Fish, Macroinvertebrate, and Habitat Survey of Three Willapa National Wildlife Refuge Streams

by

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Several biologists from the Columbia River Fisheries Program Office provided much needed help and expertise during this study. Special thanks go to Rod Engle, who did much of the snorkeling, Tom Hoffman, who helped collect stream habitat inventory information, and Jeff Hogle, who led the electroshocking crew. Chet Conklin conducted the macroinvertebrate analysis and helped with fish sampling.

INTRODUCTION

In September and October 2003, staff from the Columbia River Fisheries Program Office (CRFPO) conducted fish, macroinvertebrate, and habitat surveys of three small, unnamed creeks that flow across Willapa National Wildlife Refuge (WNWR). The goal of this project was to provide the refuge with initial baseline studies of the three unnamed streams for population attributes of salmonids and other fish species, the macroinvertebrate community, and habitat quality and quantity. These surveys were not comprehensive watershed analyses. They were intended to be initial baseline surveys that would assist WNWR staff in future management actions.

STUDY LOCATION

The study area included three unnamed creeks that flow into the southeast corner of Willapa Bay near the mouth of the Bear River (Figure 1). The lower reaches of these creeks flow across WNWR and private property that is being considered for acquisition by the refuge. For this study we named the most northerly stream North Creek, the central stream Middle Creek, and the most southerly stream South Creek. Each of the creeks originates in the Bear River ridge and drains westerly into a tidal channel that parallels U. S. Highway 101. The channel flows northward and joins Greenhead Slough before passing under Highway 101 where it enters Willapa Bay near the mouth of the Bear River (Figure 2).

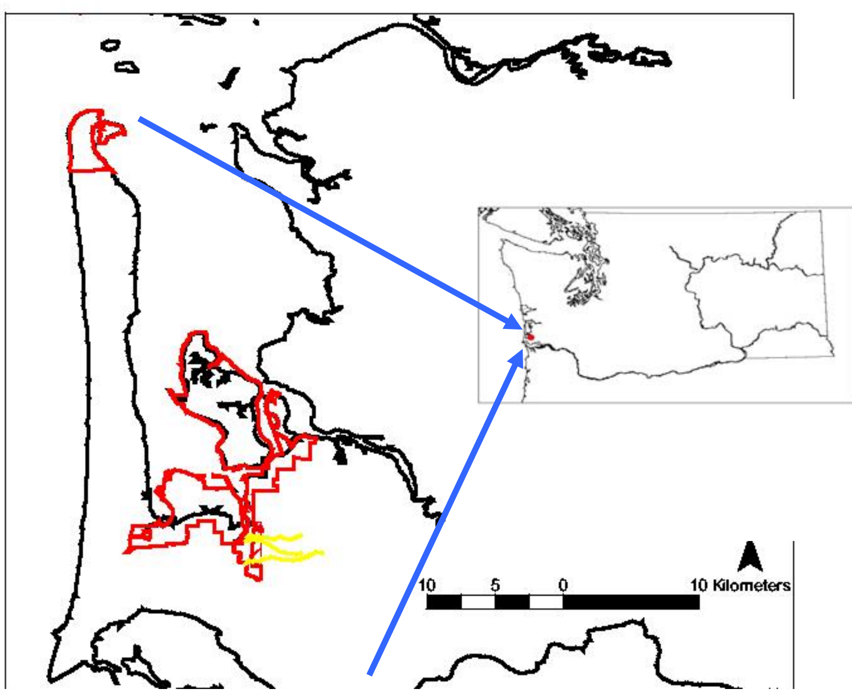

Figure 1. General location of study area showing boundaries of Willapa National Wildlife Refuge in red and study streams in yellow.

STUDY METHODS

The lower reaches of each stream flow into tidally influenced wetlands. Stream surveys began upstream of the area of tidal influence. We limited the survey area to the reaches of the creeks estimated to be within or near the existing and potential future boundary of WNWR (Figure 2). Biologists surveyed North Creek from a point about 100 meters upstream from the head of tide to the approximate future WNWR boundary. They began their survey of Middle Creek from a point near the head of tidal influence and continued to the first logging road that crosses the creek. The crew surveyed South Creek starting from a site about 100 meters downstream from an abandoned logging road bridge and continuing upstream to the estimated boundary of the proposed land acquisition.

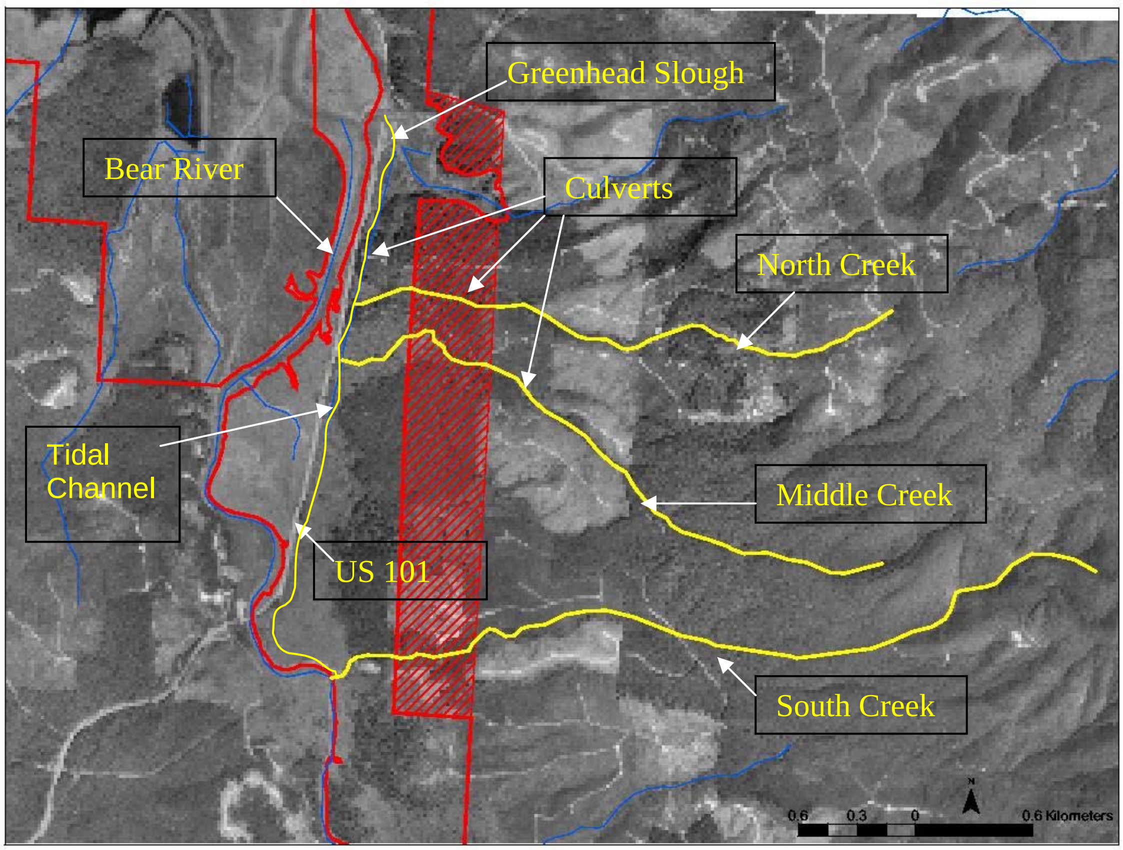

Figure 2. Detailed map showing existing refuge boundaries (red line), proposed refuge addition (red diagonal lines) and three study streams (bold and in yellow).

The surveys included biological and physical/chemical sampling on each of the three creeks. In addition, CRFPO biologists examined a logging road culvert that crosses the tidal channel adjacent to U.S. Highway 101 to assess the culvert's fish passage suitability.

Physical/Chemical Surveys

Using Geographic Information System (GIS) data and ArcGIS software and a hydrology extension we estimated the drainage areas of each of the creeks. We took point measurements of streamflow (m^3/second) at base flow and after early fall rains, total dissolved oxygen (mg/l), temperature (ºC), and conductivity (µS/cm) at each creek. Temperature data loggers were placed in North and Middle creeks to collect data over a longer time period. We removed these data loggers on January 23, 2004.

Stream habitat units were surveyed according to the US Forest Service Region 6 Level II Stream Inventory protocol (Anonymous, 2002). Our methods differed from this protocol in that we measured all standard parameters (e.g. length, width, and depth) at each habitat unit rather than estimating them. We measured more detailed habitat characteristics (e.g canopy density and bankfull width) along the three creeks at the following frequencies:

- 20% of the surveyed habitat units in North Creek;
- 100% of the slow water and 50% of the fast water units in Middle Creek; and
- 100% of the units in South Creek.

The Wolman pebble count technique (Wolman, 1954) was used to measure surface substrate composition in two reaches (upper and lower) of North Creek and one reach in both Middle and South creeks. Pebble counts were taken at fast and slow water units within each stream reach. The results of the counts for each reach were used to generate D35, D50, D84, and D95 values for the reach. The "D" values represent the cumulative percentage (i.e. 35, 50, 84, and 95) of substrate particles that are smaller than a certain size. This technique is used to characterize rivers that flow over coarse material and to broadly describe substrate character, not to identify specific salmon spawning sites.

In our analysis, we discuss general patterns of very small substrate (fines) and substrates suitable for salmonid spawning (6-128 mm) because of their importance to salmonid ecology (Kondolf and Wolman 1993). We define fines as particles less than 6 mm, spawning substrates for small bodied salmonids (35 cm< long) as those between 6 and 64 mm, and spawning substrates for large bodied salmonids (> 35 cm long at maturity) as those between 65 and 128 mm. (Kondolf and Wolman 1993). Although chum salmon (*Oncorhynchus keta*) and coho salmon (*O. kisutch*) are often larger than 35 cm long at maturity, they frequently spawn in substrates smaller than 65 mm. (McMahon 1983, Hale et al. 1985, Pauley et al. 1988, Laufle et al. 1986). Therefore, we consider substrates suitable for smaller bodied salmonids as potentially suitable for chum and coho salmon as well.

Biological Sampling

Fish

Biologists from the CRFPO snorkeled the lower, slower flowing, and ponded reaches of each stream and electrofished the upper, narrower, and faster flowing sections. Salmonids collected by electrofishing were anaesthetized, identified to species, measured to total length, allowed to recover, and released into the stream near the point of capture. As an estimate of abundance, the catch per unit effort (CPUE=number of a species captured/minute sampled) was calculated for each species of salmonid collected by electrofishing (Anderson and Neumann 1996). Snorkelers identified fish that they observed to species when possible. They estimated and recorded the lengths of smaller salmonids, but did not estimate the size of adult fish.

Macroinvertebrates

The macroinvertebrate sampling crew collected five kick net samples at locations from each stream in riffle areas previously located and evaluated by CRFPO personnel for riparian habitat, physical stream measurements, and chosen chemical parameters. Invertebrates were separated from detrital material in the laboratory under 10x magnification (the majority of invertebrates were early instars) and identified on a best effort basis to family/genus level. Washington State Department of Ecology (DOE) protocols were followed for collection, preservation, and processing macroinvertebrates (Plotnikoff and Wiseman, 2001). Unusual or dubious identifications were verified with Rob Plotnikoff (DOE) at the DOE Lab on November 29, 2003.

A Benthic Index of Biological Integrity (B-IBI) (Karr and Dudley, 1991) was calculated for each stream from macroinvertebrate kick net samples. The B-IBI is an overall assessment of stream habitat based on the macroinvertebrate community condition. Several measures or metrics (usually 10) are used to calculate the B-IBI, which is a single number. Scores for each metric are 1, 3, or 5 and are summed to generate a total score between 10 and 50. This approach compares what is found at a study site to a high quality baseline stream in the region. In general, scores of 46 to 50 represent excellent conditions; 38 to 45, good conditions; 28 to 37, fair conditions; 18 to 27, poor conditions; and 10 to 17 very poor conditions.

In addition, a functional feeding group analysis (Merritt & Cummins, 1996) was performed because of the skewed population discovered at each stream location. Sample results revealed a high abundance of a mayfly, *Leptophlebia*, which accounted for 67 percent of the overall population in North Creek, 52 percent of the population in Middle Creek and 36 percent of the population in South Creek. A functional feeding group analysis examines the ratios of various types of macroinvertebrates based on their method of feeding. Feeding groups include shredders, scrapers, collector-gatherers, filter-gatherers, and predators. Ratios of organisms from these feeding groups are compared to criteria established for streams to determine the habitat conditions of study streams. We thought that a more in-depth understanding of stream processes would be helpful to refuge managers.

Fish Passage

The survey crew investigated each stream for potential fish passage barriers such as culverts and debris jams. . These measurements were made according to the Forest

Service Region 6 Level II Stream Inventory protocol (Anonymous 2002). The crew measured physical characteristics of road culverts on North and Middle creeks including culvert diameter and length, water velocity, water depth, and jumping height required of fish to enter the culvert to determine their potential as barriers to fish passage. The height of debris jams was also measured to see if these were fish passage barriers. Maximum water velocity in the tidal channel road culvert was measured during an outgoing tide to determine its suitability for fish passage.

RESULTS

Physical/Chemical Surveys

Watershed statistics

The watershed areas for each of the streams are relatively small and similar in size ranging from 1.9 to 2.6 km^2. The estimated watershed statistics for each of the streams are shown in Table 1.

Table 1. Estimated stream watershed statistics.

Stream	Watershed Perimeter (m)	Area (Acres)	Area (Hectares)	Area ($mile^2$)	Area (km^2)
North Creek	6718	462	187	0.7	1.9
Middle Creek	8167	651	263	1.0	2.6
South Creek	10348	509	206	0.8	2.1

Water quality and stream discharge

Point measurements of temperature and dissolved oxygen were within the State of Washington water quality limits for class A streams on the sampling dates (Washington Administrative Code (WAC) 173-201A). Temperatures ranged from 12.0 to 13.1° C and dissolved oxygen ranged from 9.5 to 10.4 mg/l.

Stream discharges on September 30, 2003, a baseflow period, were 0.01 m^3/s (0.4 cfs), 0.02 m^3/s (0.8 cfs), and 0.01 m^3/s (0.4 cfs) in North, Middle, and South creeks, respectively. Discharges on October 16 and 17, during early autumn rains, were 0.1 m^3/s (3.5 cfs), 0.1 m^3/s (4.1 cfs), and 0.1 m^3/s (3.7 cfs) for North, Middle, and South creeks, respectively. Stream water quality and flow measurements are summarized in Table 2.

Table 2. Point measurements for Willapa National Wildlife Refuge streams.

	North Creek	Middle Creek	South Creek
Temperature (°C)	12.0	12.1	13.1
Dissolved oxygen (mg/l)	10.4	10.0	9.5
Discharge (m^3/s) on 9/30/03	0.01	0.02	0.01
Discharge (m^3/s) on 10/16-17/03	0.1	0.1	0.1
Conductivity (μS/cm)	62.5	63	67

Physical habitat measurements

Table 3 summarizes physical habitat measurements that were taken during the stream inventory.

Table 3. Physical habitat survey results for North, Middle, and South creeks.

Parameter	North Creek	Middle Creek	South Creek
Drainage area (acres/hectares)	462/187	651/263	509/206
Distance Surveyed (m)	437	230	74
Pool Area (%)	68.2	92.3	73.2
Pools/km	37	13	40
Total Pool Area (m^2)	763.4	746.5	70
Mean Pool Area (m^2)	47.7	248.8	23.5
Mean Pool Volume (m^3)	11.6	65.8	12.4
Large Woody Debris/km	42	0	27
Substrate (%)			
<6 mm	30	17	47
6-64 mm	60	80	53
65-128 mm	10	3	0
Canopy Density (%)	94-100	100	100
Gradient (%)	1.4	0.7	0.8

Pools or slow water areas occupied much of the surveyed habitat in all three creeks. The mean pool volume was highest in Middle Creek (66 m^3) and similar in North and South creeks (12 m^3). Mean pool area was largest in Middle Creek (249 m^2), followed by North Creek (48 m^2) and South Creek (24m^2). The surveyed reach of Middle Creek was primarily composed of few relatively long stretches of slow water. North and South creeks had similar numbers of pools per kilometer. Pools in South Creek were smaller in average area, but slightly greater in volume than those in North Creek. Nickelson (cited in McMahon 1983) suggested that optimum coho rearing pools are from 10 to 80 m^3 in volume and from 50 to 250 m^2 in area.

Large Woody Debris

During the surveys, CRFPO biologists recorded the following numbers and sizes of LWD[1] in the three creeks:

- North Creek had 2 pieces of large size LWD, 4 pieces of medium size LWD, and 12 pieces of small size LWD in 432 meters of stream. This equates to 42 pieces of LWD per km
- Middle Creek had no pieces of any size LWD in 230 meters of surveyed stream.
- South Creek had no pieces of either large or medium size LWD and 2 pieces of small size LWD in 74 meters of stream. This equals 27 pieces of LWD per stream km.

Substrate

Pebble counts and visual estimates of substrate in the three streams showed that there was less sand and gravel in Middle Creek and a much higher percentage of fines in South Creek. Figure 3 shows percent occurrences of particle size groups obtained during the pebble count surveys. Note that there are two sets of pebble counts for North Creek (upper and lower). Pebble counts showed that fine to coarse gravel (6 to 64 mm) dominated the substrate composition in each of the streams and ranged from 53% in South Creek to 80% in Middle Creek. However, fine material less than 6 mm in size was common in each stream.

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[1] The U.S. Forest Service Stream Inventory Handbook protocol (Anonymous 2002) describes three classes of large woody debris (LWD:

- large = diameter > 36” at a length of 35 feet from the large end;
- medium = diameter > 12” at a length of 35 from the large end; and
- small = diameter > 6” at a length of 25 feet from the large end.

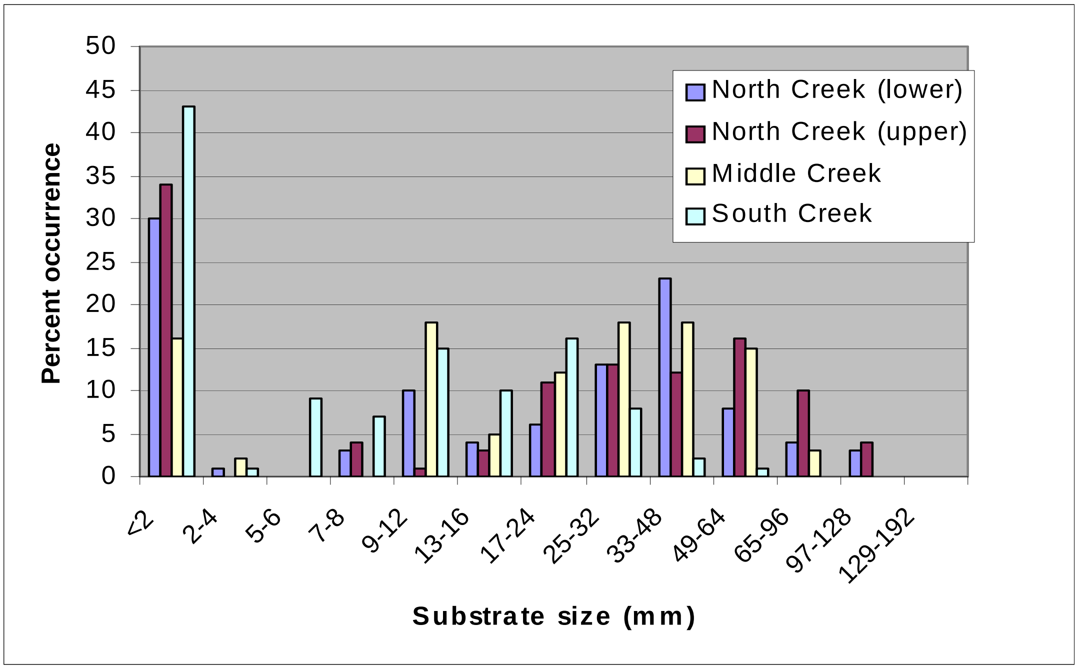
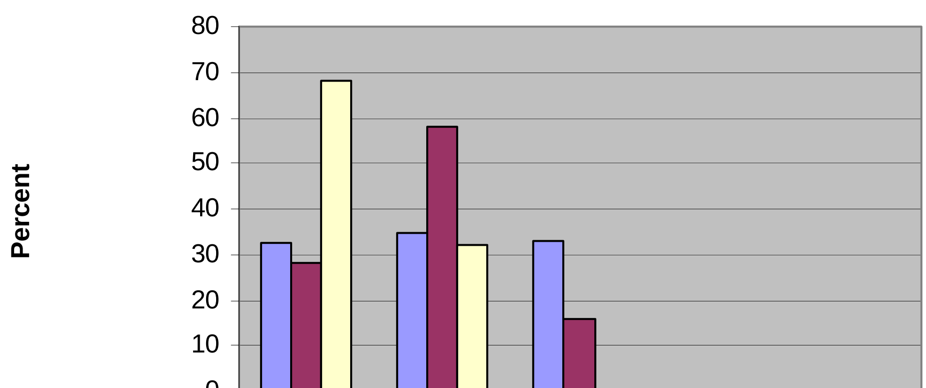


Figure 3. Percent occurrence of substrates by size.

Visual estimates of substrate composition (Figure 4) showed a similar pattern. North Creek had a nearly even distribution of sand, gravel, and cobble[2]. Middle Creek had the smallest percentage of sand while South Creek had the greatest percentage.



	%Sand	%Gravel	%Cobble	%Boulder	%Bedrock
North Creek	33	35	33	0	0
Middle Creek	28	58	16	0	0
South Creek	68	32	0	0	0

Figure 4. Visual estimates of substrate composition.

[2] The U.S. Forest Service Stream Inventory Handbook protocol (Anonymous 2002) describes the following substrate size classes: sand <2 mm; gravel 2 to 64 mm; and cobble 64 to 256 mm.

Off Channel Habitat

Off channel habitat (side channels, off channel ponds, and backwaters) was not common in the surveyed reaches of the streams. However, each stream contained multiple channels outside of the surveyed reaches. Beaver ponds were present outside of the surveyed stream reaches.

Riparian Vegetation

The inventory of riparian vegetation showed small trees (22.9 to 53.1 cm dbh) and saplings (12.7 to 22.6 cm dbh) of red alder and black cottonwood were the dominant overstory vegetation in the inner riparian zone. Douglas fir and black cottonwood of small tree size were dominant in the outer riparian zone. North Creek had the only site where large or mature conifers were dominant in the riparian zone. Understory was primarily grassland/forb in the inner zone and varied from grassland/forb to cottonwood to conifer in the outer zone. Canopy closure over all three streams was high ranging from 94 to100 percent at North Creek to 100 percent at both Middle and South creeks

Biological Sampling

<u>Fish</u>

Smaller Salmonids

Electrofishing captured juvenile coho salmon and cutthroat trout (*O. clarki*) in all three streams. Table 4 summarizes the catches of coho and cutthroat by stream. Coho salmon were relatively most abundant in Middle Creek, followed by North Creek upstream from the road culvert, North Creek downstream from the road culvert, and South Creek. Two size classes of coho salmon were present in Middle Creek. The smaller group averaged 87 mm. in length while the larger fish averaged 120 mm. The smaller sized group was most likely young-of-the-year (age-0) coho and the larger fish were yearling sized (age-1) (Quinn and Peterson 1996). The average length of coho salmon in both North and South creeks was 80 mm.

Cutthroat trout were also collected in each creek although they were less abundant than coho salmon. Cutthroat were present both upstream and downstream of the road culvert in North Creek.

Table 4. Summary of salmonids caught by electrofishing in Willapa National Wildlife Refuge study streams.

		North Creek u/s of Culvert	North Creek d/s of Culvert	Middle Creek	South Creek
Coho					
	# Caught	5	6	29	9
	CPUE	1.1	0.9	2.3	0.5
	Size Range (mm)	73-98	70-87	61-120	72-94
	Average Size (mm)	83	76	76	80
Cutthroat					
	# Caught	1	1	2	4
	CPUE	0.2	0.1	0.2	0.2
	Size Range (mm)	128	163	146-205	136-192
	Average Size (mm)	128	163	176	161

Snorkelers observed juvenile coho salmon in the 80 to 100 mm size range and one estimated to be 150 mm long, two 75-mm-long juvenile trout, and an unidentified 150-mm-long juvenile salmonid in North Creek. Turbid water in Middle and South creeks reduced visibility and snorkelers saw no juvenile fish in either of those streams.

Adult Salmon

Snorkelers saw two adult coho and one unidentifiable adult salmon in North Creek about 100 meters upstream from its mouth. They also saw four to six adult salmon (one possibly a chum) in the lower reaches of Middle Creek.

Other Species

Riffle or reticulate sculpin, *Cottus gulosus or C. perplexus*, were collected in all three streams. Roni (2002) notes that confusion exists over the taxonomy of riffle and reticulate sculpins and the difficulty in identifying the two species. He referred to the two species collectively as reticulate sculpin. Two western brook lamprey, *Lampetra richardsoni*, were caught in South Creek. Crayfish, *Pacifasticus lenisculus,* were captured in North Creek. Snorkelers observed a red-legged frog, *Rana aurora*, in the lower section of South Creek.

Macroinvertebrates

The reference stream chosen for comparison with the refuge streams was Upper Padden Creek located in the Puget Lowland ecoregion. This stream has similar flow and forested conditions and is the most acceptable stream available for B-IBI comparison purposes. It has a DOE River Invertebrate Prediction and Classification System score of 0.94 (1.00 being an undamaged system). Although its stream gradient, percent cobble, and canopy cover differ from the study streams, it was the closest available for use in this survey based on its other measured characteristics.

Twelve metrics were initially chosen to evaluate the three streams. A high score of 5 (plecoptera richness) and a low score of 1 (percent clingers) were removed because a ten metric B-IBI is the most common form found in the literature. Table 5 summarizes the metrics chosen for the B-IBI analysis, the scores for each stream, and the score for Padden Creek. The detailed report of the macroinvertebrate sampling and analysis is in a separate document (Conklin 2004) that is available from the CRFPO.

The B-IBI scores based on the selected ten metric scale showed North Creek with a result of 40, meaning that North Creek condition is about 80 percent of that found in Upper Padden Creek. Middle Creek scored a 36 or registered 72 percent of the undamaged condition of the Upper Padden, and South Creek came in at 32 or 64 percent of the undamaged stream.

Table 5. Chosen metrics used to calculate a B-IBI for each stream.

Ten metric score			**Score**		**Score**		**Score**
B-IBI	Upper Padden*	North	**40**	Middle	**36**	South	**32**
Total Taxa	25	41	5	30	5	22	5
Plecoptera Richness	5	7	5	5	5	5	5
Trichoptera Richness	4	8	5	4	5	5	5
Ephemeroptera Richness	4	6	5	2	3	3	3
Tolerance Value 3 Richness	10	15	5	12	5	11	5
Tolerance Value 7 Richness	3%	5%	5	10%	3	5%	3
Top 3 Dominance percentage	52%	67%	3	52%	5	36%	5
HBI score	4	2.5	3	3.3	3	2.8	3
Percent Predators	12%	8%	3	12%	5	27%	1
Percent Scrapers	4%	3%	5	1%	1	0%	1
Percent Filterers	30%	4%	1	2%	1	2%	1
Percent Clingers	28%	3%	1	1%	1	1%	1
Twelve metric score			46		42		38

**Reference stream*

There were more invertebrates captured in North Creek and the number of unique taxa was almost double that of South Creek (Figure 5).

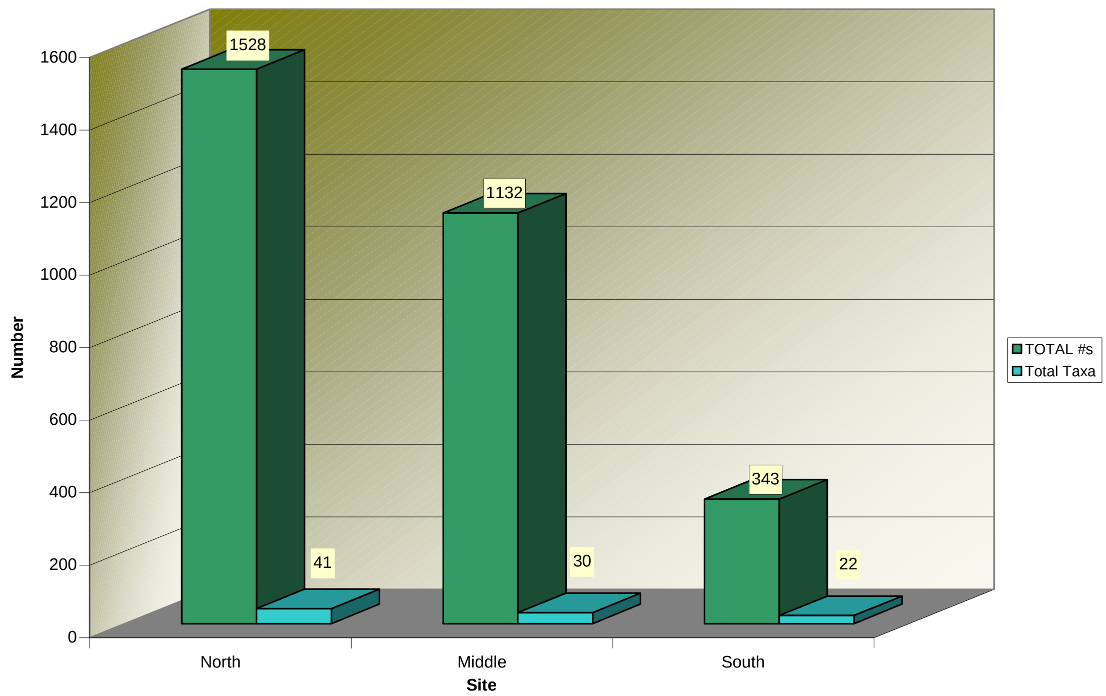


Figure 5. All streams total invertebrate numbers vs. total taxa.

The dominant invertebrate in all three streams was the Ephemeropteran, *Leptophlebia*, a small detritivore. *Leptophlebia* amounted to two thirds of the population in North Creek, half the population in Middle Creek, and one third of the population in South Creek.

The functional feeding group analysis resulted in the following findings:

- All of the streams are strongly heterotrophic. This means that the energy required to power the systems comes from outside sources such as leaf and needle drop from riparian trees and bushes rather than from sources within the streams (e.g. algae). The paucity of clinger and scraper invertebrates in the three streams suggests that there is very little primary production occurring here.
- The low ratio of shredders to collectors indicates that the ratio of coarse particulate organic matter is low compared to fine organic particulate matter.
- The low ratio of filter-gatherers to collector-gatherers indicates that fine particulate organic matter in suspension is low compared to fine particulate organic matter in the substrate. The dominance of *Leptophlebia*, a collector-gatherer is the main reason for the low ratio.
- Stable channel substrates, such as cobbles and boulders, that provide hiding and anchoring places for invertebrates and collection areas for detritus are only minimally available in the surveyed reaches of the three streams. The low ratio of

scrapers plus filter-gatherers to shredders plus collector-gatherers indicates low channel stability.

- Padden Creek, a high quality reference stream, has a more even balance of feeding groups than the study streams. This reflects a more diversified and stable substrate, which is a more hospitable environment for macroinvertebrates.

Fish Passage

Potential barriers to fish passage were encountered on North and Middle creeks. North Creek flows through a logging road culvert on land within the proposed refuge acquisition. This culvert is two meters in diameter by 14 meters long. Headcutting left the lower end of this culvert 0.48 meter above the water surface of the plunge pool (Figure 6).

Figure 6. North Creek culvert.

This culvert is likely to be a barrier to most chum salmon and juvenile salmonids. It may be a passage impediment to some coho and adult cutthroat. During our September 30 survey we also noted a 0.9-meter-high debris dam on the lower reach of the creek. This was judged to be a passage barrier at the low flow of 0.01 cubic meters per second (m^3/s) on that date. Cutthroat and coho were caught upstream of this debris jam so this block is likely to be passable at higher flows during the spawning migration periods.

The same logging road that crosses North Creek also crosses Middle Creek. Middle Creek passes through two culverts at this road. The smaller (south) culvert (Figure 7) is a partially collapsed concrete pipe measuring 0.7 meter in diameter by 7.3 meters long. The north (larger) culvert (Figure 8) is a round-bottomed, metal structure that measures 1.2 meters in diameter by 8 meters long. The south culvert had no drop to the pool downstream and the north one had a drop of 0.2 meter. In an unclogged condition both culverts would be passable for some migrating fish.

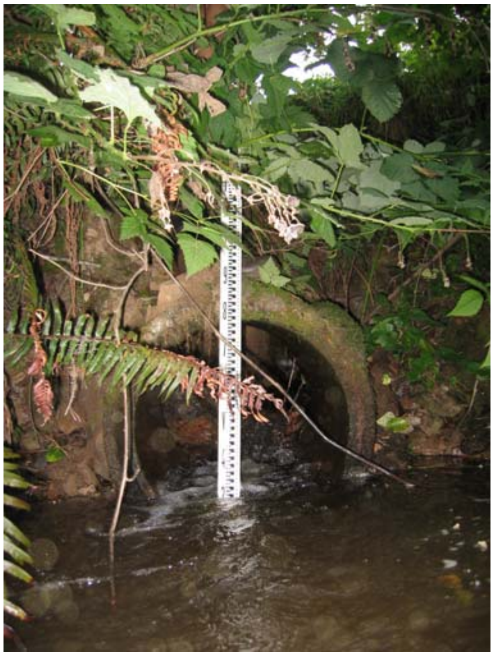


Figure 7. Smaller (south) Middle Creek culvert.

Figure 8. Larger (north) Middle Creek culvert.

Beaver had apparently plugged the upstream end of the larger culvert with branches. This diverted some of the creek's flow over the logging road. The culverts, in their plugged and collapsed conditions, are likely to be a barrier to upstream fish migration. There is a beaver dam a short distance upstream of the road culverts. Two debris dams, each about 0.6 meter high, were encountered in the lower reach of Middle Creek. Both were deemed to be passage barriers at the low streamflows (0.8 cfs) that existed at the time of observation. These blocks are also thought to be passable at higher streamflows since coho and cutthroat were collected upstream of their locations.

A beaver dam is located downstream of the surveyed reach of South Creek. This dam was not surveyed, but it does not appear to be a barrier to adult salmon passage since juvenile coho and adult chum salmon were seen upstream of the dam. An abandoned logging road bridge crosses South Creek upstream of the beaver dam. This bridge is not a barrier to fish passage.

We also measured water velocity at the logging road culvert in the tidal channel that parallels Highway 101. Water velocity on October 17, 2003, during an outgoing tide, was 1.5 m/sec. The difference between high and low tides during this tidal exchange was 0.75 meters (2.47 feet) at Paradise Point on Long Island. This was the smaller of the tide changes on that day. The other tide change that day was 1.95 meters (6.41 feet) so water velocity in the culvert during that exchange would likely have been greater. Higher velocities would also have lasted longer. About 12 adult chum salmon were seen in the pool downcurrent from the culvert. This culvert constricted the tidal channel's flow and increased water velocity through the culvert during both incoming and outgoing tides. This culvert seems to delay upstream migrating adult salmonids, which must wait until incoming or slack tides to pass it.

DISCUSSION

Physical/Chemical Surveys

Physical Habitat Measurements

Large Woody Debris

Large woody debris in North and South creeks was present in numbers comparable to those found in other WNWR streams by Barndt et al. (2000), but was absent in the surveyed reach of Middle Creek. Barndt et al. (2000) considered LWD in the range of 23 to 73 pieces per kilometer to be relatively common in the other WNWR streams. However, the numbers of LWD that we encountered in the three survey streams were much less than what would be expected in an old growth forest stream. Streams that are about 5 meters wide in southwest Washington old growth forests can have from 250 to 850 pieces of LWD per kilometer (from Bilby and Bisson1998).

The lack of large woody debris in Middle Creek, very small amount in South Creek, and relatively few pieces in North Creek have reduced the habitat complexity and productivity of these streams for fish and macroinvertebrates. Large woody debris is one of the most important structural components for salmon habitat in coastal watersheds (National Research Council 1996). Large woody debris performs important functions that affect salmonids and macroinvertebrates. These include trapping and storing sediment and organic matter, forming pools, maintaining habitat complexity, providing refuge from high winter flows, and furnishing protective cover from predators. Grette (1985) noted a significant correlation in number of pools and debris pieces in low gradient western Washington streams. Andrus et al. (1988) found in a small Oregon coastal watershed that seventy percent of pools with a volume greater than 1.0 m^3 were associated with woody debris in the channel. Large woody debris is especially important to juvenile coho salmon and cutthroat trout in the winter where it provides refuge from high water velocities associated with increased streamflows. This would be particularly important in the Willapa study streams where backwaters, alcoves, or side channels are lacking.

Recruitment of large woody debris in the study streams presently occurs from trees that enter from the immediate riparian area. Culverts and beaver dams likely limit the contribution from upstream sources. The riparian habitat survey indicates that most of the riparian trees are primarily red alders of small tree and sapling size. Cederholm et al. (1997) reported that smaller sized large woody debris that naturally entered a test stream did little to change its morphology. Alder placed into that stream had a short (less than 5 years) life expectancy whereas coniferous species were expected to last at least 25 years. Grette (1985) noticed that ten-year-old alder in a stream was soft and punky while older cedar from a previous stand of timber was usually firm. Input of large woody debris from second growth conifers was found to be very slow and did not start to increase until about 60 years after timber harvest (Grette 1985).

Intentional placement would be one option to accelerate the input of high quality large woody debris in these streams. Installation of large woody debris in Pacific Northwest streams has increased the abundance of coho salmon (House and Boehne 1986, Ward and Slaney 1979 *in* Bilby and Bisson 1998). Cederholm et al.(1997) found that the winter density of juvenile coho and smolt yield increased from stream areas where intentional placement of large woody debris had occurred. The quantity, quality, and volume of large woody debris in these streams could be increased by placement of larger pieces of conifers in appropriate locations. Any placement of large woody debris must be carefully researched, planned, implemented, and monitored to ensure that it will accomplish the objective of improving habitat.

Substrate

Spawning substrate (65 to128 mm) defined as suitable for larger salmonids was present in North and Middle creeks, but was not in South Creek. Middle and North creeks contained 3% and 10%, respectively (pebble counts). However, gravel that is used by smaller bodied salmonids (cutthroat) and also by chum and coho was present in each creek. Reiser and Bjornn (1979), cited by Laufle et al. (1986) and Pauley et al. (1988), estimated that gravel ranging in size from 13 to 102 mm was necessary for successful spawning by both chum and coho salmon. Trotter (1997) indicated that cutthroat trout spawn in gravel patches where the particle size ranges from 5 mm to 50 mm in diameter. Spawning substrate that is usable by chum, coho, and cutthroat is present in all of the streams, but its suitability may be limited by the percentage of sand and silt. Fine particles comprised 30% of the pebble count in North Creek, 17% in Middle Creek, and 47% in South Creek. The percentage of smaller particles less than 6 mm was nearly equal (47%) to that of larger gravels in South Creek.

Fine-grained material in the creeks can reduce their production of salmonids. Laufle et al. (1986) indicate that preferred coho spawning habitat contains less that 20% fines. Large volumes of silt in spawning substrate restrict oxygen flow to eggs and fry, and trap fry attempting to leave the gravel (Reiser and Bjornn 1979 cited by Laufle et al. 1986). Fine-grained sediment may also limit the production of benthic invertebrates necessary for optimum rearing of juvenile fish (Reiser and Bjornn 1979 cited by Pauley et al.1989).

Winter Habitat

Available winter habitat for juvenile salmonids and macroinvertebrates is a major factor limiting the production of coho and cutthroat in streams and may be more important than summer habitat (Hickman and Raleigh 1982). During winter juvenile fish and macroinvertebrates seek shelter from high flows. This is provided by backwaters, side channels, alcoves, large woody debris, deeper pools, and larger substrate material such as boulders and cobbles. Greater habitat complexity, such as that provided by large woody debris and large substrate, enhances over-winter survival of juvenile coho salmon (Quinn and Peterson 1996). Many types of high quality winter habitat were scarce in the study streams. Large woody debris was not present in the surveyed reach of Middle Creek. Backwaters, side channels, and alcoves were not common on any of the surveyed stream reaches. Boulders were lacking in all of the surveyed stream reaches while cobbles comprised only a small percentage of substrate in North and Middle creeks. Winter habitat could be increased by constructing backwaters, alcoves, or side channels or by placing large woody debris or larger substrate at appropriate sites in the streams.

Cutthroat make extensive use of beaver ponds for overwintering and feeding (Johnson et al. 1999) and coho often use these areas as winter habitat (Narver 1978 cited by McMahon 1983). Beaver ponds on the study streams provide winter habitat for both juvenile cutthroat and coho. Maintaining beaver ponds on these streams should benefit coho and cutthroat by providing winter habitat as well as rearing and feeding areas.

The extensive marsh areas at the lower ends of each creek provide additional rearing and winter habitat for coho and cutthroat. Maintaining these wetlands will benefit the fish populations of these creeks.

Watershed Condition

Timber harvest and associated road construction have occurred on much of the middle and upper reaches of the watersheds of the three streams. The upper watersheds of the three streams are owned and managed by the Washington Department of Natural Resources and private parties. Figure 2 is an aerial view of the three streams' watersheds and shows areas where timber has been harvested. We did not survey the watersheds of the streams upstream of the proposed refuge acquisition boundary so we do not know the extent of riparian vegetation buffers on the streams, the condition of logging roads, or the presence of landslides. Impacts of clearcutting can include:

- reduced input of large woody debris (because large wood is no longer available);
- increased amounts of fine sediment in the streams (because of increased overland flow, increased sediment transport energy due to higher peak discharges and increased streambank erosion);
- higher summer and lower winter water temperatures; and
- increased peak water discharges.

Past timber harvest and associated roadbuilding may have affected habitat in the lower reaches of the three streams. Habitat and fish passage improvement measures on the WNWR reaches of streams will not be fully effective unless the conditions in the upper watersheds are addressed. For example, roads that have been improperly located or constructed and that accelerate the sedimentation of streams should be corrected before attempting to improve instream habitat (Cederholm et al. 1997).

The Washington Department of Natural Resources has rehabilitated stream habitat in upper South Creek and closed and abandoned roads in the upper watershed (Greg Johnson, Washington Department of Natural Resources, personal communication). Future salmonid management in these streams should include close communication and cooperation with the managers and owners of upstream lands to ensure that sound land use practices occur. Watershed restoration may also be accomplished on privately owned lands through other cooperative efforts such as the Service's Jobs in the Woods program. The Bear River has been designated a focus watershed under this program.

Biological Sampling

Fish

Fish surveys found that chum and coho salmon and cutthroat trout use each of the three creeks. Sightings of adult chum and coho salmon in the creeks indicate that both species likely spawn in the streams. Other observers have seen adult salmon in each of the creeks. Adult chum salmon have been observed in Middle Creek as far as 90 meters upstream of the road culverts in previous years (Eric Metcalf, The Campbell Group; Greg Johnson, Washington Department of Natural Resources, personal communication). Willapa NWR staff have reported sighting adult chum salmon in the lower reach of North Creek, Middle Creek downstream from the road culverts, and in South Creek (Charles Stenvall, Marie Fernandez, WNWR, personal communication).

Chum salmon are most likely to use the lower reaches of each creek for spawning and migration. Chum salmon typically do not pass rapids, waterfalls and other barriers such as culvert drops as easily as do other salmonids. The North Creek culvert drop is 0.49 meter and beaver have plugged the Middle Creek culverts. Therefore, it is unlikely that many chum use North Creek upstream of the road culvert or Middle Creek upstream of the road culverts at the present time. The upstream extent of chum salmon migration and spawning in South Creek is not known, but may extend beyond the potential boundary of WNWR.

Coho salmon use each of the streams for rearing and spawning. The electrofishing catch rates for coho salmon in the three study streams are comparable to or greater than those obtained by Barndt et al. (2000) in other WNWR streams. Coho salmon are presently able to pass the North Creek culvert and migrate upstream beyond the potential boundary of WNWR. They also migrate beyond the proposed refuge boundary in Middle and South creeks. The presence of age-0 and age-1 size classes of juvenile coho salmon indicates that these streams provide rearing habitat for coho up to outmigration as smolts.

Based on fish sampling results, we believe that cutthroat trout spawn and rear in each of the creeks. Cutthroat in North Creek measured 163 and 128 mm in length; in Middle Creek they were 146 and 205 mm; in South Creek they ranged between 136 and 192 mm and averaged 161 mm. Unlike previous sampling in other nearby streams on WNWR where two size classes of cutthroat trout were captured (Barndt, et al. 2000), we only caught fish in the larger size classes and did not catch any young-of-the-year cutthroat. However, snorkelers did observe young-of-the-year trout. The earlier sampling collected cutthroat ranging from 41 to 168 mm. Cutthroat trout in the size class that we caught (128 to 205 mm) were most likely yearlings or older. Young-of-the-year cutthroat trout are smaller than 60 mm long in the summer and 80 mm in the winter (Roni 2002). Age 1 cutthroat are considered to be those greater than 80 mm in the fall (Roni 2002) while age 2 cutthroat are about 160 mm long (Pauley, et al.1988). The presence of larger cutthroat indicates that they are using the creeks or their tributaries for spawning and rearing.

It is not known whether the cutthroat inhabiting the streams are anadromous, resident, or both. Anadromous and resident cutthroat trout are known to inhabit the same stream (Northcote 1997). Cutthroat the size of those collected are in the size range of smolts that migrate to sea (160 mm in protected waters to 252 mm in coastal waters (Trotter 1997)) as well as of mature resident cutthroat (150 mm as reported by Lowry 1965 *in* Northcote 1997). However, the proximity of these fish to Willapa Bay makes it likely that sea-run cutthroat are present.

Cutthroat trout were also present in lesser numbers than coho salmon. Most of the cutthroat that we collected or saw were the size of yearling and older fish. The life history of cutthroat trout and interactions between age-0 coho and age-0 cutthroat may explain the absence of age-0 cutthroat from the sampled stream reaches. Cutthroat typically spawn in small tributaries of watersheds (Trotter 1989). If coho salmon also spawn in the stream, then sea-run cutthroat will spawn in reaches upstream of those used by coho. Coho salmon emerge earlier and at a larger size than cutthroat. Bisson et al. (1988) state that this larger size, a greater level of aggression, and a body morphology that enables them to maneuver better in slow water than cutthroat may allow young-of-the-year coho to assert dominance over subyearling cutthroat and displace them from pools. Trotter (1997) hypothesized interactions between young-of-the-year coho and cutthroat when they seek rearing habitat in the spring and early summer may limit the size of cutthroat populations. In the case of the WNWR streams, the presence of coho may limit the distribution of most subyearling cutthroat to areas outside of coho presence until cutthroat are large enough to compete for space.

Macroinvertebrates

The macroinvertebrate investigations suggest that North and Middle creeks are in good to fair condition and that South Creek is in poorer condition when compared to Padden Creek, a high quality benchmark stream. North Creek, which had the greatest number of invertebrates and unique taxa, also had the greatest diversity of substrate, the highest percentage of cobble, and the most pieces of woody debris of the three streams. The three streams, South Creek in particular, have high percentages of sand and fine inorganic particulate elements in their substrates that may be inhibiting healthy stream functions for macroinvertebrates. Reducing the influx of sediment and fine inorganic particulate material would help stabilize substrate. Increased amounts of large woody debris in these streams would improve and diversify habitat for macroinvertebrates by developing pools, scouring substrate, retaining coarse particulate organic matter, and providing anchoring and feeding sites.

Fish Passage

Potential barriers or impediments to fish passage including road culverts, debris jams, and beaver dams are present in each of the three creeks. Road culverts impede fish passage on North and Middle creeks. Debris jams were found on North and Middle creeks during our survey and were determined to be passage barriers at low flows. Beaver dams occur on Middle and South creeks. In addition, the logging access road culvert on the tidal channel constricts the channel and forms a temporary velocity barrier to adult salmonids that are migrating to the creeks.

Debris accumulations that are barriers at lower flows may be passable at higher flows (Bilby and Bisson 1998). The presence of coho salmon and cutthroat trout upstream of the debris barriers and beaver dams indicates that these are passable at certain streamflows.

The logging road culvert on North Creek impedes passage by adult coho salmon and cutthroat trout and is likely to be a barrier to adult chum salmon and juvenile salmonids. A large scour pool has formed at the culvert's outlet leaving the end of the culvert about 0.48 meter higher than the pool below it. The maximum hydraulic drop allowed for road crossing structures in streams used by chum salmon is 0.24 meter (WAC 220-110-070). Formation of a large scour pool below the culvert is indicative of high water velocity in the culvert at higher flows when fish are likely to be migrating upstream. The culvert on North Creek is on property that would be acquired by the Fish and Wildlife Service. Fish passage at North Creek culvert site should be improved if the Service acquires this property. The culverts on Middle Creek are on land that is owned by another party. Improvement of fish passage at these Middle Creek barriers should be undertaken in cooperation with the landowners of this property and the Washington Department of Fish and Wildlife.

We are uncertain if the road culvert on the tidal channel is within WNWR. If the culvert is on WNWR property, then steps should be taken by the Service to remedy fish passage delay problems at this site. If the culvert is on property owned by another party, then the Service should work cooperatively with other parties to implement a mutually agreeable fish passage improvement program.

There are several options for providing fish passage at the culvert sites. These include the following, in order of effectiveness, at producing a long-term benefit for fish and wildlife:

1) removal of the culvert, restoration of the stream channel, streambanks and riparian vegetation corridor, and abandonment of the road;
2) removal of the culvert and placement of a bridge spanning the creek, restoration of the stream channel, streambank and riparian vegetation corridor; and
3) replacement of the existing culvert with a properly located and adequately sized culvert that allows for passage of adult anadromous and resident salmonids and juvenile fish

Any work in the stream channel will require a Clean Water Act section 404 permit from the Army Corps of Engineers.

<u>Connection to the Willapa Bay Estuary</u>

The road fill for Highway 101 severed the direct connection between the creeks and the tidelands at the mouths of these streams from the main body of Willapa Bay. This has altered tidal circulation and reduced tidal exchange between these areas and the main estuary. Fish movements and migrations have also been affected. Direct access to Willapa Bay for fish from the three streams has been blocked and fish must follow a detour in the channel along the highway fill to reach the main estuary. Placement of a bridge or adequately sized culvert at the location of the former stream channel would help to restore tidal circulation and improve fish access between the streams and Willapa Bay. Remnants of the former channel still exist on the Willapa Bay side of the highway fill.

SUMMARY

In summary, chum and coho salmon and cutthroat trout are species that require high quality habitat. The presence of these species in all the streams indicates that these waters are currently of high enough quality to support populations of salmonids. Protection, rehabilitation, and improvement of habitat in these streams are particularly important because cutthroat and coho juveniles occur at their highest densities in very small streams. Such small perennial streams have been found to contribute disproportionately to summer rearing habitat for sea-run cutthroat and coho in coastal watersheds (Rosenfeld et al. 1999). Trotter (1989) describes a typical sea-run cutthroat spawning stream as a small stream system (watersheds of less than 13 km^2) with a low gradient throughout or where the lower reaches drain through extensive sloughs or meadowlands. Optimum habitat for coho salmon rearing includes a mixture of pools and riffles, abundant instream and bank cover, water temperatures that average between 10° and 15°C in the summer, dissolved oxygen near saturation, and low amounts of fine sediments (Reiser and Bjornn 1979). The three streams have many of the characteristics of important habitat for chum, coho, and cutthroat.

The results of this evaluation suggest that two of the WNWR streams are in good to fair condition - North and Middle creeks - and that South Creek is in poorer condition when compared to high quality, baseline streams in western Washington. The following discusses our findings regarding the existing conditions for each stream.

North Creek

North Creek within the surveyed stream reach has the greatest diversity of habitat among the three streams. Good overhead and submerged cover and a pool-riffle ratio of 1:1 are preferred habitat for coho salmon. North Creek has the closest pool:riffle ratio to this criterion. Pools occupy about 68% of the total stream area in North Creek compared to 92% and 73% in Middle and South creeks, respectively. Canopy cover and stream gradient are suitable for salmonids. North Creek also has the most LWD of the three streams.

Substrate of suitable size for spawning salmonids comprises 70% of the total pebble count. The percentage of fines in North Creek (30%) is intermediate among the three streams and lower than any of the nearby creeks surveyed by Barndt et al (2000). Reiser and Bjornn (1979) indicate less than 20% fines provide preferred spawning habitat for coho while Lantz (1976 *in* Laufle et al. 1986) indicates that fines should be less than 40% in riffle substrate. North Creek also has the highest percentage of larger gravel and small cobble size substrate among the three creeks. This larger substrate provides spawning habitat for larger salmonids and a more stable habitat for macroinvertebrates. North Creek has the greatest total number of macroinvertebrates and the most taxa of the three streams. The large number of individuals and great diversity of the macroinvertebrate population compared to the other two streams reflects this habitat diversity.

Middle Creek

Habitat quality in Middle creek is intermediate among the three creeks, but is probably more limited by its lack of woody debris and larger sized substrate and its lower percentage of riffle area. Stream gradient is suitable for salmonids. Road culverts limit anadromous fish access to the middle and upper watershed.

Surprisingly, we found no LWD in the surveyed section of this stream. The reasons for this lack of LWD are unknown, but the culverts and beaver dam immediately upstream of the survey reach may prevent downstream movement of LWD. The lack of LWD reduces habitat complexity and may limit over-winter survival of juvenile coho and cutthroat.

Middle Creek has the greatest percentage area (92%), mean volume, and mean area of pool habitat of the three creeks. This is higher than the 50% considered optimal for coho and cutthroat habitat (Hickman and Raleigh 1982, McMahon 1983, Pauley et al. 1989). However, the large percentage of pool area provides habitat for rearing and over-wintering coho and cutthroat.

Middle Creek has the largest percentage of suitable size substrate for salmonid spawning and the lowest percentage of fines among the three creeks. It has a small percentage of suitable spawning gravel as defined for larger salmonids.

The relatively high density of juvenile coho may be the result of several factors including the available area of spawning habitat and the area and quality of rearing space downstream from the culverts. The high percentage of substrate of suitable size for spawning by salmonids in Middle Creek may allow more coho to spawn in this stream than in the other creeks. The relatively low percentage of fines would allow for greater survival of offspring to emergence resulting in the production of more juveniles. The culverts may be an impassable barrier to the upstream migration of both juvenile and adult coho. This would limit both spawning and rearing by coho to the reach downstream from the culverts. Finally, pools are the preferred habitat of rearing subyearling coho (Bisson et al. 1988, McMahon 1983). The large percentage of pool habitat in Middle Creek may attract and support greater numbers of subyearling coho.

South Creek

South Creek is intermediate in terms of pool habitat, but has the poorest quality habitat for salmonids and macroinvertebrates, primarily because of the high percentage of fines and unstable substrate. Although the percentage of substrate in the 6 to 64 mm size range is comparable to North Creek, it has the highest percentage of fines (47%) of the streams. Larger substrate between 65 and 128 mm is absent. Much of the substrate in the 6 to 64 mm range is between 6 and 32 mm.

The streambed substrate is unstable. Streambed instability may reduce the survival of salmonids to emergence and may also reduce the diversity and numbers of macroinvertebrates. Despite its classic low gradient, alluvial stream character, South Creek based on the amount sand, gravel and fine particulate matter in its substrate and the paucity of woody debris may have experienced an event of some kind. The channel braiding at the upper end of the electrofishing reach, the amount of sand and gravel, and the dearth of invertebrates all suggest this.

Habitat quality in South Creek is still high enough to support chum and coho salmon and cutthroat trout. Spawning gravel is available for chum, coho, and cutthroat and pool area is available for rearing fish. Stream gradient is suitable for salmonids. Large woody debris is present although it is small in size and not abundant.

RECOMMENDATIONS

Habitat

Large woody debris

We recommend that WNWR explore the potential for placing large woody debris into each of the three creeks. These systems would benefit from increased amounts (and quality) of stable, large woody debris and reduced influx of sediment and inorganic fine particulate material. Large woody structures would develop pools, scour substrate, retain coarse particulate organic matter, provide protective cover and refuge from high winter flow for fish, and anchoring/feeding locations for macroinvertebrates. Parties with successful experience and expertise in placement of large woody debris in coastal streams should be consulted to determine the feasibility of installing large woody debris during the planning, installation, and monitoring phases of any such projects.

Winter Habitat

We recommend that WNWR maintain existing winter habitat in beaver ponds and wetlands on the three streams. We also recommend that WNWR investigate other measures to increase winter habitat such as placement of large woody debris or the construction of off channel habitat. Parties with experience and expertise in such activities should be consulted to determine the need and feasibility of these projects.

Land use review

We recommend that the past and present land use in the watersheds of the three creeks, especially South Creek, be reviewed. The purpose of such a review would be to determine the existence of any past and ongoing processes that would negate habitat improvement efforts in the lower reaches of these streams.

Watershed planning coordination

We recommend that WNWR discuss salmon management programs, habitat improvement and restoration projects with other landowners and land management agencies on a watershed basis for each of the streams. The Fish and Wildlife Service's Jobs in the Woods Program may be another avenue through which a watershed restoration and improvement program can be implemented.

Fish Passage

North Creek culvert

We recommend that the culvert on North Creek be removed and that one of the following options be taken: 1) abandon the road; 2) bridge the creek; 3) replace the culvert with a properly sized culvert. The stream channel gradient and length should be restored and streambanks replanted with appropriate species of vegetation. Under any of the options, we recommend that WNWR consult with biologists and engineers who are experienced with fish passage, stream restoration, and stream hydrology during project planning, implementation, and evaluation.

<u>Middle Creek culverts</u>

We recommend that WNWR work with the landowners of the property, the Washington Department of Natural Resources and Washington Department of Fish and Wildlife to improve passage at the culverts on Middle Creek. Improvement of fish passage at this site could include removal of the culverts plus either abandoning the road, bridging the creek, or replacing the culverts with properly sized culverts. The stream channel substrate, gradient, and length should be restored and streambanks revegetated with appropriate species of vegetation. Under any of the options, we recommend that the participating parties consult with biologists and engineers who are experienced with fish passage, stream restoration, and stream hydrology during project planning, implementation, and evaluation.

<u>Tidal channel culvert</u>

We recommend that the existing culvert on the main tidal channel be removed and replaced with a bridge if the Service is the owner of the property on which the culvert is located. If another party owns this culvert, then we recommend that the Service work cooperatively with the landowner, the Washington Department of Natural Resources, Washington Department of Fish and Wildlife, and any other appropriate parties to develop a plan to improve fish passage conditions and tidal circulation. We recommend that the participating parties consult with biologists and engineers who are experienced with fish passage, stream restoration, tidal hydraulics, and road construction during project planning, implementation and evaluation.

<u>Tidal channel restoration</u>

We recommend that WNWR investigate the potential for installing a bridge or culvert at Highway 101 where the tidal channel connecting Willapa Bay and the creek channels has been blocked. Any study of such a project should be a multi-disciplinary effort that includes participants with expertise in estuarine ecology, fisheries biology, wildlife biology, tidal hydraulics, tidal wetlands, estuary processes, highway construction, water quality, and fish passage.

REFERENCES

Anderson, R.O. and R.M. Neumann. 1996. Length, weight, and associated structural indices. Pages 447-481 *in* B.R. Murphy and D.W. Willis, editors. Fisheries techniques, 2nd edition. American Fisheries Society, Bethesda, Maryland.

Andrus, C.W., B.A. Long, and H.A. Froehlich. 1988. Woody debris and its contribution to pool formation in a coastal stream fifty years after logging. Canadian Journal of Fisheries and Aquatic Sciences. 45: 2080-2086.

Anonymous. 2002. Stream inventory handbook Level I & II version 2.2. U. S. Department of Agriculture, Forest Service, Region 6. 99 pp.

Barndt, S.A., T.C. Coley, J.C. Taylor, and B.A. Ensign. 2000. Physical and biological characteristics, and salmonid restoration potential, of seven Willapa National Wildlife Refuge waterbodies. U.S. Fish and Wildlife Service Columbia Basin Ecoregion, Columbia River Fisheries Program Office, Vancouver, Washington. 13 pp.

Bilby, R.E. and P.A. Bisson. 1998. The function and distribution of large woody debris. Pages 324-346 in R.J Naiman and R.E. Bilby, (Eds) River ecology and management: lessons from the Pacific coastal ecoregion. Springer-Verlag New York. New York, New York.

Bisson, P.A., K. Sullivan, and J.L. Nielsen. 1988. Channel hydraulics, habitat use, and body form of juvenile coho salmon, steelhead, and cutthroat trout in streams. Transactions of the American Fisheries Society 117:262-273.

Cederholm, C.J., R.E. Bilby, P.A. Bisson, T.W. Bumstead, B.R. Fransen, J. Scarlett, and J.W. Ward. 1997. Response of juvenile coho salmon and steelhead to placement of large woody debris in a coastal Washington stream. North American Journal of Fishery Management 17:947-963.

Conklin, C. 2004. Willapa Bay refuge macroinvertebrate survey, October 16, 17 2003. Prepared for U.S. Fish and Wildlife Service, Columbia River Fisheries Program Office, Vancouver, Washington. 31 pp.

Gregory, S.V., G.A. Lamberti, D.C. Erman, K.V. Koski, M.L. Murphy, and J.R. Sedell. 1987. Influences of forest practices on aquatic production. Pages 233-255 in E.O. Salo and T.W. Cundy, (Eds) Streamside Management: Forestry and Fisheries Interactions. Institute of Forest Resources Contribution Number 57, University of Washington, Seattle, Washington, USA.

Grette, G.B. 1985 The role of large organic debris in juvenile salmonid rearing habitat in small streams. M.S. Thesis, University of Washington, Seattle, Washington. 105 pp.

Hale, S.S., T.E. McMahon, and P.C. Nelson. 1985. Habitat suitability index models and instream suitability curves: chum salmon. U.S. Fish and Wildlife Service Biological Report 82(10.108). 48 pp.

Hickman, T. and R.F. Raleigh. 1982. Habitat suitability models: cutthroat trout. U.S. Department of the Interior, Fish and Wildlife Service. FWS/OBS-82/10.5. 38 pp.

House, R.A. and P.L.Boehne.1985.Evaluation of instream enhancement structures for salmonid spawning and rearing in a coastal Oregon stream. North American Journal of Fisheries Management 5:283-295.

Johnson, O., M.H. Ruckelshaus, W.S. Grant, F.W. Waknitz, A. M. Garrett, G.J. Bryant, K.Neely, and J.J. Hard. 1999. Status review of coastal cutthroat trout from Washington, Oregon, and California. NOAA Technical Memorandum NMFS-NWFSC-37. National Marine Fisheries Service, Northwest Fisheries Science Center, Conservation Biology Division, Seattle, Washington. 292 pp.

Karr, J.R. and D.R. Dudley. 1981. Ecological perspective on water quality goals. Environmental Management 5:55-68.

Kondolf, G.M. and M.G. Wolman. 1993. The sizes of salmonid spawning gravels. Water Resources Research 29(7): 2275-2285.

Lantz, R.L. 1976. Protection of salmon and trout streams in logging operations. Pages 14-20 *in* A.R. Grove, editor. Stream management of salmonids. Trout 17(1): winter supplement.

Laufle, J.C., G.B. Pauley, and M.F. Shepard. 1986. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (Pacific Northwest)—coho salmon. U.S. Fish and Wildlife Service Biological Report 82(11.48). U.S. Army Corps of Engineers, TR EL-82-4. 18 pp.

Lowry, G.R. 1965. Movement of cutthroat trout, *Salmo clarki clarki* (Richardson) in three Oregon coastal streams. Transactions of the American Fisheries Society 94:334-338.

McMahon, T.E. 1983. Habitat suitability index models: coho salmon. U.S. Department of the Interior, Fish and Wildlife Service FWS/OBS-82/10.49. 29 pp.

Merritt, R.W., and K.W. Cummins, 1996. An introduction to the aquatic insects of North America. Kendall/Hunt Publishing Company, Dubuque, Iowa. 862 pp.

Narver, D.W. 1978. Ecology of juvenile coho salmon: can we use present knowledge for stream enhancement? Pages 38-42 *in* B.G. Shepherd and R.M. J. Grinetz (editors): Proceedings of the 1977 Northeast Pacific chinook and coho salmon workshop. Dept. of Fisheries and Environment, Vancouver. Canada Fisheries Marine Service Tech. Rept. 759.

National Research Council. 1996. Upstream: salmon and society in the Pacific Northwest. Committee on Protection and Management of Pacific Northwest Salmonids, Board on Environmental Studies and Toxicology, Commission on Life Sciences. National Academy Press, Washington, D.C. 452 pp.

Northcote, T.G. 1997. Why sea-run? An exploration into the migratory/residency spectrum of coastal cutthroat trout. Pages 20-26 *in* J.D. Hall, P.A. Bisson, and R.E. Gresswell, editors. Sea-run cutthroat trout: biology, management, and future conservation. Oregon Chapter, American Fisheries Society, Corvallis, Oregon.

Pauley, G.B., K.L. Bowers, and G.L. Thomas. 1988**.** Species Profiles: Life Histories and Environmental Requirements of Coastal Fishes and Invertebrates (Pacific Northwest)—chum salmon. U.S. Fish Wildlife Service Biological Report 82(11.81) U.S. Army Corps of Engineers TR EL-82-4. 17 pp.

Pauley, G.B., K. Oshima, K.L. Bowers, and G.L. Thomas. 1989. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (Pacific Northwest)--sea-run cutthroat trout. U.S. Fish Wild. Service Biological Report 82(11.86). U.S. Army Corps of Engineers TR EL-82-4. 21 pp.

Plotnikoff, R.W., and C. Wiseman. 2001. Benthic macroinvertebrate protocols for rivers and streams. Pub No. 01-03-028, Washington Department of Ecology, Environmental Assessment Program, Olympia, Washington.

Quinn, T.P. and N.P. Peterson. 1996. The influence of habitat complexity and fish size on over-winter survival and growth of individually marked juvenile coho salmon *(Oncorhynchus kisutc*h) in Big Beef Creek, Washington. Canadian Journal of Fisheries and Aquatic Science 53: 1555-1564.

Reiser, D.W. and T.C. Bjornn. 1979. Influence of forest and rangeland management of anadromous fish habitat in the western United States and Canada. 1. Habitat requirements of anadromous salmonids. U.S. Department of Agriculture, Forest Service General Technical Report PNW-96. 54 pp.

Roni, P. 2002. Habitat use by fishes and Pacific giant salamanders in small western Oregon and Washington streams. Transactions of the American Fisheries Society 131(4):743–761.

Rosenfeld, J., M. Porter, and E. Parkinson. 1999. Habitat factors affecting the abundance and distribution of juvenile cutthroat trout *(Oncorhynchus clark*i) and coho salmon *(Oncorhynchus kisutc*h). Canadian Journal of Fisheries and Aquatic Science. 57: 766–774.

Trotter, P.C. 1989. Coastal cutthroat trout: a life history compendium. Transactions of the American Fisheries Society 118:463-473.

Trotter, P.C. 1997. Sea-run cutthroat trout: life history profile. Pages 7 to 15 *in* J.D. Hall, P.A. Bisson, and R.E. Gresswell, editors. Sea-run cutthroat trout: biology, management, and future conservation. Oregon Chapter, American Fisheries Society, Corvallis, Oregon.

Ward, B.R. and P.A. Slaney. 1979. Evaluation of in-stream enhancement structures for the production of juvenile steelhead trout and coho salmon in the Keogh River: progress 1977 and 1978. British Columbia Ministry of Environment. Fisheries Technical Circular 45. 47 pp.

Wolman, M.G. 1954. A method of sampling coarse bed material. Transactions of the American Geophysical Union 35:951-956.