AN ABSTRACT OF THE THESIS OF

Douglas S. Bateman for the degree of Master of Science in Fisheries Science presented on January 23, 1998. Title: A Comparison of Nest Site Selection and Reproductive Effort by Reticulate Sculpin (Cottus perplexus) in Two Streams of Different Geologies in the Central Coast Range of Oregon

Abstract approved: ________________________________

Hiram W. Li

Nest sites of reticulate sculpin (Cottus perplexus) were located in two stream reaches, one from a basalt basin and one from a sandstone basin. Stream reaches were similar in gradient, basin area, elevation, climate, and riparian vegetation but differed in biologic community structure and substrate characteristics. An electivity index was used to determine if selection for nest sites occurred and also to compare patterns of selection between habitat types and stream reaches. Eggs from nests were collected so comparisons in reproductive effort could be made between streams and habitat types.

Cobble sized substrate was positively elected in all habitat units examined and moderate embeddedness (6-25%) was positively elected in all units but one. No nests were found on bedrock, wood, or fine sediment substrate. A small number of nests were found on both larger gravel and boulder size particles. Only two out of 471 nests located were associated with rocks which were embedded 51% or more.
Reproductive effort on a per nest basis was greater in the basalt stream. Nest weights in the basalt stream exceeded nest weights in the sandstone stream by 90% (95% confidence interval 52-152%) on average and the number of eggs per nest was 39% (95% confidence interval 8-79%) greater in the basalt stream. Differences in reproductive effort per nest within an individual stream were not detected in comparisons among scour pools, riffles, high cobble density and low cobble density habitat units. Reproductive effort per nest varied through the sampling period with intermediate effort early, low effort in the mid portion and the highest effort late. This pattern was apparent in both streams but statistically significant in the sandstone stream only.

Nest densities were similar at 0.16 nest/m² and 0.17 nest/m² for the basalt and sandstone streams respectively. Differences in nest densities within streams were not detected between scour pools and riffles in either stream or between high and low cobble density units in the basalt stream. A difference was detected between high and low cobble density units in the sandstone stream (p=0.02). Nest densities were greater on average in the tailout portions of pools as opposed to the head and body portions in both streams but statistically significant in the sandstone stream only (p=0.04).

We speculate that because patterns of electivity were similar between streams and between different habitat types within a stream, all with different levels of habitat availability, that male fitness is tightly linked with habitat selection for nest sites. Our results would suggest that reticulate sculpin nest site selection and reproductive effort are not strongly influenced by habitat on a
geomorphic channel unit scale. It may be more appropriate to delineate sculpin habitat by substrate patches within geomorphic habitat units.
A Comparison of Nest Site Selection and Reproductive Effort by Reticulate Sculpin (Cottus perplexus) in Two Streams of Different Geologies in the Central Coast Range of Oregon

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Douglas S. Bateman

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Dean of Graduate School

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Douglas S. Bateman, Author
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A Comparison of Nest Site Selection and Reproductive Effort by Reticulate Sculpin (Cottus perplexus) in Two Streams of Different Geologies in the Central Coast Range of Oregon

CHAPTER 1

Introduction

Reticulate sculpin, Cottus perplexus, is a common part of the fish fauna throughout their distribution: Puget Sound south to the Rogue River and east to the Cascade Mountains of Oregon and Washington (Bond 1963, 1973). Information on factors which might limit production of reticulate sculpin is rare compared to the abundance of these fish throughout their range (Bond 1963, Krohn 1968, Finger 1982). In this thesis I investigate one potential limiting factor; habitat associated with reproduction.

Two papers are presented here as Chapters 2 and 3. In Chapter 2, I present results concerning variables associated with individual nest-sites and examine patterns of selection between scour pools and riffles and between high cobble and low cobble density units within and between the study reaches of the two streams. In Chapter 3, I present results on reproductive effort and nest densities on a habitat...
In Chapter 3, I present results on reproductive effort and nest densities on a habitat unit scale. Comparisons are made between scour pools and riffles and between high and low cobble density units within and between study reaches of the two streams. In Chapter 4, I record the major conclusions from Chapters 2 and 3.

This study began in the spring of 1995 with a preliminary field season. I surveyed many third order streams in the central Oregon Coast Range and determined the composition of the cottid community and species distributions. Study streams were subsequently selected from this group. Techniques for locating nests and determining nest densities were developed during this period, primarily in Cummins Creek, Lane County, Oregon. It was during my work in Cummins Creek, which has all four species of cottids occurring along the central Oregon Coast, that I realize the importance of investigating a single cottid species and establishing baseline information on behavior in allopatric conditions. It would be difficult to speculate whether observed behavior was a response to habitat quality or to a competitive interaction with another cottid without this information. The data reported here were gathered during the spring spawning season of 1996.
Chapter 2

Nest Site Selection by Reticulate Sculpin (*Cottus perplexus*) in Two Streams of Different Geologies in the Central Coast Range of Oregon

Douglas S. Bateman and Hiram W. Li
Abstract

Nest sites of reticulate sculpin were located in two stream reaches, one from a basalt basin and one from a sandstone basin. Stream reaches were similar in gradient, basin area, elevation, climate, and riparian vegetation but differed in biologic community structure and substrate availability. An electivity index was used to determine if selection occurred and also to compare patterns of selection between habitat types and stream reaches.

Strong positive selection was shown for moderately embedded cobble substrate in both stream reaches and all habitat types investigated. No nests were found on bedrock, wood, or particles smaller than large gravel. A small number of nests were found on both large gravel and boulder size particles. Only two out of 471 nests located were associated with rocks which were embedded 51% or more. No nests were located under rocks which were embedded by 75% or more.

Management activities which would result in decreased availability of moderately embedded cobble could potentially have detrimental effects on reticulate sculpin reproduction.
Introduction

The reticulate sculpin (*Cottus perplexus*) is an important component of fish communities in coastal streams of the Pacific Northwest. This fish is widely distributed and accounts for a large portion of total biomass and production in these streams (Krohn 1968; Bond 1963). It is commonly found in second and third order streams in association with species listed as sensitive, threatened, or endangered by states and the federal government such as coho salmon (*Oncorhynchus kisutch*) and anadromous, coastal cutthroat trout (*Oncorhynchus clarki*) (Bond 1963; Bond et al. 1988). Furthermore, the reticulate sculpin has a potential role as an ecological indicator of habitat quality in the freshwater environment of anadromous salmonids because its life cycle is entirely freshwater and they are a non-game species that is not subject to fishing pressure. Many elements of its life history and ecological interactions have been documented, e.g. temperature and dissolved oxygen requirements (Bond 1963), competition with invertebrates (Davis and Warren 1965), competition and predation with salmonids (Phillips and Claire 1966; Brocksen et al. 1968; Krohn 1968; Moyle 1977), predation and competition with other species of sculpin (Finger 1979), food habitats (Bond 1963; Pasch and Lyford 1972), age class structure (Bond 1963, Krohn 1968), fecundity and spawning period (Bond 1963; Patten 1971), and production (Davis and Warren 1965; Krohn 1968).
In general, cottids are iteroparous and polygynous with males actively guarding nest sites after spawning (Hann 1927; Bailey 1952; Bond 1963; Mousseau et al. 1987; Goto 1990, 1993). Spawning typically occurs during spring but has been reported to occur in the fall for some species (Bond 1963). Eggs are adhesive and usually deposited on the underside of a stone or some other solid substrate (Smith 1922; Simon and Brown 1943; Bailey 1952; Bond 1963; Millikan 1968). A quantitative study enumerating habitat available and habitat used for nesting is lacking and consequently habitat selected for nest sites by cottids in general and the reticulate sculpin specifically is poorly understood. It is also not well understood how differences in landscape elements such as topology, geology, and land use constrain availability of instream habitat and therefore nest site selection.

Cottids have been observed using a wide variety of substrates for nest sites (Bond 1963; Millikan 1968), but preferences between different substrate types has not be reported. Bond (1963) associated reticulate sculpin nests with rubble sized particles. The size of the object the eggs are attached to could be important for both stability and cover. If the nest is disturbed by high flows, spawning fish of other taxa, or large mammals such as deer, elk, or beaver, the nest would be lost. Cover is important because exposed males and eggs would likely be more susceptible to predation (Downhower and Brown 1980). Embeddedness of the nest rock could affect the abundance of naturally occurring nest sites or energy expenditures by males in excavation and
maintenance of nest sites (Morris 1955; Marconato and Bisazza 1988). The type of substrate around the nest site and its embeddedness could influence food resources (Gregory et al. 1987), and the dispersal and survival of larvae (Bond 1963). Little is known of water depths used by cottids but different depths could influence nest site selection by affecting the quality of cover or the probability of the nest becoming dewatered. Water velocity has been noted as a factor which can influence behavior of aquatic organisms (Statzner et al. 1988). Bond (1963) reported reticulate sculpin nests with water velocities ranging for 0.06 to 0.14 m/sec. It is possible at low water velocities that gas and waste exchange in the nest cavity is inhibited. In areas of high water velocities substrate may become unstable.

We had three objectives in this study; 1) determine if selection for nest sites occurs, 2) determine if nest-site selection varies by habitat type within a stream and 3) determine if nest-site selection varies between streams where habitat availability is different.

**Study Sites**

Two third order streams were selected in the Oregon Coast Range mountains (Figure 2.1). The climate is maritime with mild, wet winters and dry summers (Franklin and Dyrness 1988). Both streams drain directly into the Pacific Ocean and have hydrographs dominated by rain (Swanston 1991). Both
Figure 2.1. Location of study basins along the central Oregon Coast. Rocky Creek (sandstone) is 14 km north of Newport Oregon and Rock Creek (basalt) is approximately 63 km south of Rocky Creek.
basins have vegetation typical of the Sitka spruce (*Picea sitchensis*) and western hemlock (*Tsuga heterophylla*) zones (Franklin and Dyrness 1988). Geology differs between the basins, with Rocky Creek dominated by siltstone of the Astoria formation and Rock Creek dominated by Yachats Basalt (Baldwin 1964). Rocky Creek is managed as industrial forest land and Rock Creek has been managed by the United States Forest Service as a wilderness area since the 1960’s following minor harvesting associated with a homestead near the base of the watershed.

Basin area above the downstream end of the study reach is 13.72 km² for Rocky Creek and 14.89 km² for Rock Creek. Study reaches both have gradients of 2% and are dominated by riffles and scour pools. Both study reaches are bound by changes in gradient on the downstream end and by junctions with a tributary on the upstream end. The dominant overstory vegetation of riparian areas along both streams is red alder (*Alnus rubra*) of approximately 50 years of age, though western hemlock and Sitka spruce occur frequently. Understory vegetation is dominated by salmonberry (*Rubus spectabilis*) and swordfern (*Polystichum munitum*).

Rainfall for the 1995 water year, recorded at Newport Oregon, was 113% of mean annual precipitation for the period 1961-90. Rainfall as a percent of normal for months closely associated with spawning were: March 50%, April 174%, May 142%, and June 39% (Oregon Climate Service).
The fish community of Rocky Creek is composed of resident cutthroat trout (*Oncorhynchus clarki*) and reticulate sculpin (*Cottus perplexus*); a culvert prevents passage by anadromous fish. The Rock Creek fish community is composed of steelhead trout (*Oncorhynchus mykiss*), searun and resident cutthroat trout, pacific lamprey (*Lampetra tridentata*), reticulate sculpin and coastrange sculpin (*Cottus aleuticus*). The coastrange sculpin has a distribution which is limited to below the study reach. Other aquatic vertebrates observed in both streams were the tailed frog (*Ascaphus truei*) and the Pacific giant salamander (*Dicamptodon ensatus*).

**Methods**

Sampling occurred during the spring spawning season of 1996. We recognized that habitat selected could vary with time. To make comparisons between streams and habitat types meaningful we used a systematic sampling pattern with a random start. Sampling of units of each type from each stream were spread evenly throughout the spawning season.

For both study reaches we used the methods of Bisson et al. (1982) to classify habitat into discrete units by type. All habitat types could not be sampled for nest sites so we elected to sample scour pools and riffles. These habitats commonly account for a large portion of the available habitat in stream reaches of gradients similar to those found in this study (Hicks 1989). Some units
containing large accumulations of woody debris were excluded from the study due to diver safety considerations.

Each habitat unit was categorized by visually estimating the percent of streambed covered by particles cobble sized or larger (> 7.6 cm). Pools with ≤30% of their bottom surface area covered in substrate cobble size or larger were classified as low cobble pools (LPL), those with >30% were classified as high cobble pools (HPL). Riffles with ≤40% of their bottom surface area covered in cobble size or larger particles were classified as low cobble riffles (LRI), those with >40% were classified as high cobble riffles (HRI). Four units of each type (HPL, LPL, HRI, and LRI) in each stream were randomly selected for sampling. A total of 32 units were sampled; there were 16 from each stream.

Every nest site in the sampled units was located by a diver who examined every rock and piece of wood in each unit. Undercut banks were sampled to the extent the diver could reach. When a nest was found, the diver recorded the length, width, and height of the nest rock, embeddedness of the nest rock, embeddedness of the substrate within 0.5 m² of the nest site, dominant substrate within 0.5 m² of the nest site, depth of the water, and mean water velocity (Armour and Platts 1983).

We measured nest rock length, depth, and width with a meter stick. The embeddedness of the substrate within 0.5 m² of the nest site and the dominant substrate within 0.5 m² of the nest site were determined by ocular estimates (Platts et al. 1983). Mean water velocity was measured with a Marsh-McBirney
model 201 D or a model 2100 Swoffer portable water current meter. Water depth was measured with a meter stick or a fiberglass surveyor's rod. Prior to the initiation of sampling, lengths of white PVC pipe were driven into the streambed so that the top of the pipe was flush with the water surface. This was done in a single day while stream stage was constant and allowed standardization of water depths through the sampling period.

To quantify habitat available for nesting we randomly selected 30 sample points in each habitat unit. Data were collected for each random point within a habitat unit using the same methods as described for nests. Data collection for random points was done immediately prior to sampling for nests so that data were collected from an undisturbed environment.

To determine if selection occurred we used the electivity index of Vanderploeg and Scavia (1979). We selected this index because it is unaffected by the relative abundance of different habitat classes which allows meaningful comparisons between habitat units and types when habitat availabilities differ (Lechowicz 1982). This index calculates electivity by the formula:

\[
W_i = \frac{p_i/r_i}{\sum_{i=1}^{n} p_i/r_i}
\]
Where $W_i$ = electivity for class $i$, $p_i$ = proportion of use occurring in class $i$, $r_i$ = proportion of available habitat that is class $i$. The index ranges from 0 to 1; random use is defined as $1/n$ where $n$ = the number of different classes available. When $W_i$ exceeded $1/n$ we called electivity positive (selected for) and when $W_i$ was less than $1/n$ we called electivity negative (selected against). In classes where no use occurred we assumed negative electivity and dropped the class from the analysis for clarification of relationships among remaining variables.

For electivity index analysis, classes were determined for each variable as follows. Particles were grouped by size based on either their long axis or their volume. Dominant substrate and nest rock size (long axis) were classed as: fines ($\leq 0.471$ cm), gravel (0.472-7.6 cm), cobble (7.61-30.4 cm), boulder ($> 30.4$ cm). Nest rock size (volume) categories were categorized as: fines ($\leq 0.105$ cm$^3$), gravel (0.106-439.0 cm$^3$), cobble (439.1-28,095.0 cm$^3$), and boulder ($> 28,095.1$ cm$^3$). Five embeddedness categories were used; each category represented a different range of percent surface area covered by fine sediment: 1) 76-100%, 2) 51-75%, 3) 26-50%, 4) 6-25%, and 5) 0-5%. Classes of embeddedness, dominant substrate, and nest rock long axis are simplifications of categories used by Platts et al. (1983), with categories added for bedrock and wood. Depths were classified in 10 cm intervals up to 90 cm and >90 cm. Velocities could not be standardized between units due to changes in flow over time. It did not seem appropriate to use an electivity index under these conditions so we present
velocity data as a percent of total observations for both use and availability for each velocity class grouped by stream for scour pools and riffles.

**Results**

Rocky Creek (sandstone) had more bedrock and fines and less gravel and cobble than Rock Creek (basalt). Boulders and wood were rare in both streams (Figure 2.2). Rock Creek had 32% of available cobble in the 6-25% embeddedness class and only 25% of available cobble in the 26-50% embeddedness class. Rocky Creek had 26% of available cobble in the 6-25% embeddedness class and 45% of available cobble in the 26-50% embeddedness class (Figure 2.3). Habitat availability also differed for substrate size and embeddedness between habitat types within streams. Higher densities of cobble were found in HPLs and HRIs than in LPLs and LRIIs, and pools of both streams had more bedrock and fines than did the riffles (Figure 2.4). Substrate in the lower embeddedness classes (0-5%, 6-26%, and 26-50%) provided a higher proportion of available habitat in the HPLs and HRIs (Figure 2.5).

Positive or negative electivity was observed for all variables appropriate to analysis by the index of Vanderploeg and Scavia (1979). Very few units had values for $W_i$ which fell on the random use line indicating that selection for nest sites by reticulate sculpin did occur and overall patterns of electivity exhibited for
Figure 2.2. Substrate availability by size class (long axis) for Rock Creek (basalt) and Rocky Creek (sandstone). (BR=bedrock)
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Figure 2.4. The proportion of available substrate by size class (long axis) in four different habitat types for Rock Creek (basalt) and Rocky Creek (sandstone). (HPL=high cobble density pools, HRI=high cobble density riffles, LPL=low cobble density pools, and LRI=low cobble density riffles)(BR=Bedrock)
Figure 2.5. Proportion of available substrate by embeddedness class in four different habitat types in Rock Creek (basalt) and Rocky Creek (sandstone). (HPL=high cobble density pools, HRI=high cobble density riffles, LPL=low cobble density pools, and LRI=low cobble density riffles)
variables were similar between streams and between habitat types (Figures 2.6-
2.11).

Cobble-size rock (long axis and volume) was used for more than 90% of the
nest sites in both streams, and was positively elected in all but one habitat
unit in both streams (Figures 2.6 & 2.7). Electivity for gravel (volume) was mixed
in Rocky Creek and negative in all but one unit in Rock Creek, indicating that fish
in Rocky Creek used slightly smaller rocks than the fish in Rock Creek (Figure
2.7). This could be due to the smaller size of the fish in Rocky Creek (Figure
2.8). Unanimous negative election was observed in both streams for gravel
(long axis) (Figure 2.6). Only one nest was found on a boulder sized rock
(volume), while 22 nests were found on boulders (long axis). The smallest rock
with a nest measured 5 cm (long axis). No nests were found on wood, bedrock,
or fines.

Electivity for nest rocks embeddedness was positive for the low to
moderately embedded (6-25%) class in all but one of the units sampled (Figure
2.9). The percentage of total nest rocks embedded 6-25% was 69% for Rocky
Creek and 60% for Rock Creek. Only two nests were found on rocks in the 51-
75% embeddedness class and no nests were found on rocks embedded more
than 75%. Rock Creek had 16% of nest rocks embedded 26-50% and 24% of
nest rocks embedded 0-5%. Rocky Creek had 15% of nest rocks embedded 26-
50% and 16% of nest rocks embedded 0-5%.
Figure 2.6. Electivity for nest rock size using measurements of the long axis of the rock to determine class membership. (V&S Index values refer to Vanderploeg and Scavia's selectivity coefficient W (1979), (HPL=high cobble density pools, LPL=low cobble density pools, HRI=high cobble density riffles, LRI=low cobble density riffles)(each symbol represents one habitat unit).
Figure 2.7. Electivity for nest rock size using volume to determine class membership in Rock Creek (basalt) and Rocky Creek (sandstone). (∞ represents situations where use was observed but no available habitat was detected within the habitat unit by the 30 random points resulting in division by zero)
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Figure 2.9. Electivity for different levels of nest rock embeddedness for Rock Creek (basalt) and Rocky Creek (sandstone).
Figure 2.10. Electivity for dominant substrate in a 0.5 m² area around the nest rock for Rock Creek (basalt) and Rocky Creek (sandstone).
Figure 2.11. Electivity shown for different levels of embeddedness in 0.5 m² area around nest rocks in Rock Creek (basalt) and Rocky Creek (sandstone).
Cobble was positively elected as the dominant substrate around nest sites in all but three of the units sampled. Electivity for gravel was mixed in both streams but positive election was more common in Rocky Creek where fish were smaller. Electivity for bedrock and fines was almost always negative (Figure 2.10). Electivity for substrate embeddedness around nest sites was mixed but predominantly positive for the 6-25% and 26-50% classes, mixed but mostly negative for 0-5% and unanimously negative for 51-75% (Figure 2.11). No nests were found on rocks where the surrounding substrate had an average embeddedness of more than 75%.

Intermediate depths (20-60 cm) were commonly elected positively and negative electivity was observed for shallow water (< 10 cm) and, possibly, for depths > 60 cm, although sample size was low. Patterns of electivity for different depths were similar between streams. Available depths differed between pools and riffles, and Rock Creek had more pools with depths greater than 70 cm than did Rocky Creek (Figure 2.12).

Water velocities ranged from 0 m/sec to 1.6 m/sec and spawning was observed at velocities up to 1.11 m/sec. For the lowest velocity class, use was low compared to availability except in pools from Rock Creek. In Rocky Creek 8% of riffle and 19% of pool habitat fell in the 0.02 m/sec velocity class while only 0% of riffle spawning and 1% pool spawning occurred in this velocity category. In Rock Creek 5% of riffle and 8% of pool spawning was in the 0.02 m/sec class and 1% and 5% of use (Figure 2.13).
Figure 2.12. Electivity for water depth, in 10 cm increments, at nest sites in Rock Creek (basalt) and Rocky Creek (sandstone).
Figure 2.13. Mean water velocities available (from 30 random points per unit) and water velocities found at nest sites in riffles and pools for Rock Creek (basalt) and Rocky Creek (sandstone).
Discussion

Patterns of electivity exhibited by reticulate sculpin did not differ markedly between the two study reaches or between the four different habitat types investigated. Sample sizes were small for between habitat type comparisons and some variable classes may show differences with larger sample sizes. Cobble of moderate embeddedness was the most common habitat selected for nesting in all areas. Bedrock, fines, depths < 10 cm, and areas of high embeddedness were almost always negatively elected regardless of their abundance or the abundance of moderately embedded cobble. We speculate that reproductive success is probably tightly linked to habitat variable classes for which election was nearly unanimous. If this were not the case, given the range of available habitat in this study, we should have observed a more mixed pattern of electivity in all classes of the variables investigated. We expected to find some nests on woody debris and in crevices of bedrock but did not. It is possible that due to the shape of cavities associated with wood and bedrock that nests on these substrates would be more exposed to predation and high water velocities which could result in mechanical damage to eggs from mobilized substrate. Wood was rare relative to rock in both study reaches although it was present and several hundred pieces of wood were examined without locating a nest; leading us to conclude that wood is relatively unimportant as a nesting substrate in stream reaches similar to the ones in this study, probably for some of the same reasons.
expressed above. However, Millikan (1968) found 16 nests of the riffle sculpin 
(*Cottus gulosus*) on rotted logs in Connor Creek, Washington, which is a low 
gradient stream dominated by sand and wood substrate. This may indicate that 
wood could be a possible nesting substrate for reticulate sculpin under different 
conditions.

We propose that suitable nest rocks are delimited by some minimum rock 
size based on the fact that no nest was ever located on a rock with a long axis 
smaller than the length of the guarding male (unpublished data). This hypothesis 
is supported by the observations of Downhower and Brown (1980) who noted 
that the minimum tile size for nesting male mottled sculpin (*Cottus bairdi*) was 
one which was large enough to cover both the male and the eggs. From a 
comparison of electivity in nest rock sizes it is apparent that the smaller fish in 
Rocky Creek, will use slightly smaller rocks than those in Rock Creek. Whether 
minimum rock size is primarily a response to cover, stability, or a combination of 
the two factors is not discernible from our data. We can see however, that for 
very large rocks electivity is mostly negative suggesting that factors other than 
just rock size are important.

As a practical matter, the cobble class for rock size (volume) and rock 
size (long axis) both captured over 90% of the rock sizes used as nests but rock 
size (long axis) is a much easier value to either measure or estimate and would 
be the variable of choice for estimating the availability of reticulate sculpin 
spawning habitat under conditions similar to this study.
We think that embeddedness is acceptable until it approaches zero or 50%. Why zero embeddedness is not acceptable could be complex and may include issues of substrate stability in high flows, within nest conditions for larvae, and possibly nest defense. A total lack of embeddedness may result in nest cavities being more accessible to small predators such as stoneflies. Water velocities within the nest may also be higher making it difficult for larvae to avoid being swept out of the nest. If substrate is more mobile in areas of zero embeddedness it is likely that these sites would be poor areas for larvae to enter interstices as they disperse. As embeddedness approaches 50% it may be that fines entrained then deposited during even small fluctuations in flow, could result in males needing to clear the nest after each event or possibly to fan the eggs to ensure oxygenated water is available and waste products removed (Morris 1955). Also food and larval dispersal could be an issue in areas of high embeddedness. We observed larvae burrowed into fine gravel beneath nest rocks up to a depth of 4 cm, but larvae were not observed burrowed into sand or silt. We also observed adult males to feed readily when we offered them caddisfly larvae indicating that they will feed, at least opportunistically, while guarding a nest. The opportunity for guarding males to feed occasionally during the nesting period could impact the quality and duration of nest defense and male survival rates.

We attribute the avoidance of low velocity areas (less than 0.02 m/sec) in the pools of Rocky Creek to the greater abundance of fine material available for
transport in this stream. Freshly deposited fines were often noted along the margins and slack water areas of Rocky Creek after small fluctuations in flow, and we found fewer nests in these locations. Similar depositions were not observed along the margins or in slack water areas of Rock Creek after flows of similar magnitudes, and more nests were found in low-velocity areas.

Depth, like velocity, appears to be important in the extremes; shallow water was not used for nesting presumably to avoid the dewatering of nests during low flows. The possible avoidance of areas where the greatest depths were found in scour pools could be due to the intense scouring which forms these features during high flows.

We would predict similar behavior in reticulate sculpin in other stream reaches similar to those of this study. We would expect behavior to differ as gradient, basin size, climate, and substrate composition change. The presence of another species of cottid would also likely cause habitat selection to vary even in stream reaches with similar physical characteristics to those of this study. Management activities which would result in decreased availability of moderately embedded cobble could potentially have detrimental effects on reticulate sculpin reproduction.
References


Smith, B. G. 1922. Notes on the nesting habits of Cottus.


Chapter 3

Reproductive Effort and Nest Densities of Reticulate Sculpin in Two Streams of Different Geologies in the Central Coast Range of Oregon

Douglas S. Bateman and Hiram W. Li
Abstract

In two streams of the central Oregon Coast Range, reproductive effort by reticulate sculpin on a per nest basis was found to be 90% (95% confidence interval 52-152%) greater for nest weight and 39% (95% confidence interval 8-79%) greater for mean egg number in the basalt over the sandstone stream. Differences in reproductive effort per nest among scour pools, riffles, high cobble density and low cobble density habitat units were not detected in either stream. Reproductive effort varied through the spawning season with a similar pattern in both streams but statistical significance was found only in the sandstone stream.

Nest densities were similar at 0.16 nest/m² and 0.17 nest/m² for the basalt and sandstone streams respectively. Differences in nest densities were detected between high and low cobble density units in the sandstone stream only. Nest densities were found to be higher in pool tailouts as opposed to the head and body portions but the pattern was statistically significant in only the sandstone stream.

Our results would suggest that reticulate sculpin nest site selection and reproductive effort are not strongly influenced by habitat on geomorphic channel unit scale. It may be that a smaller scale is more appropriate, where sculpin habitat is delineated by substrate patches within the geomorphic habit unit.
**Introduction**

Often the goal of fisheries management is to predict the abundance and distribution of fish, this requires knowledge of the life history and ecology of the species of interest. Reproduction is an essential part of an organism’s life cycle and an understanding of habitat requirements can be important in predicting fish distributions and abundance. In the Pacific Northwest land managers are actively engaged in physical alterations of stream channels with the intention of improving freshwater habitat conditions for native salmonids. Little attention has been paid to the potential impacts of these activities non-salmonid fishes.

The reticulate sculpin is commonly found in association with salmonids throughout its range (Bond 1963; Bond et al. 1988), and has some potential as an indicator of freshwater habitat quality in the pacific northwest (Bond 1963, Bateman and Li in prep). The reticulate sculpin (*Cottus perplexus*) is considered a habitat generalist and uses both pool and riffle habitat when allopatric with other cottids (Finger 1982; Bond 1963). Bateman and Li (in prep), found that reticulate sculpins nested in both pools and riffles and that nest sites in both were associated with moderately embedded cobbles. However, whether nest densities or reproductive effort per nest (number or mass of eggs) varies among habitat types such as pools and riffles is unknown. Therefore, predictions of potential impacts on reticulate sculpin reproduction from the alteration of habitat at the unit scale are difficult.
In a previous paper (Bateman and Li in prep) we examined reticulate sculpin nest site selection on a microhabitat scale. In this paper our objective is to determine if the density of nests or reproductive effort, on a per nest basis, varies across larger channel units. To accomplish this we compared reproductive effort per nest and nest densities among: 1) scour pool and riffle habitats, 2) habitat units with a high percentage of cobble substrate as opposed to habitat units with a lower percentage of cobble substrate, 3) the head and body of pools and the tailouts, and 3) between two different streams.

Methods

Our two study streams in the central Oregon Coast Range were described by Bateman and Li (in prep). Habitat units were determined as per Bisson et al; (1982). Scour pools and riffles were additionally classified as either high cobble density pools (HPL), low cobble density pools (LPL), high cobble density riffles (HRI), or low cobble density riffles (LRI). Riffles with ≤ 40% of their bottom area occupied by cobble or larger sized substrate were LRI's and HRI's were riffles with > 40% of their bottom area covered with cobble size or larger particles. LPL’s and HPL’s were similarly defined but 30% was used as the cut off between high and low. Four units of each habitat type were randomly selected in each of the two study streams; 16 habitat units were selected from each stream and 32 habitat units total.
Reticulate sculpin have been observed to begin spawning during March and continue till early June in western Oregon (Bond 1963). We began sampling 2 April 1996 and continue until 10 June 1996 when gravid females were no longer observed in either stream but eggs were still present. To reduce possible confounding effects of time on nest densities and reproductive effort, units were systematically sampled with a random start by stream in groups containing one of each of the four habitat types. To account for possible differences in reproductive effort per nest and differing densities of nests through time, units were assigned to one of three sampling periods each corresponding to approximately one third of the total study time.

The area of each unit was estimated by measuring the length of the unit along the thalweg and multiplying this length by the mean width. Mean width of a unit was estimated to be the average of three width measurements taken at one quarter, one half, and three quarters the distance from the downstream boundary to the upstream boundary of the unit. The head and body portion of pools were separated from the pool tailouts by an imaginary line drawn perpendicular to the direction of flow at the inflection point where the rate of depth decrease begins to lessen immediately downstream from the area of maximum depth. The areas for pool tailouts and the head and body portions of pools were estimated in the same manner as described above.

All nests were located by divers (Bateman and Li in prep), and eggs were collected, placed in a 6% formalin solution (Snyder 1983), and given a unique
label. When guarding males were positively identified we made attempts to collect them with a slurp gun. If the unit was a pool it was also noted whether the nest was located in the head and body area or the tailout. To evaluate diver efficiencies in locating nests, 10% of the area was randomly selected in one unit of each habitat type, HPL, LPL, HRI, and LRI, per stream and all substrate items larger than small gravel were removed from that area. No additional nests were found and we assumed a 100% sampling efficiency when calculating nest densities.

The weight of each egg mass was estimated by pouring the contents of each collection jar into a tea strainer, blotting the tea strainer on a paper towel, then weighing the tea strainer with eggs on an electronic balance (Ohaus, model c151) and recording the weight to the nearest 0.05 g. The eggs were then removed from the tea strainer and returned to their collection jar with the original formalin solution. The strainer without eggs was reweighed and weight of the eggs was calculated as the difference between the two measurements. The mean of three repetitions of this process for each egg mass was used in analyses.

To estimate the number of eggs per nest we randomly selected 15 nests from the pool of available nests for each habitat type (HPL, LPL, HRI, and LRI) from each stream and counted the eggs in those nests. A mean weight for an individual egg was calculated for each of the 120 selected nests. Mean individual egg weights were then used as the dependent variable to develop regression
equations which were used to predict the number of eggs in uncounted nests based on that nest's weight. Separate linear regression equations were developed by stream for periods 1 and 2 combined and for period 3 (Quatro Pro 6.0, Novel).

Statistical Analysis

Mean nest weight per unit, an estimate of the mean number of eggs per nest per unit, and nest density (nests/m²) per unit were compared within each stream between: habitat types (pools and riffles), cobble density types (high and low cobble density units), and time periods using analysis of variance (ANOVA) (SAS Institute 1989). Models initially contained as main effects; habitat types, cobble density types, and time periods. We examined all possible interactions between main effects and systematically removed interaction terms with p-values > 0.05. The main effects, habitat type and cobble density type, were always retained in the model regardless of their level of significance. Time period was removed when its p-value was > 0.05 in both streams. If time period was significant (p ≤ 0.05) in one or both streams it was retained in the models for both streams. Following ANOVA, if time period was significant, a multiple comparison test (Tukey's) using the GLM procedure (SAS Institute 1989) was used to evaluate differences in means. Reported mean differences and confidence intervals are from backtransformations of the least square means for each effect.
For comparisons of reproductive effort between streams, mean differences and 95% confidence intervals reported are from least square means generated by the model described above with the addition of stream as a main effect.

The relationship between male length and egg mass size was evaluated by the regression equation \( Y = \beta_0 + \beta_1(L^2) + \beta_3(S) \) where \( Y \) is the dependent variable nest weight, \( \beta_0 \) is the y axis intercept, \( \beta_1 \) is the slope of the regression line, \( L^2 \) is male length squared, and \( \beta_3(S) \) is the coefficient and dummy variable for stream. Males from both streams were combined and the model reduced to \( Y = \beta_0 + \beta_1(L^2) \) when stream was found to be nonsignificant (\( p=0.5 \)).

Differences in nest densities between tailouts and the head and body portion of pools were evaluated by stream using a paired t-test (Quatro Pro, version 6.0). Results presented are from a two tailed test.

To meet assumptions of normality and constant variance the values of mean egg number per unit and mean nest weight per unit were log transformed and values for nest density per unit were square root transformed. In Rock Creek, distributions of nest densities were not normalized by the transformation until two potential outliers were removed. Because we had no biologic basis for classifying these units as outliers we analyzed these data using ANOVA with parametric assumptions and the square root transformed data minus the potential outliers and also using ANOVA with the data rank transformed and including the potential outliers.
As there is no publish literature concerning reproductive effort or nest densities in naturally spawning cottid populations it was not feasible to calculate statistical power a priori. We present mean differences with 95% confidence intervals in conjunction with several different response levels in lieu of performing a restrospective power analysis. This was done so that results could be evaluated across a range of potential biologically significant effects. Response levels, or potential biologically significant effects, were establish as 10, 30, and 50% of the smaller mean under comparison. When a potential biologically significant effect lies outside the 95% confidence interval around the difference in means, we accept the biological null of no difference at that effect level. If the potential biologically significant effect is contained within the 95% confidence interval around the difference in means, we conclude that the results are inconclusive (Steidl et al. 1997).

Results

Reproductive Effort

In the randomly selected sample of 120 nests we found that individual eggs from Rock Creek (basalt) were 56% heavier on average (95% confidence interval, 46-65%) than the eggs in Rocky Creek (sandstone). Significant differences in mean egg weight were also noted among time periods (p=0.0002).
Mean individual egg weights from period 3 were significantly less than mean individual egg weights from period 1 and period 2 ($p < 0.05$) but mean individual egg weights from period 1 and period 2 did not differ significantly ($p > 0.05$). Differences in mean individual egg weight were not detected between pools and riffles or between cobble densities ($p = 0.46$ and $p = 0.9$). All tests for interactions between factors had $p$-values $> 0.5$. The four regression equations used to predict the number of eggs per nest based on nest weight are listed in Table 3.1.

Reproductive effort on a per nest basis differed between streams. Mean nest weight and mean number of eggs per nest in Rock Creek (basalt) exceeded Rocky Creek (sandstone) by 90% (95% confidence interval 52-152%) and 39% (95% confidence interval 8-79%) respectively, indicating that nests in Rock Creek contained more and larger eggs than did nests in Rocky Creek (Figure 3.1). Males captured, while guarding nests, in Rock Creek were larger than the males in Rocky Creek (Figure 3.2). Male length accounted for a significant portion of the variability in nest weight ($r^2 = 0.65$; $p = 0.0001$).

There were no significant interactions between factors for either mean nest weight per unit or mean egg number per unit in either stream. No detectable differences were observed in mean nest weight per unit ($p = 0.39$) or mean egg number per unit ($p = 0.33$) between scour pools and riffles in Rocky Creek. Also no differences were detected in Rocky Creek for mean nest weight per unit ($p = 0.77$) or mean egg number per unit ($p = 0.81$) between cobble density types. In Rock Creek, results were similar to those of Rocky Creek with no differences.
Table 3.1. Median value for the mass of an individual egg for Rock Creek (basalt) and Rocky Creek (sandstone) and the associated regression equation used to predict the number of eggs per nest based on mass by time period. Numbers in () are standard deviations.

<table>
<thead>
<tr>
<th>Rock Creek</th>
<th>Period</th>
<th>Mass/Egg</th>
<th>Regression Equation</th>
<th>R-squared</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>0.02 (0.003)</td>
<td>y=56.5x</td>
<td>0.96</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.019 (0.004)</td>
<td>y=56.5x</td>
<td>0.96</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0.017 (0.002)</td>
<td>y=63.6x</td>
<td>0.96</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Rocky Creek</th>
<th>Period</th>
<th>Mass/Egg</th>
<th>Regression Equation</th>
<th>R-squared</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>0.013 (0.002)</td>
<td>y=75.9x</td>
<td>0.95</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.012 (0.002)</td>
<td>y=75.9x</td>
<td>0.95</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0.011 (0.001)</td>
<td>y=88.8x</td>
<td>0.97</td>
</tr>
</tbody>
</table>
Figure 3.1. Frequency distributions of two measures of reproductive effort for Rock Creek (basalt) and Rocky Creek (sandstone).
Figure 3.2. Relationship between male length and the weight of their egg mass in Rocky Creek and Rock Creek. (Length is total length)
detected in mean nest weight per unit ($p=0.12$) or mean egg number per unit ($p=0.12$) between scour pools and riffles. Also, no differences were detected in mean nest weight per unit ($p=0.76$) or mean egg number per unit ($p=0.74$) between cobble density types.

For three possible biologically significant effects, 10, 30, and 50% of the smaller mean under comparison, we observed the 95% confidence interval around the difference in means of pools and riffles for the variable nest weight to include all three effects in both Rock and Rocky Creeks (Figure 3.3 (A)). The 95% confidence interval around the difference in mean nest weight between cobble density types included all three possible biologically significant effects in Rocky Creek but contained only the 10% effect in Rock Creek (Figure 3.3 (B)). This indicates that in Rock Creek, if the minimum biological effect size were considered to be 30% or greater, no biologically significant difference existed between cobble density types. If the minimum biologically significant effect were considered to be 10%, results are inconclusive. Results are inconclusive for mean nest weight between cobble density types in Rock Creek for all levels of biological significance investigated. This is also true for the difference in mean nest weight between pools and riffles for both streams.

The 95% confidence interval around the difference in the mean number of eggs per nest did not contain any of the different levels of potential biologically significant effects in either stream for either comparison (Figure 3.3 (C,D)). This indicates that if we consider 10% to be the minimum biologically significant effect
Figure 3.3. The 95% confidence interval around the difference in means for the factors habitat type (pools and riffles), cobble type (high and low cobble density), and position (head and body portion of pools vs pool tailouts) are presented with 10, 30, and 50% of the smaller mean as possible levels of biologically significant differences in mean nest weight per unit, mean egg number per nest per unit, and nest density per unit. (R= Rock Creek (basalt), Y=Rocky Creek (sandstone), Habitat Type compares pools and riffles, Cobble Type compares high cobble density and low cobble density units, Position compares pool head and body portions to pool tailouts)
size we can be confident that there is no biologically significant difference in mean egg number per nest between riffles and pools or between cobble density types.

No significant difference in reproductive effort among time periods was detected in Rock Creek, but differences were observed in Rocky Creek for both mean nest weight and mean egg number per nest (Table 3.2). The mean number of eggs per nest in period 3 was significantly different from the mean number of eggs per nest in periods one and two ($p \leq 0.05$). There were no significant differences between periods one and two. The mean number of eggs per nest in period 3 exceeded the mean number of eggs per nest in periods one and two by 1.74 (95% confidence interval, 1.01-3.03) and 2.15 (95% confidence interval, 1.24-3.73) times respectively. Mean nest weight during period 3 was significantly different from mean nest weight during period 2 ($p \leq 0.05$). There were no detectable differences between period 3 and period 1 or between period 1 and period 2. Period 3 mean nest weight exceeded period 2 by 1.86 times (95% confidence interval, 1.06-3.27). Although not statistically significant, the pattern of mean values in Rock Creek was similar to that found in Rocky Creek (Table 3.2).

Nest Density

Nest densities were very similar between streams. A total of 1,493 m$^2$ of stream bottom was sampled in Rock Creek (basalt) and a total of 232 nests were
Table 3.2. Back transformed mean and standard deviations for log transformed data by factor and time period with associated p values for Rock Creek (basalt) and Rocky Creek (sandstone).

<table>
<thead>
<tr>
<th></th>
<th>Nest Weight</th>
<th>Egg Number</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rock Cr.</td>
<td>Rocky Cr.</td>
</tr>
<tr>
<td></td>
<td>Mean(SD)</td>
<td>P-value(^a)</td>
</tr>
<tr>
<td>Period 1</td>
<td>2.16 (1.29)</td>
<td>0.78</td>
</tr>
<tr>
<td>Period 2</td>
<td>1.82 (1.46)</td>
<td></td>
</tr>
<tr>
<td>Period 3</td>
<td>2.12 (1.40)</td>
<td></td>
</tr>
<tr>
<td>Period 1</td>
<td>118 (1.31)</td>
<td>0.46</td>
</tr>
<tr>
<td>Period 2</td>
<td>100 (1.45)</td>
<td></td>
</tr>
<tr>
<td>Period 3</td>
<td>134 (1.41)</td>
<td></td>
</tr>
</tbody>
</table>

\(^a\) Values from ANOVA table.
found for a density of 0.16 nests/m². In Rocky Creek (sandstone) a total of 1,412 m² of stream bottom was sampled and a total of 239 nests were found for a density of 0.17 nests/m². Nest densities from individual habitat units ranged from 0 to 0.59 nests/m² in Rock Creek and from 0.03 to 0.41 nests/m² in Rocky Creek (Figure 3.4).

In Rock Creek, when two potential outliers were removed from the data set, there was some evidence of an effect of habitat type on nest density (p=0.04). Riffles had nest densities which on average exceeded those of pools by 4% (95% confidence interval 0.02-14%). When the two potential outliers where included and ranked data were analyzed, no difference in nest densities between pools and riffles was detected (p=0.32). In Rocky Creek no difference in nest density was detected between habitat types (p=0.7). The 95% confidence interval around the difference in means for pools and riffles included the 10% effect but not the 30 or 50% effect (Figure 3.3 (E)). This indicates that if the minimum biologically significant effect size is considered to be 30% or greater, we can be confident in no biologically significant difference in nest densities between pools and riffles in Rocky Creek. If the minimum biologically significant effect size is considered to be 10% results are inconclusive.

No difference was detected in nest densities between cobble density types in Rock Creek with (p=0.6) or without potential outliers (p=0.4). The 95% confidence interval around the difference in means did not include any of our potential biologically significant effects indicating that no difference exists
between cobble density types if the minimum biologically significant effect size is considered to be 10% or larger (Figure 3.3 (F)). There was evidence of a difference in nest densities between cobble density types in Rocky Creek (p=0.02). Nest densities were on average 30% (95% confidence interval 1-101%) greater in high cobble density units than in low cobble density units (Figure 3.4).

Differences in nest density between the head and body portion of pools and their tailouts was statistically significant in Rocky Creek (p=0.04) and there was no detectable difference in Rock Creek (p=0.26). Nest densities in tailouts of Rocky Creek were 45% (95% confidence interval, 3-135%) greater on average than densities found in the head and body portions. In Rock Creek the 95% confidence interval around the difference in mean nest density for pool tailouts and head and body portions included all three potential biologically significant effect sizes indicating that results in this stream were inconclusive for the effects investigated. Patterns were similar between streams and nest densities were higher in the tailout portions of pools in all but three units in both streams combined (Figure 3.5). Suitable substrate for spawning was rare to totally lacking in tailouts of all three units where head and body nest densities exceeded tailout densities (Figure 3.5).
Figure 3.4. Nest densities from four different habitat types in Rocky Creek (sandstone) and Rock Creek (basalt). (HPL = high cobble density pool, LPL = low cobble density pool, HRI = high cobble density riffle, and LRI = low cobble density riffle. * indicates outliers which were removed for parametric analyses)
Figure 3.5. Nest densities found in head and body portions of pools and tailout areas in Rock Creek (basalt) and Rocky Creek (sandstone). (H&B= head and body area, Tail= tailout area, Low= low cobble density pool, High= high cobble density pool. Numbers adjacent to triangles are habitat unit numbers unique only to that stream and allows nest densities of head and body to be compared directly to densities found in the tailout of the same unit)
Discussion

Large differences in reproductive effort existed between streams. Fecundity in reticulate sculpin has been shown to increase with size (Patten 1971). Fish appeared to be smaller in Rocky Creek (sandstone) than in Rock Creek (basalt). Size differences between streams could be the result of a disturbance event which eliminated a year class from the sandstone stream but collections of fish from the study streams in spring of 1997 (Bateman and Li in prep) indicate that size differences between streams persisted one year latter making this explanation unlikely.

A comparison of life history and production of cottids in sandstone and basalt streams has not been reported. Hicks (1989) observed similar salmonid biomass in a comparison of sandstone and basalt streams of the central Oregon Coast. He noted that sandstone streams generally had smaller substrate and more bedrock than basalt streams, an observation also made by Connolly (1996) and consistent with the streams of this study. Hicks (1989) speculated that invertebrate production would be higher in basalt streams due to a larger proportion of riffle habitat and that salmonids in sandstone streams obtain a more substantial portion of their food from terrestrial sources. Observations of cottid consumption of invertebrates of terrestrial origin are lacking and the literature available strongly links cottid food habitats with invertebrates of autochthonous origin (Bond 1963; Pasch and Lyford 1972; Baltz et al. 1982;
Dineen 1951; Li and Moyle 1976). If the hypothesis proposed by Hicks is correct it is possible that differences in the size of fish and reproductive effort in this study are a reflection of greater autochthonous production in Rock Creek. However, it is unknown whether reproductive effort is a phenotypic response to habitat or a genotypic response to natural selection which might favor different traits in one stream over the other. Much could be learned from accurately aging fish from both populations.

Differences in reproductive effort over the length of the spawning season might be the result of age class specific spawning periods. Larger and presumably older fish have been observed spawning earlier than smaller conspecifics in both Cottus gobio (Marconato and Bisazza 1988) and Cottus hangiongensis by Goto (1987). Marconato and Bisazza (1988) also observed mean egg diameter to declining through the spring spawning period. If a similar pattern occurs in reticulate sculpin, larger fish may be spawning during period 1 and the decline in reproductive effort during period 2 may be due to the hatching of eggs in the nests of large early spawning fish while new nests contain the eggs of smaller less fecund females. Standard deviations are highest in period 2 for both nest weight and egg number in both streams. We have also noted that the smaller fish from Rocky Creek have a higher egg per unit of weight ratio than the larger fish in Rock Creek and that egg size declined through the spawning season. The hypothesis of size segregated spawning is more consistent with the pattern seen in Rock Creek but is also supported by the pattern seen in
Rocky Creek where differences in mean egg numbers are greater between periods 2 and 3 than are the differences in nest weight. It is also interesting to note that nest densities did not vary significantly with time thus rates of polygyny must have increased during period 3 for size segregated spawning to have occurred.

Differences in nest densities do not appear to be biologically significant but results are ambiguous in some cases and suffer from small sample size. The strongest response is seen in Rocky Creek for cobble density types and pool head and body vs tailouts. The results from both of these comparisons supports the contention that cobble can limit reproduction although the relationship is not entirely clear from these data due to the way the data were collected. Levels we selected for distinguishing between low and high cobble densities may have been to high and cobble may not become limiting until much lower levels of abundance. Also it may be more appropriate to distinguish % area of cobble from % area cobble of by levels of embeddedness (Bateman and Li in prep).

The abundance of different substrate types was not estimated separately for tailouts and the head and body portion of pools. This omission made it difficult to evaluate the relative importance of these areas with a small sample size such as ours.

Additional research will be required to determine whether the geomorphic habitat scale is useful in predicting reticulate sculpin distributions and abundance. Our results would suggest that these fish are not strongly influenced
by habitat at this scale but there is some uncertainty. It may be that a smaller scale is more appropriate, where sculpin habitat is delineated by substrate patches within geomorphic habit units. With additional research reproductive effort may become a useful tool for evaluation of instream conditions and monitoring habitat changes over time. It might be particularly applicable in bedrock dominated stream systems where attempts are made to reestablish substrates lost due to splash damming or other anthropogenic activities.
References


Chapter 4

Conclusions

The conclusions I reached from the studies reported in Chapters 2 and 3 are as follows:

- Selection for nest sites by reticulate sculpin (*Cottus perplexus*) does occur. Selected nest sites are strongly associated with cobble sized substrate of moderate embeddedness. Water depth and velocity are probably important at extreme values while intermediate values appear to be less important than substrate size and embeddedness.

- Habitat selected for nest sites did not vary across the range of conditions sampled in this study. The availability of cobble substrate of moderate embeddedness varied widely between streams and habitat types, yet it was positively elected in all environments indicating a likelihood that reproductive success is linked to this habitat in stream reaches similar to those of this study.

- Nest densities are not strongly associated with habitat on the scale investigated in this study. It may be more appropriate to evaluate cottid
habitat by substrate patches within geomorphic scale habitat units. Nest densities alone would be a poor measure of reproductive effort in multiple stream comparisons.

- Reproductive effort per nest was different between streams but similar between habitat types compared within a stream. We found larger males tended to have larger egg masses and as nest densities were similar across habitat types we can speculate that larger fish were not highly concentrated in one or more of the habitats types investigated by us.

- Reproductive effort per nest was higher later in the spawning season and nests tended to have a higher egg per unit of weight ratio later in the season.
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