat is an important element of spawning success in a myriad of fish species, including Lake Trout *Salvelinus namaycush* (Marsden and Krueger 1991; Claramunt et al. 2005), Walleye *Sander vitreus* (Raabe and Bozek 2012), Muskellunge *Esox masquinongy* (Nohner and Diana 2014), Bluegill *Lepomis macrochirus* (Gosch et al. 2006), Black Crappie *Pomoxis nigromaculatus* (Phelps et al. 2011), and Yellow Perch *Perca flavescens* (Craig 2000). The absence of suitable spawning habitat may have negative consequences for natural reproduction (Lapointe et al. 2014), and in extreme cases it can result in the extirpation of a species where it was once a sustained population (Dombeck et al. 1984).

Habitat availability in aquatic systems is highly variable (Kovalenko et al. 2012; Tokeshi and Arakaki 2012; Herb et al. 2014), with system-specific characteristics contributing to potential spawning habitat deficiency. When suitable habitat is not available, managers often choose to introduce habitat with the goal of increasing spawning success (Geiling et al. 1996; Roni et al. 2008). Habitat introductions are justified by a myriad of conditions, intended for a wide range of fish species and life stages,

For a species to naturally persist in an environment, successful reproduction is necessary. In many fish species, reproduction consists of deposition and fertilization of

*Corresponding author: stepheng@iastate.edu

Received May 20, 2021; accepted September 21, 2021

This is an open access article under the terms of the Creative Commons Attribution-NonCommercial-NoDerivs License, which permits use and distribution in any medium, provided the original work is properly cited, the use is non-commercial and no modifications or adaptations are made.

and encompass several habitat types (e.g., rock, plant, soil, synthetic, or a combination of these; Taylor et al. 2019). Substantial resources are allocated toward aquatic habitat rehabilitation activities (Bernhardt et al. 2005; Barletta et al. 2010; Lusk et al. 2012), making our understanding of these practices economically important. Habitat creation has been directly linked to increases in spawning fish and egg life stages (i.e., nests, eggs, or developing embryos; Taylor et al. 2019) as well as increases in fish biomass (Smokorowski and Pratt 2007). Yet, habitat types contain inherent variation that may influence their effectiveness for a particular species and desired management goal (Taylor et al. 2019), as different species can display an affinity for particular habitat types. For instance, Coastal Cutthroat Trout *Oncorhynchus clarkii* and Coho Salmon *Oncorhynchus kisutch* in British Columbia streams preferred gravel-cobble-rather than boulder-bed-sized substrate (Kondolf and Wolman 1993; Rosenfeld et al. 2000) but Burbot *Lota lota* in Lake Michigan selected rubble substrate rather than bedrock ridges (Edsall et al. 1993). Furthermore, stocked juvenile Muskellunge selected intermediate-complexity coarse woody habitat more often than low- and high-complexity coarse woody habitat in an Illinois reservoir (Wagner et al. 2015), whereas Black Crappie in an Illinois small impoundment selected short vegetation at a low density over other potential habitat combinations for their nest sites (Phelps et al. 2011). Consequently, understanding species-specific habitat requirements is crucial for habitat introductions to be successful.

Yellow Perch require suitable environmental conditions to successfully reproduce that includes appropriate habitat (Henderson 1985; Carlander 1997). Suitable spawning habitat for Yellow Perch consists of boulders and gravel, rigid macrophytes, tree roots, submerged trees, and submerged branches (Scott and Crossman 1973; Fisher et al. 1996; Craig 2000). Yellow Perch lay a unique egg mass (hereafter, referred to as a "skein") that can be up to 2.1 m in length and 0.1 m in width that is deposited and ideally entangles on a structure (Scott and Crossman 1973). This entanglement is vital to embryonic success, as optimal skein fertilization and proper oxygen supply occur when the skein is extended (Reyes et al. 1992; Hart et al. 2006; Ward et al. 2012). Furthermore, proper entanglement mitigates the negative effects of wind on Yellow Perch skeins that can cause damage by dislodging and transporting them to less desirable sites (Clady and Hutchinson 1975; Clady 1976).

Some aquatic systems have limited or are void of suitable spawning habitat for Yellow Perch (e.g., shallow windswept lakes and ponds with increased turbidity and decreased vegetation). When adequate spawning structures for Yellow Perch are sparse, managers may choose to introduce supplemental habitat with the goal of increasing reproduction. The use of habitat enhancement for Yellow

Perch reproduction has been investigated, but it is challenging to assess and has resulted in variable success (Day 1983; Fisher 1996; Hanchin et al. 2003). Part of the variation among studies may be due to the different types of habitat additions and complexities that have been used, as Yellow Perch can be selective when considering spawning structures (Fisher et al. 1996; Robillard and Mardsen 2001) and the location of skein deposition can influence skein survival (Huff et al. 2004). Conifer trees are frequently used as introduced spawning habitat for Yellow Perch because they are readily available (Hanchin et al. 2003) and have complex branching (Mangan et al. 2005). Woody habitat is also an important component of reproductive success for Yellow Perch (Sass et al. 2006). However, these structures vary considerably in their complexity at the time of addition (Hanchin et al. 2003) and can lose branch complexity quickly after being placed within a water body (Willis et al. 2010). Trees with complex branching may positively affect egg skein survival by favoring adequate entanglement, whereas trees with limited branching complexity may result in little or no entanglement, resulting in reduced skein survival. Yet, little is known regarding how habitat complexity affects the deposition or survival of Yellow Perch skeins, which has implications for habitat enhancements that are designed to benefit Yellow Perch reproduction. Therefore, determining the types of spawning habitat that are preferred by Yellow Perch and how those preferences affect egg survival are critical to maximizing habitat enhancements and developing self-sustaining populations.

Our overarching objective was to evaluate the deposition and survival of Yellow Perch egg skeins as a function of coniferous tree complexity. We had two specific research questions: (1) do Yellow Perch select certain tree complexities to deposit their skeins, and (2) does tree complexity influence skein survival? Insights from this research will provide valuable information for fisheries managers who are introducing coarse woody habitat to an aquatic system to benefit Yellow Perch populations.

METHODS

Study system.—Dickcissell Lake is a 5.3-ha small impoundment located in Boone County, Iowa, USA. Dickcissell Lake has a gradually sloping shoreline, a mean depth of 2.3 m, and a maximum depth of 3.7 m, and it lies in a watershed that primarily consists of agriculture. The lake contains a limited amount of coarse woody habitat that was introduced by the Iowa Department of Natural Resources (Iowa DNR) over the past 10 years. The predominant aquatic vegetation in Dickcissell Lake is coontail *Ceratophyllum demersum*, but sago pondweed *Stuckenia pectinata* and muskgrass *Chara* spp. are also present. Game fish include Yellow Perch, Largemouth

Bass *Micropterus salmoides*, and Channel Catfish *Ictalurus punctatus*.

Habitat additions.—In February 2020, we placed 30 eastern red cedar *Juniperus virginiana* trees (hereafter, “trees”) on the ice at Dickcissell Lake for the habitat addition. We harvested trees from nearby public land that ranged from 2.1 to 2.4 m in height and from 1.1 to 1.4 m in width at their widest points. After harvest, the trees were manipulated with a chainsaw to five different complexities ranging from 1 as the least complex (all branches removed) to 5 as the most complex (all primary and secondary branches remaining; the classification was adapted from Mallory et al. 2000; Wagner et al. 2015; Figure 1). We placed the trees in groups of two of the same complexity level (1–5), resulting in 15 tree groups (experimental unit) and three replicates per treatment (complexity level). The locations for the tree groups were predetermined using ArcGIS 10 (version 2.0.20) by converting a polyline circle to 15 equidistant points within the littoral zone (Gorr and Kurland 2013), establishing 15 tree groups around the inside perimeter of the lake. The tree group locations around the lake were used to account for the demic structure of Yellow Perch populations (Aalto and Newsome 1989, 1993), and tree groups rather than individual trees were used to allow for a higher probability of encounter (Hanchin et al. 2003). We placed all of the tree groups in 1.8 m of water to mitigate the negative effects of solar radiation on skein survival (Williamson et al. 1997; Huff et al. 2004) and to eliminate depth as a confounding factor. Depth was determined by using an ice flasher (Humminbird Ice 35) after cutting a hole in the ice with an auger. We adjusted the tree groups from the predetermined location to find the correct depth by traveling perpendicular to the shoreline until the desired depth was located. Due to the homogenous slope of the lake bottom, we only adjusted seven of the tree groups from the original locations, with a 3.1-m maximum adjustment distance. We anchored the trees with a 41 × 20 cm (~16 kg) cinder block that was attached to their base with 9-gauge galvanized fencing wire and spaced them 1.5 m apart at their widest points to avoid overlapping branches or the potential loss of available spawning habitat. We randomly assigned tree complexities to each tree groups location.

Snorkeling and skein survival estimates.—Snorkeling took place when the water temperature reached 8°C (i.e., the lower limit of spawning temperature for Yellow Perch; Craig 2000) and occurred every 2 d from March 31, 2020, to May 5, 2020. Snorkeling did not occur from April 13, 2020, to April 20, 2020, due to cold water temperatures (5.9–7.1°C). On each snorkeling occasion, we visually inspected all of the trees for skeins. If we found a new skein, it was marked by attaching a numbered binder clip to a branch in close proximity, making each skein individually identifiable for the remainder of the spawning

season. Viability estimates (the percentage of viable eggs) continued throughout all of the snorkeling occasions until embryonic development had reached terminus. We estimated skein viability as the percentage of viable eggs remaining in the skein (nearest 10%), which was determined by a visual observation while snorkeling. We considered milky or opaque eggs to be dead and transparent eggs to be viable (Hart et al. 2006). One individual conducted all of the snorkeling surveys to mitigate issues pertaining to inherent human variability of viability estimates.

Statistical analyses.—The selection of tree complexities for egg skein deposition was determined by using a modified version of the linear food selection index (L ; Strauss 1979) that substitutes habitat for fish diets (see Fisher et al. 1996). The index is calculated as

$$L = r_i - p_i,$$

where r_i is the proportion of tree groups with complexity i with skeins present, and p_i is the proportion of tree groups with complexity i available. The L value ranges from -1 to 1 , with 0 indicating neutral or random selection. Because we introduced equal proportions of habitat and did not compare them with other natural structures, the value of L ranges from -0.2 to 0.8 , with values below 0.3 indicating avoidance and above 0.3 indicating preference. Variance (s^2 ; Strauss 1979) of L was calculated as

$$s^2L = \frac{r_i(1 - r_i)}{n_r} + \frac{p_i(1 - p_i)}{n_p}.$$

Daily skein survival was analyzed with Program MARK (White and Burnham 1999), using a nest survival model (Dinsmore et al. 2002) to generate maximum likelihood estimates of daily survival rates. Although nest survival models were originally designed for avian research, fisheries researchers have implemented them to assess nest success of Smallmouth Bass *Micropterus dolomieu* in Lake Michigan (Kaemingk et al. 2011) and Ontario, Canada (Suski and Ridgway 2007). The nest survival models assume the following: (1) the nests are correctly aged when they are first encountered, (2) the nest fates are correctly determined, (3) the nest discovery and nest checks do not influence survival, (4) the nest fates are independent, and (5) there is homogeneity of daily nest survival rates (Dinsmore et al. 2002).

The nest survival models require that each “nest” (in this instance, an individual egg skein) be assigned success or failure on each sample date. In avian research, nest success is defined as ≥ 1 egg hatched regardless of clutch size (Dinsmore et al. 2002). However, it is more challenging to determine nest success for species that can produce



FIGURE 1. Images of trees that were introduced into Dickcissell Lake, Iowa, in February of 2020 that were manipulated to five complexities: **(A)** complexity 1 = branches and twigs completely absent, few or no stubs remaining of main branches; **(B)** complexity 2 = almost all branches absent, remaining primary branches are only stubs with twigs absent; **(C)** complexity 3 = most primary and all secondary branches absent, some stubs and parts of primary branches remain, twigs absent; **(D)** complexity 4 = most primary and secondary branches remain, some twigs remain; and **(E)** complexity 5 = foliage remains, all primary and secondary branches remain, most twigs remain. The classification for structural complexity was adapted from Mallory et al. (2000) and Wagner et al. (2015).

millions of eggs in a single spawning event (Burton and Burton 2018). The results of research regarding in situ skein survival estimates for Yellow Perch are wide ranging (e.g., from 7.7% [Clady 1976] to $\geq 96\%$ survival [Williamson et al. 1997]), and skein viability estimates by

visual observations of a snorkeler are challenging. Therefore, a survival benchmark that produces a realistic standard for a snorkeler to correctly estimate is essential. We deemed all skeins that sustained viability estimates at 50% or more as successful and skeins that fell below 50%

survival as failures. We also evaluated survival benchmarks that were lower (30%) and higher (60%) than 50% to test how a range of success metrics affected our results. The model results at a benchmark of 30% skein survival were identical to those from models at the 50% benchmark. At 60% survival, the number of successful nests decreased to five, hindering our ability to construct more complex models containing tree complexities. However, despite the limited sample size, the top model from the 30% and the 50% benchmarks remained the same in this model set. Thus, we determined that a survival benchmark at 50% provided an accurate depiction of skein success and that egg skein survival thresholds had little effect on our ability to assess the effect of tree complexity.

Four sampling occasions over 7 d were missed due to cold water temperatures in the middle of the spawning season. This event may have caused a violation of the assumption of obtaining a correct age for each skein, as all of the skeins ($n=4$) that were deposited during this period could not be aged precisely and were consequently assigned an age of zero when they were discovered. This may have decreased the daily survival estimates for these skeins, as they may have been older than their assigned age. Additionally, three previously discovered skeins were found to be failures in the snorkeling survey following the missed sampling occasions. The nest survival models use the probability of surviving between intervals ($1-S$) to estimate the daily survival of failed nests (Dinsmore et al. 2002). With the time interval between sampling occasions extended, the daily survival estimates for these three skeins may have been biased high. To evaluate the potential effects of the missed sampling occasions on model order and skein survival estimates, alternative input files containing different assigned ages (4- and 7-d change) for the skeins in question were created and used to rerun all models in Program MARK. After rerunning all of the models with the new input files, the most supported model was unchanged and the discrepancy in survival estimates were negligible (≤ 0.01). Therefore, we believe the missed sampling occasions had a minimal influence on our results.

We developed a set of a priori hypotheses to evaluate factors that may influence the survival rates of Yellow Perch skeins. The factors included groups of five complexities of introduced trees (1 = least complex [Com 1], 5 = most complex [Com 5]), time (t), and constant survival (\cdot). Once the most supported model was established, we calculated skein survival for a documented incubation period that was similar to our sampling duration (27 d; Mansueti 1964; Craig 2000) by exponentiation of the daily survival rate by 27. Next, we used the delta method to calculate 95% confidence intervals for the point estimate (Powell 2007). Competing hypotheses were stated as models using the logit link function and compared using Akaike's information criterion corrected for small sample size (AIC_c ;

Burnham and Anderson 1998), ΔAIC_c , model weight (W_i), model likelihood, number of parameters (K), and deviance.

RESULTS

Skein Deposition Selectivity

Across all groups and tree complexities, 35 Yellow Perch skeins were observed (complexity 1 tree groups = 1 skein, complexity 2 tree groups = 3 skeins, complexity 3 tree groups = 10 skeins, complexity 4 tree groups = 11 skeins, and complexity 5 tree groups = 10 skeins). The mean number of skeins per tree group ranged from 3.7 ($\pm 95\%$ CI = 3.0 to 4.3) for tree complexity 4 to 0.3 ($\pm 95\%$ CI = 0 to 1.0) for tree complexity 1 (Figure 2). Yellow Perch displayed selection for tree complexities 4 and 5 but used tree complexities 1, 2, and 3 in proportion to their abundance (Figure 3).

Skein Survival

A total of 9 (26%) of the 35 observed skeins remained at or above the 50% threshold and were successful (Table 1). The majority (five skeins; 56%) of successful skeins were deposited on complexity 4 tree groups, with three (33%) successful skeins on complexity 3 groups, and one (11%) on complexity 5 groups (Table 1). Yellow Perch deposited skeins throughout the sampling period (Table 1).

A total of 15 candidate models were evaluated comparing the effects of tree complexity on the daily survival of Yellow Perch skeins (Table 2). Three models had ΔAIC_c values that were less than 2.0 and w_i greater than 0.12,

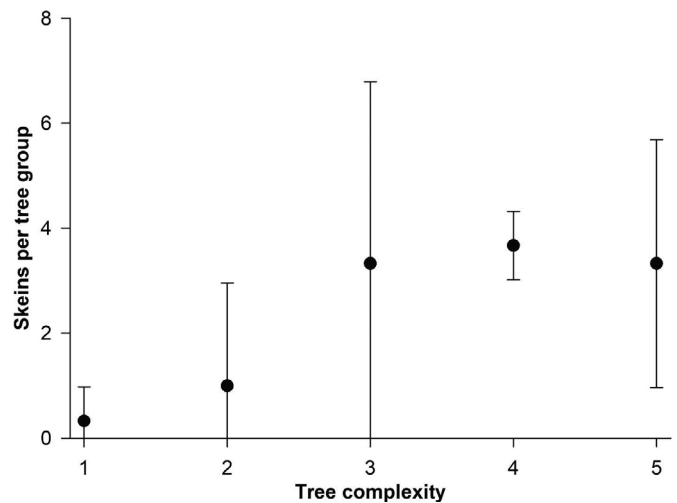


FIGURE 2. Mean ($\pm 95\%$ CI) number of Yellow Perch skeins deposited on introduced tree groups that were manipulated to five complexities (e.g., 1 = least complex, 5 = most complex) in Dickcissel Lake, Iowa, from March 31 to May 5, 2020.

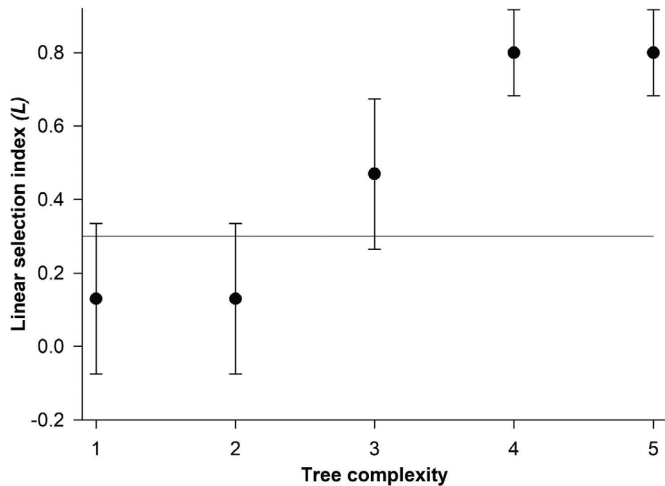


FIGURE 3. The linear selection index (L ; $\pm 95\%$ CI) for Yellow Perch from March 31 to May 5, 2020, for five tree complexities (e.g., 1 = least complex, 5 = most complex) that were introduced into Dickcissell Lake, Iowa. A value < 0.3 indicates avoidance, a value > 0.3 indicates preference, and 0.3 (noted by horizontal line) indicates neutral or random selection.

providing similar levels of support in explaining skein survival (Table 2). Models 4 through 15 contained ΔAIC_c values greater than 3.0 and w_i less than 0.07, indicating little support (Table 2). The most supported model indicated that skeins that were deposited on tree complexities 1, 2, and 5 (hereafter, referred to as “low and high tree complexities”) had lower daily survival rates than did skeins that were deposited on tree complexities 3 and 4 (hereafter, referred to as “intermediate tree complexities”); $\beta = -1.29$; 95% CI = -2.32 to -0.27). The second-ranked model ($\Delta AIC_c = 1.86$) suggested that skeins that were deposited on the low and high tree complexities ($\beta = -1.40$; 95% CI = -2.58 to -0.28) and complexity 3 ($\beta = -0.37$; 95% CI = -2.10 to 1.35) had lower daily skein survival than complexity 4; however, the effect size for complexity 3 was small and the slope was not different from zero. Finally, the third-ranked model ($\Delta AIC_c = 1.93$) indicated that skeins that were deposited on tree complexities 1 and 2 had lower daily survival than those deposited on complexity 5 ($\beta = -0.25$; 95% CI = -1.67 to 1.18); however, the effect size was small and the slope was not different from zero. Model 3 also suggested that skeins that were laid on intermediate tree complexities had higher daily survival than those that were laid on complexity 5 ($\beta = 1.23$; 95% CI = 0.14 to 2.33).

Based on estimates from the top-ranked model, the daily survival rate for skeins that were deposited on low and high tree complexities was 0.91 (95% CI = 0.84 to 0.95), while that for skeins that were deposited on intermediate tree complexities was 0.97 (95% CI = 0.94 to 0.99). The differences in daily survival estimates were

amplified for cumulative skein survival to the 27-d incubation period. For instance, cumulative 27-d survival for skeins that were deposited on low and high tree complexities was 0.07 (95% CI = 0.06 to 0.08), while cumulative survival of skeins that were deposited on intermediate tree complexities was 0.48 (95% CI = 0.43 to 0.52).

DISCUSSION

Understanding the effectiveness of introduced habitat can guide management decisions to be more productive, both ecologically and economically. Our results indicate that the structural complexity of trees influenced both skein deposition and egg survival in Yellow Perch. Information regarding selection for and survival of skeins on introduced habitat in Yellow Perch provides insight into the most efficacious manner to administer habitat additions that are directed at improving spawning success.

Tree complexity influenced the selection of spawning habitat by Yellow Perch. The mean number of deposited skeins was 3 to 11 times greater for intermediate and high-complexity tree groups than for low-complexity tree groups. Furthermore, the linear selection index indicated that Yellow Perch selected for intermediate- and high-complexity tree groups but not for low-complexity tree groups. The number of deposited Yellow Perch skeins can vary from 0.13 skeins per tree (Day 1983; Hanchin et al. 2003; Mangan et al. 2005) to 5.4 skeins per tree (Fisher 1996; Mangan et al. 2005). This is comparable to the mean number of skeins that we observed on our tree groups. Additionally, Eurasian Perch *Perca fluviatilis* deposits skeins on complex structures rather than other available substrates (Snickars et al. 2010; Čech et al. 2011; Westrelin et al. 2018). This range in observed skein deposition in the current and existing research suggests that Yellow Perch are selective when they are choosing spawning structures and appropriate structures can considerably increase deposition on suitable habitat. That Yellow Perch displayed increased selection for complex trees in our study suggests an affinity for more complicated structures. Therefore, the addition of complex trees may increase the selection of introduced habitat by Yellow Perch, potentially leading to increased reproductive success that accomplishes the objective of introduced habitat.

Despite a preference for depositing skeins on complex trees, our most supported model indicated that daily and cumulative survival rates for skeins that were deposited on trees of the highest complexity were similar to survival on the least complex trees and lower than skeins that were deposited on intermediate tree complexities. Although the second- and third-ranked models contained alternative complexity groupings from the top model, both support the findings of the top model as indicated by the non-significant beta estimates among groups. Decreased

TABLE 1. Estimated skein viability on introduced cedar trees for Yellow Perch in Dickcissel Lake, Iowa, from March 31 to May 5, 2020, as a function of tree complexity group and sample day. A 50% viability benchmark deemed skeins a success (S) or failure (F) after their last observation. An X indicates that a skein that is not yet observed or a missed sampling occasion (days 15–21).

Skein ID	Complexity group	Sample day																		
		1	3	5	7	9	11	13	15	17	19	21	23	25	27	29	31	33	35	37
1311	1	X	X	X	X	X	X	X	X	X	X	X	70	0	F	F	F	F	F	F
111	2	X	X	X	X	X	X	X	X	X	X	X	90	90	80	70	50	30	F	F
112	2	X	X	X	X	X	X	X	X	X	X	X	90	90	80	80	70	20	F	F
121	2	100	90	90	80	80	80	80	X	X	X	X	20	F	F	F	F	F	F	F
211	3	X	X	100	90	80	70	70	X	X	X	X	70	70	70	S	S	S	S	S
212	3	X	X	X	X	X	X	X	X	X	X	X	90	60	60	S	S	S	S	S
221	3	X	X	X	X	X	100	90	X	X	X	X	80	80	80	60	60	50	40	F
223	3	X	X	X	X	X	X	X	X	X	X	X	X	80	80	80	0	F	F	F
1111	3	100	90	90	90	0	F	F	F	F	F	F	F	F	F	F	F	F	F	F
1112	3	90	90	90	90	90	80	80	X	X	X	X	80	50	40	F	F	F	F	F
1113	3	X	100	90	90	90	90	90	X	X	X	X	70	50	30	F	F	F	F	F
1114	3	X	X	X	X	100	100	80	X	X	X	X	60	50	50	S	S	S	S	S
1121	3	X	100	90	90	80	80	70	X	X	X	X	60	50	40	F	F	F	F	F
1122	3	X	X	X	100	80	80	80	X	X	X	X	80	70	40	F	F	F	F	F
311	4	X	X	100	90	90	90	80	X	X	X	X	70	50	50	S	S	S	S	S
312	4	X	X	X	X	90	90	90	X	X	X	X	80	80	80	70	60	60	40	F
321	4	X	X	100	80	70	0	F	F	F	F	F	F	F	F	F	F	F	F	F
322	4	X	X	X	X	X	X	90	X	X	X	X	60	60	60	0	F	F	F	F
1011	4	X	X	X	90	80	80	80	X	X	X	X	70	70	70	50	S	S	S	S
1021	4	90	90	90	90	80	80	70	X	X	X	X	60	60	40	F	F	F	F	F
1022	4	X	90	90	90	90	90	80	X	X	X	X	60	60	50	S	S	S	S	S
1411	4	X	X	X	X	X	X	X	X	X	X	X	X	50	50	40	30	30	20	F
1421	4	X	100	90	90	80	70	70	X	X	X	X	70	60	60	S	S	S	S	S
1422	4	X	X	100	100	70	70	70	X	X	X	X	70	70	60	S	S	S	S	S
1423	4	X	X	X	100	90	80	70	X	X	X	X	70	60	10	F	F	F	F	F
611	5	X	X	100	90	90	90	90	X	X	X	X	80	80	40	F	F	F	F	F
612	5	X	X	X	100	100	90	90	X	X	X	X	20	F	F	F	F	F	F	F
621	5	X	X	X	100	90	80	0	F	F	F	F	F	F	F	F	F	F	F	F
622	5	X	X	X	X	100	90	90	X	X	X	X	80	70	70	60	40	10	F	F
911	5	80	70	70	70	70	70	70	X	X	X	X	0	F	F	F	F	F	F	F
912	5	X	90	80	20	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F
913	5	X	90	80	80	70	70	70	X	X	X	X	0	F	F	F	F	F	F	F
914	5	X	X	X	X	X	X	X	X	X	X	X	X	X	100	90	80	80	50	10
921	5	100	0	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F
1521	5	X	X	X	X	X	X	X	X	X	X	X	90	80	70	70	S	S	S	S

survival on low tree complexities may be explained by the position of the trees in the water column. Low-complexity tree groups lacked the primary and secondary branching that elevated the more complex trees above the substrate. The majority of each low-complexity tree group was close to the lake bottom. This absence of separation resulted in large portions of deposited skeins on low-complexity trees that were lying directly on the substrate rather than the tree. Yellow Perch skeins that were deposited on the lake bottom displayed lower survival than did those that were

deposited on vegetation (Smith et al. 2001), likely due to decreased oxygen levels from siltation or infection by microorganisms (Wootton 1998).

The skeins that were deposited on the most complex trees did not suffer the aforementioned issues of bottom contact, but they still displayed lower survival than did those that were deposited on intermediate tree complexities. Although the mechanism is different, skeins that were laid on tree complexity 5 may have also incurred egg mortality that was associated with oxygen depletion. For the

TABLE 2. Nest survival models used to estimate survival (S) of Yellow Perch egg skeins in Dickcissell Lake, Iowa, from March 31, 2020, to May 5, 2020, using 50% egg skein survival as the nest success benchmark. The effects included groups of five complexities of introduced trees (1 = least complex, 5 = most complex; Com 1, Com 2, Com 3, Com 4, Com 5), time (t), and constant survival (.). The model comparisons were based on AIC_c , ΔAIC_c , model weight (W_i), model likelihood, number of parameters (K), and deviance; vs. = versus.

Model	AIC_c	ΔAIC_c	W_i	Model likelihood	K	Deviance
$S(\text{Com } 1 = 2 = 5 \text{ vs. Com } 3 = 4)$	96.40	0.00	0.33	1.00	2	92.36
$S(\text{Com } 1 = 2 = 5 \text{ vs. Com } 3 \text{ vs. Com } 4)$	98.26	1.86	0.13	0.39	3	92.19
$S(\text{Com } 1 = 2 \text{ vs. Com } 3 = 4 \text{ vs. Com } 5)$	98.32	1.93	0.13	0.38	3	92.25
$S(\text{Com } 1 = 2 = 3 = 4 \text{ vs. Com } 5)$	99.56	3.17	0.07	0.21	2	95.53
$S(\text{Com } 1 = 2 \text{ vs. Com } 3 = 5 \text{ vs. Com } 4)$	99.80	3.40	0.06	0.18	3	93.73
$S(\text{Com } 1 = 2 = 3 \text{ vs. Com } 4 \text{ vs. Com } 5)$	99.81	3.41	0.06	0.18	3	93.74
$S(\text{Com } 1 = 2 \text{ vs. Com } 3 \text{ vs. Com } 4 \text{ vs. Com } 5)$	100.20	3.80	0.05	0.15	4	92.07
$S(.)$	100.82	4.43	0.04	0.11	1	98.81
$S(\text{Com } 1 = 2 = 3 = 4 = 5)$	100.82	4.43	0.04	0.11	1	98.81
$S(\text{Com } 1 = 2 \text{ vs. Com } 3 = 4 = 5)$	101.15	4.76	0.03	0.09	2	97.12
$S(\text{Com } 1 = 2 = 4 \text{ vs. Com } 3 = 5)$	101.21	4.82	0.03	0.09	2	97.18
$S(\text{Com } 1 = 2 = 4 \text{ vs. Com } 3 \text{ vs. Com } 5)$	101.60	5.20	0.02	0.07	3	95.52
$S(\text{Com } 1 = 2 = 3 \text{ vs. Com } 4 = 5)$	102.66	6.26	0.01	0.04	2	98.62
$S(\text{Com } 1 = 2 \text{ vs. Com } 4 = 5 \text{ vs. Com } 3)$	103.04	6.64	0.01	0.04	3	96.96
$S(t)$	117.41	21.02	0.00	0.00	16	83.61

eggs to be properly oxygenated, Yellow Perch skeins should be completely extended to limit overlap (Treasurer 1983). The most complex trees contain many primary and secondary branches that may have prohibited the skeins from fully extending. We hypothesize that this may have caused the skeins to crease, creating areas that were not properly oxygenated, and increased egg mortality. Ward and Barnes (2020) observed a 52% decrease in Yellow Perch egg survival when the skeins were overlaid on the bottom of a 1.89-L bucket rather than supported by artificial vegetation. Consequently, decreases in skein survival that are potentially caused by depleted oxygen supply may be the result of trees that are either lacking or have an overabundance of complexity, creating a Goldilocks effect (Katz et al. 2012; Lane 2016). Therefore, skein survival may be maximized with habitat containing an intermediate amount of interstitial space.

Beyond wood, Yellow Perch often deposit their skeins on aquatic vegetation and other natural habitat (Scott and Crossman 1973), but we did not compare skein deposition and survival between natural and introduced structures. *Perca* spp. have displayed tendencies to prefer hard and complex structures for depositing their skeins (Čech et al. 2009). However, the dominant vegetation in Dickcissell Lake is coontail, which does not have a rigid stalk to adequately support skeins. Furthermore, coontail was only present in the shallow areas (<1 m) of the lake, far from all tree groups, minimizing any potential biotic or abiotic factors that may have affected skein deposition site or survival.

In the current study, we observed preferences for skein deposition and increased skein survival on particular

complexities of introduced habitat. Although this information is beneficial for managers who are considering habitat introductions, it does not provide evidence of an increase in Yellow Perch reproduction or recruitment. Several biotic and abiotic factors affect Yellow Perch survival in the early life stages (e.g., Sanderson et al. 1999; Dembkowski et al. 2017), and we did not monitor past the egg stage. Furthermore, because we did not monitor reproduction in the Yellow Perch population in Dickcissell Lake over several years, we do not know whether the addition of habitat increased total spawning effort or simply changed the locations of skein deposition. However, suitable spawning structures and factors that contribute to increased skein survival are critical to understand when introducing habitat. Finally, even egg skeins with <50% survival that were deemed mortalities in our survival analysis still had the potential to produce thousands of larvae that may substantially contribute to recruitment. Nonetheless, the 50% survival benchmark for determining egg skein survival still provided a meaningful metric that allowed us to compare skein survival among the tree complexities.

Maximizing the benefits of tree introductions for the reproduction Yellow Perch requires an understanding of tree decomposition rates and the establishment of appropriate timelines to replace deficient habitat when it is necessary. Morphological and chemical tree characteristics result in contrasting decomposition rates when they are introduced into aquatic systems (Bilby et al. 1999). For instance, recycled conifer trees (e.g., Christmas trees) lost needles and fine branching after 1 year of submersion in a Texas reservoir (Daugherty et al. 2014), whereas the life

span of immersed conifer trees in Idaho reservoirs is reported to be 4 to 7 years (Mabbott 1991). Furthermore, introduced conifer trees deteriorated to an intermediate complexity after 5 years and to a low complexity after 10 years of submersion in a small impoundment in South Dakota (Willis et al. 2010). Our results suggest that managers should routinely monitor and replace habitat when it falls below an intermediate complexity. Therefore, available tree species that display prolonged longevity when they are submerged may be preferred for the purpose of increasing spawning habitat abundance for Yellow Perch.

ACKNOWLEDGMENTS

We thank B. Dodd and A. Otting of the Iowa Department of Natural Resources Boone Fisheries Management office for assistance with study consideration and field work. Funding for this project was provided by the Iowa State University Experiment Station (Project 3815). There is no conflict of interest declared in this article.

ORCID

Stephen J. Grausgruber  <https://orcid.org/0000-0003-2601-7313>

Michael J. Weber  <https://orcid.org/0000-0003-0430-3087>

Joseph E. Morris  <https://orcid.org/0000-0002-6910-070X>

REFERENCES

- Aalto, S. K., and G. E. Newsome. 1989. Evidence of demic structure for a population of Yellow Perch (*Perca flavescens*). *Canadian Journal of Fisheries and Aquatic Sciences* 46:184–190.
- Aalto, S. K., and G. E. Newsome. 1993. Winds and the demic structure of a population of Yellow Perch (*Perca flavescens*). *Canadian Journal of Fisheries and Aquatic Sciences* 50:496–501.
- Baily, K. M., and E. D. Houde. 1989. Predation on eggs and larvae of marine fishes and the recruitment problem. *Advances in Marine Biology* 25:1–83.
- Bardonnnet, A., and J. L. Baglinière. 2000. Freshwater habitat of Atlantic Salmon (*Salmo salar*). *Canadian Journal of Fisheries and Aquatic Sciences* 57:479–506.
- Barletta, M., A. J. Jaureguizar, C. Baigun, N. F. Fontoura, A. A. Agostinho, V. M. F. Almeida-Val, A. L. Val, R. A. Torres, L. F. Jimenes-Segura, T. Giarrizzo, N. N. Fabré, V. S. Batista, C. Lasso, D. C. Taphorn, M. F. Costa, P. T. Chaves, J. P. Vieira, and M. F. M. Corrêa. 2010. Fish and aquatic habitat conservation in South America: a continental overview with emphasis on neotropical systems. *Journal of Fish Biology* 76:2118–2176.
- Bernhardt, E. S., M. A. Palmer, J. D. Allan, G. Alexander, K. Barnas, S. Brooks, J. Carr, S. Clayton, C. Dahm, J. Follstad-Shah, D. Galat, S. Gloss, P. Goodwin, D. Hart, B. Hassett, R. Jenkinson, S. Katz, G. M. Kondolf, P. S. Lake, R. Lave, J. L. Meyer, T. K. O'Donnell, L. Pagano, B. Powell, and E. Sudduth. 2005. Synthesizing U.S. river restoration efforts. *Science* 308:636–637.
- Bilby, R. E., J. T. Heffner, B. R. Fransen, J. W. Ward, and P. A. Bisson. 1999. Effects of immersion in water on deterioration of wood from five species of trees used for habitat enhancement projects. *North American Journal of Fisheries Management* 19:687–695.
- Burnham, K. P., and D. A. Anderson. 1998. *Model selection and inference*. Springer-Verlag, New York.
- Burton, D., and M. Burton. 2018. *Essential fish biology*. Oxford University Press, Oxford, UK.
- Carlander, K. D. 1997. *Handbook of freshwater fishery biology*, volume 3: life history data on ichthyopercid and percid fishes of the United States and Canada. Iowa State University Press, Ames.
- Čech, M., J. Peterka, and M. Říha. 2009. Distribution of egg strands of Perch (*Perca fluviatilis* L.) with respect to depth and spawning substrate. *Hydrobiologia* 630:105–114.
- Čech, M., J. Peterka, M. Říha, M. Muška, J. Hejzlar, and J. Kubečka. 2011. Location and timing of the deposition of egg strands by Perch (*Perca fluviatilis* L.): the roles of lake hydrology, spawning substrate and female size. *Knowledge and Management of Aquatic Ecosystems* 403:article 08.
- Clady, M. D. 1976. Influence of temperature and wind on the survival of early stages of Yellow Perch, *Perca flavescens*. *Journal of the Fisheries Research Board of Canada* 33:1887–1893.
- Clady, M. D., and B. Hutchinson. 1975. Effects of high winds on eggs of Yellow Perch in Oneida Lake, New York. *Transactions of the American Fisheries Society* 104:524–525.
- Claramunt, R. M., J. L. Jonas, J. D. Fitzsimons, and J. E. Marsden. 2005. Characteristics and interstitial predators on Lake Trout egg deposition and mortality. *Transactions of the American Fisheries Society* 134:1048–1057.
- Craig, J. F. 2000. *Percid fishes: systematics, ecology and exploitation*. Blackwell Science, Oxford, UK.
- Dahlberg, M. D. 1979. A review of survival rates of fish eggs and larvae in relation to impact assessments. *Marine Fisheries Review* 41(3):1–12.
- Daugherty, D. J., M. T. Driscoll, D. E. Ashe, and J. W. Schlechte. 2014. Effects of structural and spatiotemporal factors on fish use or artificial habitat in a Texas reservoir. *North American Journal of Fisheries Management* 34:453–462.
- 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, Federal Aid in Sport Fish Restoration Project F-29-R-20 through R-22, Study 13, Final Report, Columbus.
- Dembkowski, D. J., M. J. Weber, and M. R. Wuellner. 2017. Factors influencing recruitment and growth of age-0 Yellow Perch in eastern South Dakota glacial lakes. *Fisheries Ecology and Management* 24:372–381.
- Dinsmore, S. J., G. C. White, and F. L. Knopf. 2002. Advanced techniques for modeling avian nest survival. *Ecology* 83:3476–3488.
- Dombeck, M. P., B. W. Menzel, and P. N. Hinz. 1984. Muskellunge spawning habitat and reproductive success. *Transactions of the American Fisheries Society* 113:205–216.
- Edsall, T. A., G. W. Kennedy, and W. H. Horns. 1993. Distribution, abundance, and resting microhabitat of Burbot on Julian's Reef, southwestern Lake Michigan. *Transactions of the American Fisheries Society* 122:560–574.
- Fisher, S. J. 1996. Early life history of Yellow Perch in eastern South Dakota lakes. Master's thesis. South Dakota State University, Brookings.
- Fisher, S. J., K. L. Pope, L. T. Templeton, and D. W. Willis. 1996. Yellow Perch spawning habits in Pickerel Lake, South Dakota. *The Prairie Naturalists* 28:65–75.
- Fitzsimons, J. D. 1995. Assessment of Lake Trout spawning habitat and egg deposition and survival in Lake Ontario. *Journal of Great Lakes Research* 21:337–347.
- Geiling, W. D., J. R. M. Kelso, and E. Iwachewski. 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. *Canadian Journal of Fisheries and Aquatic Sciences* 53:79–87.
- Gorr, W. L., and K. S. Kurland. 2013. GIS tutorial 1: basic workbook. Esri Press, Redlands, California.
- Gosch, N. J. C., Q. E. Phelps, and D. W. Willis. 2006. Habitat characteristics at Bluegill spawning colonies in a South Dakota glacial lake. *Ecology of Freshwater Fish* 15:464–469.
- Haddy, J. A., and N. W. Pankhurst. 2000. The effects of salinity on reproductive development, plasma steroid levels, fertilization and egg survival in Black Bream *Acanthopagrus butcheri*. *Aquaculture* 188:115–131.
- Hanchin, P. A., D. W. Willis, and T. R. St. Sauver. 2003. Influence of introduced spawning habitat on Yellow Perch reproduction in Lake Madison, South Dakota. *Journal of Freshwater Ecology* 18:291–297.
- Hart, S. D., D. L. Garling, and J. A. Malison. 2006. Yellow Perch (*Perca flavescens*) culture guide. Iowa State University, North Central Regional Aquaculture Center, NCRAC Culture Series 103, Ames.
- Henderson, B. A. 1985. Factors affecting growth and recruitment of Yellow Perch, *Perca flavescens* Mitchell, in South Bay, Lake Huron. *Journal of Fish Biology* 26:449–458.
- Herb, W. R., L. B. Johnson, P. C. Jacobson, and H. G. Stefan. 2014. Projecting cold-water fish habitat in lakes of the glacial lakes region under changing land use and climate regimes. *Canadian Journal of Fisheries and Aquatic Sciences* 71:1334–1348.
- Hickford, M. J. H., M. Cagnon, and D. R. Schiel. 2010. Predation, vegetation and habitat-specific survival of terrestrial eggs of a diadromous fish, *Galaxias maculatus* (Jenyns, 1842). *Journal of Experimental Marine Biology and Ecology* 385:66–72.
- Huff, D. D., G. Grad, and C. E. Williamson. 2004. Environmental constraints on spawning depth of Yellow Perch: the roles of low temperature and high solar ultraviolet radiation. *Transactions of the American Fisheries Society* 133:718–726.
- Kaemingk, M. A., A. Clem, and T. L. Galarowicz. 2011. The influence of habitat and environment on Smallmouth Bass (*Micropterus dolomieu*) nest sites and nest success in northern Lake Michigan. *Journal of Great Lakes Research* 37:380–385.
- Katz, G. L., M. W. Denslow, and J. C. Stromberg. 2012. The Goldilocks effect: intermittent streams sustain more plant species than those with perennial or ephemeral flow. *Freshwater Biology* 57:467–480.
- Kondolf, G. M., and M. G. Wolman. 1993. The sizes of salmonid spawning gravels. *Water Resources Research* 29:2275–2285.
- Kovalenko, K. E., S. M. Thomaz, and D. M. Warfe. 2012. Habitat complexity: approaches and future directions. *Hydrobiologia* 685:1–17.
- Lane, P. A. 2016. A cautionary tale: the Goldilocks' effect in measuring ecological complication in food webs. *Food Webs* 8:1–11.
- Lapointe, N. W. R., S. J. Cooke, J. G. Imhof, D. Boisclair, J. M. Casselman, R. A. Curry, O. E. Langer, R. L. McLaughlin, C. K. Minns, J. R. Post, M. Power, J. B. Rasmussen, J. D. Reynolds, J. S. Richardson, and W. M. Tonn. 2014. Principles for ensuring healthy and productive freshwater ecosystems that support sustainable fisheries. *Environmental Reviews* 22:110–134.
- Lusk, R. D., M. J. Otto, and J. W. Neal. 2012. Considerations for building small impoundments. Pages 23–47 in J. W. Neal and D. W. Willis, editors. *Small impoundments management in North America*. American Fisheries Society, Bethesda, Maryland.
- Mabbott, L. B. 1991. Artificial habitat for warmwater fish in two reservoirs in southern Idaho. U.S. Forest Service General Technical Report RM-207.
- Mallory, E. C., M. S. Ridgway, A. M. Gordon, and N. K. Kaushik. 2000. Distribution of woody debris in a small headwater lake, central Ontario, Canada. *Archiv Fur Hydrobiologie* 148:587–606.
- Mangan, M. T., M. L. Brown, and T. R. St. Sauver. 2005. Yellow Perch use of introduced spawning habitat. *Journal of Freshwater Ecology* 20:381–388.
- Mansueti, A. J. 1964. Early life development of the Yellow Perch, *Perca flavescens*. *Chesapeake Science* 5:46–66.
- Marsden, J. E., and C. C. Krueger. 1991. Spawning by hatchery-origin Lake Trout (*Salvelinus namaycush*) in Lake Ontario: data from egg collections, substrate analysis, and diver observations. *Canadian Journal of Fisheries and Aquatic Sciences* 48:2377–2384.
- Moyle, P. B., and J. J. Cech. 2016. *Fishes*. Pearson, Noida, India.
- Nohner, J. K., and J. S. Diana. 2014. Muskellunge spawning site selection in northern Wisconsin lakes and a GIS-based predictive habitat model. *North American Journal of Fisheries Management* 35:141–157.
- Paradis, A. R., P. Pepin, and J. A. Brown. 1996. Vulnerability of fish eggs and larvae to predation: review of the influence of the relative size of prey and predator. *Canadian Journal of Fisheries and Aquatic Sciences* 53:1226–1235.
- Pepin, P. 1991. Effect of temperature and size on development, mortality, and survival rates of the pelagic early life history stages of marine fish. *Canadian Journal of Fisheries and Aquatic Sciences* 48:503–518.
- Phelps, Q. E., A. M. Lohmeyer, N. C. Wahl, J. M. Zeigler, and G. W. Whitley. 2011. Habitat characteristics of Black Crappie nest sites in an Illinois impoundment. *North American Journal of Fisheries Management* 29:189–195.
- Powell, L. A. 2007. Approximating variance of demographic parameters using the delta method: a reference for avian biologists. *The Condor* 109:949–954.
- Raabe, J. K., and M. A. Bozek. 2012. Quantity, structure, and habitat selection of natural spawning reefs by Walleyes in a north temperate lake: a multiscale analysis. *Transactions of the American Fisheries Society* 141:1097–1108.
- Reyes, M. R., H. H. Arzbach, and E. Braum. 1992. In situ development of perch eggs, *Perca fluviatilis* L. (Pisces, Percidae) in a small eutrophic lake, Lake Plussee, Holstein, Germany. *Internationale Revue Ergebnisse Hydrobiologie* 77:467–481.
- Robillard, S. R., and J. E. Marsden. 2001. Spawning substrate preferences of Yellow Perch along a sand-cobble shoreline in southwestern Lake Michigan. *North American Journal of Fisheries Management* 21:208–215.
- Roni, P., K. Hanson, and T. Beechie. 2008. Global review of the physical and biological effectiveness of stream habitat rehabilitation techniques. *North American Journal of Fisheries Management* 28:856–890.
- Rosenfeld, J., M. Porter, and E. Parkinson. 2000. Habitat factors affecting the abundance and distribution of juvenile Cutthroat Trout (*Oncorhynchus clarki*) and Coho Salmon (*Oncorhynchus kisutch*). *Canadian Journal of Fisheries and Aquatic Sciences* 57:766–774.
- Sanderson, B. L., T. R. Hrabik, J. J. Magnuson, and D. M. Post. 1999. Cyclic dynamics of a Yellow Perch (*Perca flavescens*) population in an oligotrophic lake: evidence for the role of intraspecific interactions. *Canadian Journal of Fisheries and Aquatic Sciences* 56:1534–1542.
- Sass, G. G., J. F. Kitchell, S. R. Carpenter, T. R. Hrabik, A. E. Marburg, and M. G. Turner. 2006. Fish community and food web responses to a whole-lake removal of coarse woody habitat. *Fisheries* 31:321–330.
- Scott, W. B., and E. J. Crossman. 1973. *Freshwater fishes of Canada*. Bulletin of the Fisheries Research Board of Canada 184.
- Smith, C., A. Douglas, and P. Jurajda. 2001. Oviposition site selection and embryo mortality in Perch. *Journal of Fish Biology* 58:880–882.
- Smokorowski, K. E., and T. C. Pratt. 2007. Effect of a change in physical structure and cover on fish and fish habitat in freshwater ecosystems: a review and meta-analysis. *Environmental Reviews* 15:15–41.
- Snickars, M., G. Sundblad, A. Sandström, L. Ljunggren, U. Bergström, G. Johansson, and J. Mattila. 2010. Habitat selectivity of substrate-spawning fish: modelling requirements for the Eurasian Perch *Perca fluviatilis*. *Marine Ecology Progress Series* 398:235–243.

- Steinhart, G. B., E. A. Marschall, and R. A. Stein. 2004. Round Goby predation on Smallmouth Bass offspring in nests during simulated catch-and-release angling. *Transactions of the American Fisheries Society* 133:121–131.
- Strauss, R. E. 1979. Reliability estimates for Ivlev's electivity index, the forage ratio, and a proposed linear index of food selection. *Transactions of the American Fisheries Society* 108:344–352.
- Suski, C. D., and M. S. Ridgway. 2007. Climate and body size influence nest survival in a fish with parental care. *Journal of Animal Ecology* 76:730–739.
- Taylor, J. J., T. Rytwinski, J. R. Bennett, K. E. Smokorowski, N. W. R. Lapointe, R. Janusz, K. Clarke, B. Tonn, J. C. Walsh, and S. J. Cooke. 2019. The effectiveness of spawning habitat creation or enhancement for substrate-spawning temperate fish: a systematic review. *Environmental Evidence* 8:19–50.
- Tokeshi, M., and S. Arakaki. 2012. Habitat complexity in aquatic systems: fractals and beyond. *Hydrobiologia* 685:27–47.
- Treasurer, J. W. 1983. Estimates of egg and viable embryo production in a lacustrine Perch, *Perca fluviatilis*, 1983. *Environmental Biology of Fishes* 8:3–16.
- Wagner, C. P., M. J. Weber, and D. H. Wahl. 2015. Structural complexity influences littoral coarse woody habitat selection by juvenile Muskellunge. *North American Journal of Fisheries Management* 35:14–19.
- Ward, M. J., and M. E. Barnes. 2020. Vegetation during incubation improves the hatching success of Yellow Perch eyed eggs. *International Journal of Innovative Studies in Aquatic Biology and Fisheries* 6(2):1–4.
- Ward, M. J., T. R. St. Sauver, D. O. Lucchesi, B. Johnson, K. Hoffman, and J. Stahl. 2012. Evaluation of three spawning techniques for Yellow Perch. *Proceedings of the South Dakota Academy of Science* 91:107–112.
- Westrelin, S., R. Roy, L. Tissot-Rey, L. Berges, and C. Argillier. 2018. Habitat use and preference of adult Perch (*Perca fluviatilis* L.) in a deep reservoir: variations with seasons, water levels and individuals. *Hydrobiologia* 809:121–139.
- White, G. C., and K. P. Burnham. 1999. Program MARK: survival estimation from populations of marked animals. *Bird Study* 46(Supplement 1):120–138.
- Williamson, C. E., S. L. Metzgar, P. A. Lovera, and R. E. Moeller. 1997. Solar ultraviolet radiation and the spawning habitat of Yellow Perch, *Perca flavescens*. *Ecological Applications* 7:1017–1023.
- Willis, D. W., R. D. Lusk, and J. W. Slipke. 2010. Farm ponds and small impoundments. Pages 501–544 in W. A. Hubert and M. C. Quist, editors. *Inland fisheries management in North America*. American Fisheries Society, Bethesda, Maryland.
- Wootton, R. J. 1998. *The ecology of teleost fishes*, 2nd edition. Kluwer, London.